NSW GOVERNMENT | Environment, Climate Change & Water

Towra Point Nature Reserve Ramsar site

Ecological character description

NSW GOVERNMENT | CMA Sydney Metropolitan CATCHMENT MANAGEMENT AUTHORITY

Acknowledgements

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Symbols for conceptual diagrams are courtesy of the Integration and Application Network (ian.umces.edu/symbols), University of Maryland Center for Environmental Science.

This publication has been prepared with funding provided by the Australian Government to the Sydney Metropolitan Catchment Management Authority through the Coastal Catchments Initiative Program.

Published by:

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ISBN 978 1 74232 132 5
DECCW 2010/510
June 2010

Printed on environmentally sustainable stock

Cover photographs
Main: Towra Lagoon (DECCW)
Right top: Bar-tailed godwits (P. Straw/AWSG)
Right centre: Saltmarsh and mangroves (J. Dahlenburg/SMCMA)
Right bottom: Pied oystercatchers (P. Straw/AWSG)

Summary

Towra Point Nature Reserve Ramsar site consists of 386.5 hectares of wetlands that lie on the southern shore of Botany Bay, approximately 16 kilometres from Sydney city centre. The entire Ramsar site lies within Towra Point Nature Reserve, which is managed by the Department of Environment, Climate Change and Water NSW (DECCW).

At the time of designation in February 1984, the Ramsar site included 281.7 hectares within the nature reserve boundary. Since then additions have been made to both the nature reserve and the Ramsar site; consequently the area of Towra Point Nature Reserve is now 603.7 hectares and the area of the Ramsar site is 386.5 hectares. It is recommended that the Ramsar site boundary be extended to include the 2008 additions to the nature reserve, i.e. to include the whole of the current boundary of the nature reserve.

This ecological character description (ECD) includes information specific to the Ramsar site, as well as to the nature reserve as a whole and to the adjacent aquatic reserve (as detailed in the text). The wetland types, the ecosystem components, processes and services, and the limits of acceptable change are much the same for the nature reserve and the Ramsar site and are highly interconnected with those of the aquatic reserve, and consequently cannot be easily discussed separately. Much of the available information to support this ECD was collected for the nature reserve as a whole and cannot easily be disaggregated to apply solely to the Ramsar site. DECCW has updated the Ramsar information sheet in 2010 to extend the Ramsar site boundaries to match the nature reserve boundaries.

When Towra Point Nature Reserve was listed as a Ramsar site in 1984 it met Ramsar criteria 1, 2, 3 and 6. However, in 2009, the site is recognised as meeting criteria 2, 3, 4 and 8. The site no longer meets criterion 1 (rare or unique wetland types) because the biogeographic classification has been changed from the Interim Biogeographic Regionalisation for Australia (IBRA) to Australian Drainage Divisions, which places Towra Point in the Southeast Coast Drainage Division. The South East Coast is much larger than the Sydney Basin bioregion (under IBRA) and there are more extensive areas of mangroves and saltmarsh in other estuaries. The site no longer meets criterion 6 (1% or more of population of a waterbird species) because Towra Point no longer supports 1% of the estimated international population of eastern curlew, as a result of the species' estimated international population having increased. Criterion 4 (critical life cycle stages for plant or animal species) and criterion 8 (re resources for supporting fish populations) have been met because there is new evidence about the importance of the area for migratory species, little tern breeding and fish habitat.

The critical ecosystem components, processes and services and the limits of acceptable change at Towra Point are strongly related to the criteria for which the site was listed, especially the site's biodiversity values and importance for threatened species. Towra Point Nature Reserve supports the largest wetland of its type in the greater Sydney region and represents vegetation types that are now rare in the area. Sixty per cent of saltmarsh communities and 40% of mangrove communities in the Sydney region are found at Towra Point, in addition to a significant area of seagrass adjacent to the wetland. The diversity of vegetation types supports many biological interactions and a complex food web. This includes four nationally threatened species, and 24 threatened species and five endangered ecological communities protected under NSW legislation. Towra Point is a critical roosting and feeding habitat for large numbers of migratory shorebird species and a significant nesting site for the endangered little tern (*Sterna albifrons*). The mangroves and seagrass provide protection and food for juvenile fish species, and the release of crab larvae from

saltmarsh areas during spring ebb tides provides a reliable source of food for a variety of fish species and a critical link in the estuary's food web. Towra Point is important in providing ecological connectivity for itinerant species, and is important for maintaining biodiversity in the greater Sydney region. Key limits of acceptable change include maintaining the geomorphological, hydrological and physicochemical conditions of the wetland types at Towra Point that support its biota.

Describing the ecological character of any wetland ecosystem is central to effective management, as the description forms the baseline against which management planning and actions are determined. Towra Point is within the Botany Bay catchment which has been, and continues to be, modified for industrial and residential development. This ecological character description has been prepared retrospectively for the time of Ramsar listing in 1984, recognising that changes to the shoreline and bathymetry of Botany Bay prior to 1984 have impacted on the wetlands and continue to do so. These impacts have been exacerbated by the construction of Sydney Airport's third runway in 1994 and by the dredging of a channel in the bay. While these changes are substantial, management actions have mitigated the impact on the site's ecological character.

Limits of acceptable change for shorebirds have been determined based on data for Botany Bay, as shorebirds use suitable habitat both within and outside the Ramsar site and are counted across the whole bay. Shorebird numbers in both summer and winter have declined, with four species recorded in Botany Bay over summer in 1983–87 – broad-billed sandpiper, Latham's snipe, pectoral sandpiper and oriental plover – no longer present in 2004–08; however three new shorebird species – common sandpiper, sanderling and wandering tattler – are now occasionally recorded in Botany Bay over summer. While the limit of acceptable change for shorebird diversity – no net loss of species since time of Ramsar listing – has been exceeded, further analysis is required to understand that change in species composition and to improve the confidence in this limit of acceptable change. The limit of acceptable change for shorebird abundance – decline of no more than 50% from baseline condition in five consecutive years – is close to being exceeded, as summer shorebird numbers have decreased from 1668 (±472) in 1983–87 to 897 (±112) in 2004–08, and winter shorebird numbers have decreased from 414 (±132) in 1983–87 to 238 (±90) in 2004–08. Towra Point is also continuing to provide critical habitat for migratory species such as eastern curlew and little terns, with the numbers of eastern curlew increasing since 1984 and little terns successfully nesting and producing fledglings in most years.

Continued management will be essential to maintain the site's character. Threats to the site include its proximity to one of the largest ports in eastern Australia; alterations to the shoreline, hydrology and bathymetry of Botany Bay causing increased wave energy on the southern side of the bay; residential and industrial development within the catchment; invasive species; and the impacts of climate change including sea level rise.

Ecological character description of Towra Point Nature Reserve Ramsar site

Site name	Towra Point Nature Reserve
Location in coordinates	34°00'S, 151°10'E
General location	Approximately 16 km south of Sydney centre. Towra Point adjoins Kurnell Peninsula, forming the southern and eastern boundaries of Botany Bay.
Area	386.5 hectares
Date of listing as a Ramsar site	21 February 1984
Original Ramsar nomination criteria met by wetland	1a, 2a, 2b, 3b, 3c, dominant reason 2b
Ramsar nomination criteria met by wetland	2, 3, 4 and 8
Management authorities	Department of Environment, Climate Change and Water NSW
Date for which the description of ecological character applies	1984
Status of description	This is the first ecological character description of Towra Point Nature Reserve Ramsar site.
Date of compilation	June 2010
Name of compiler	Kirsty Brennan Waters and Catchments Science Section Scientific Services Division Department of Environment, Climate Change and Water NSW
Reference to the Ramsar Information Sheet	Towra Point Nature Reserve Ramsar information sheet, January 1998. Wetlands International Ramsar Sites Information Service, www.wetlands.org/rsis/
Reference to the management plan	NSW National Parks and Wildlife Service (2001), *Towra Point Nature Reserve plan of management*, www.environment.nsw.gov.au/resources/parks/pomfinaltowra.pdf

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1 Introduction

The Convention on Wetlands, signed in Ramsar, Iran, in 1971, is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. It is more commonly called the Ramsar Convention.

The convention was initially focused on the conservation and wise use of wetlands for the protection of waterbird habitat. However, the ecosystem is now looked at as a whole and all aspects of a wetland are protected under the treaty. Biodiversity conservation is the primary goal of wetland ecosystem conservation and wise use.

Australia became a contracting party to the Ramsar Convention in May 1974 and in 2009 has 65 sites, totalling 7,509,831.3 hectares, of designated land for the List of Wetlands of International Importance. Under the Ramsar Convention, contracting parties are required to use the 'wise use' approach and consider wetland conservation when planning development or activities in surrounding areas (Ramsar Convention 2003).

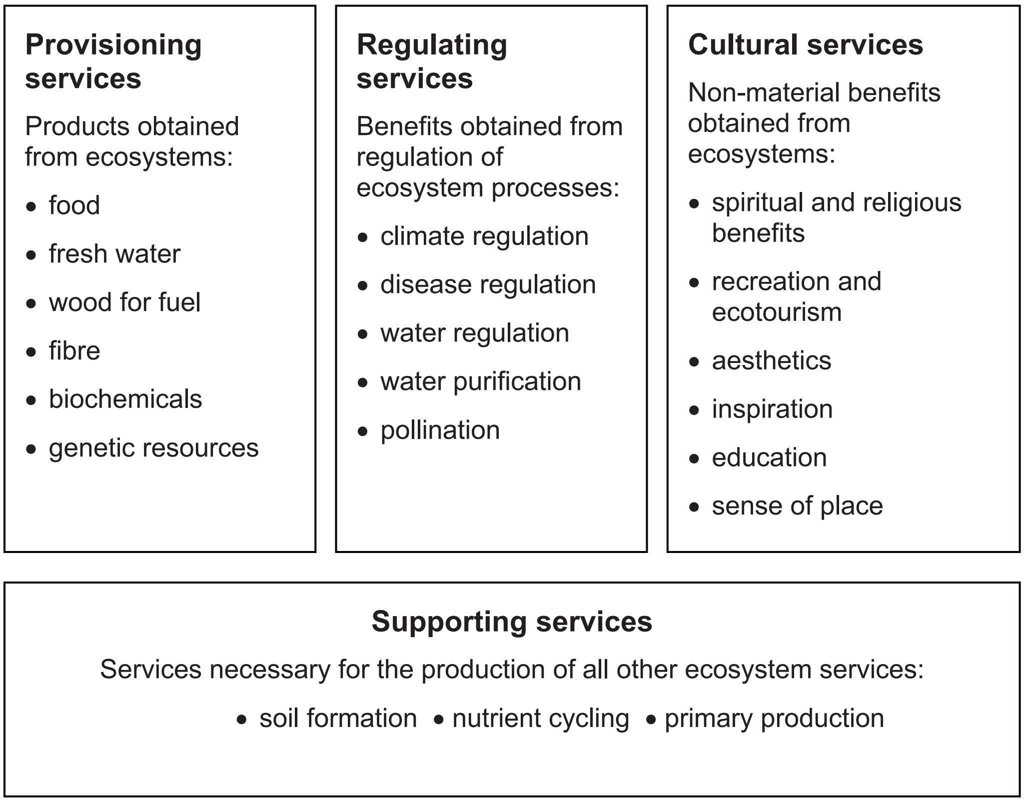
1.1 Statement of purpose

The Ramsar Convention defines ecological character as 'the combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point' (Ramsar Convention 2005).

Therefore, an ecological character description for a given wetland is a description of the living and non-living components and how they interact. An ecological character description should also provide information on the natural variability of the wetland and enable limits of acceptable change to be identified (Lambert and Elix 2006).

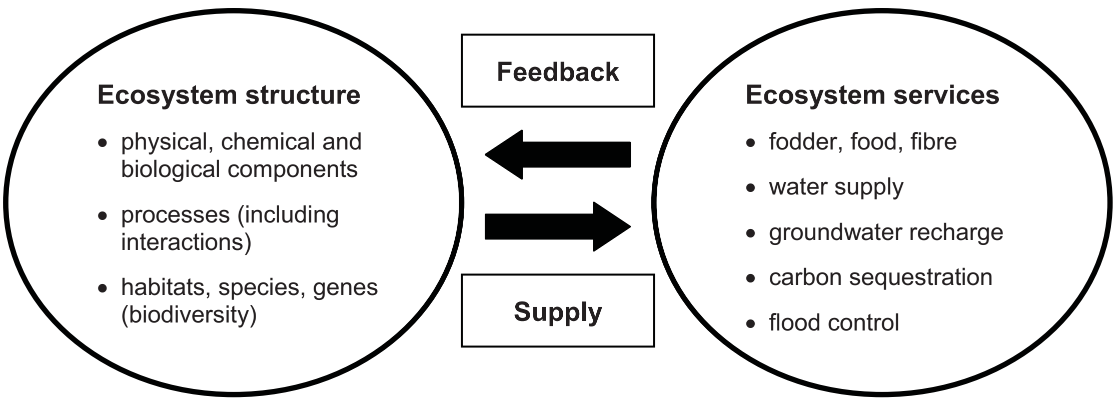
Within this context, ecosystem benefits/services are defined in accordance with the Millennium Ecosystem Assessment (2003) definition as 'the benefits that people receive from ecosystems'. The Millennium Ecosystem Assessment (2003) separates ecosystem services further into provisioning, regulating and cultural services, which directly affect people and supporting services needed to maintain these services (Figure 1).

As a part of the ecological character of a wetland, ecological processes are defined as the dynamic biotic and abiotic interactions within an ecosystem such as primary production, decomposition, carbon and nutrient cycling, sedimentation and provision of habitats for other biota (Figure 2). These may or may not provide benefits or services to humans. Components are the physical, chemical and biological elements of the system, with the latter being defined as habitat, species and genes. Due to the dynamic nature of wetland ecosystems, there is considerable overlap between the components and processes that make up a wetland's ecological character.



Source: Millennium Ecosystem Assessment (2003)

Figure 1: Summary of ecosystem services



Source: Millennium Ecosystem Assessment (2003)

Figure 2: Description of ecosystems

1.2 Reasons for describing ecological character

Under the Ramsar Convention, Australia is obliged to complete an ecological character description of the site and maintain its accuracy. The Victorian Government's Department of Sustainability and Environment (DSE) compiled a framework for describing the ecological character of Ramsar wetlands (DSE 2005). This framework has been used to compose a number of ecological character descriptions. A national framework for describing the ecological character of Ramsar wetlands was developed using DSE's framework (DEWHA 2008).

The ecological character description is an important tool to monitor the status of a wetland and set limits of acceptable change to prevent any further degradation of the area. Adoption of the 'wise use of wetlands' principles should protect the ecological character of the site through sustainable management and monitoring (Ramsar Convention 2005).

McGrath (2006) summarised the main points outlining the purpose of an ecological character description:

1 To assist in implementing Australia's obligations under the Ramsar Convention, as stated in Schedule 6 (Managing wetlands of international importance) of the Commonwealth's *Environment Protection and Biodiversity Conservation Regulations 2000*:
   a) to describe and maintain the ecological character of declared Ramsar wetlands in Australia
   b) to formulate and implement planning that promotes:
      i conservation of the wetland
      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 *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), particularly:
   a) to determine whether an action has, will have or is likely to have a significant impact on a declared Ramsar wetland in contravention of sections 16 and 17B of the EPBC Act; or
   b) to assess the impacts that actions referred to the Minister under Part 7 of the EPBC Act have had, will have or are likely to have on a declared Ramsar wetland.

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

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

1.3 Relevant treaties, legislation and regulations

Towra Point Nature Reserve is located within and adjacent to the jurisdiction of a number of different government agencies, including the Department of Environment, Climate Change and Water NSW (DECCW), Industry and Investment NSW (I&I NSW), Sutherland Shire Council, Sydney Metropolitan Catchment Management Authority (SMCMA) and NSW Maritime. A number of non-government organisations play a key role in the monitoring and protection of the site, including the Friends of Towra Point Nature Reserve, Botany Bay Busy Bees, Australasian Wader Studies Group, Botany Bay Planning and Protection Council and the National Parks Association. An integrated strategy on protection and management using a holistic environmental approach is in place (NPWS 2001a).

The international agreements and treaties, and the national, state and local legislation and policies protecting Towra Point Nature Reserve are:

- the Ramsar Convention on Wetlands (Ramsar, Iran 1971), which aims to halt the worldwide loss and degradation of wetlands by conserving them through the application of wise use principles and management systems
- the Japan–Australia Migratory Bird Agreement (JAMBA, 1981), the agreement between the Government of Australia and the Government of Japan for the protection of migratory birds and birds in danger of extinction and their environment
- the Convention on the Conservation of Migratory Species of Wild Animals (Bonn, 1983), which aims to conserve terrestrial, marine and avian migratory species throughout their range
- the China–Australia Migratory Bird Agreement (CAMBA, 1988), 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
- the Republic of Korea–Australia Migratory Bird Agreement (ROKAMBA, 2006), the agreement between the Government of the Republic of Korea and the Government of Australia for the protection of migratory birds
- the Partnership for the Conservation of Migratory Waterbirds and the Sustainable Use of their Habitats in the East Asian–Australasian Flyway (2006). The development of this partnership has been led by the Government of Australia, the Government of Japan, and Wetlands International as an initiative of the World Summit on Sustainable Development. This partnership has succeeded the Asia–Pacific Migratory Waterbird Conservation Strategy 2001–2005 and is responsible for drafting a new Flyway Partnership Action Plan for 2006–2010. The main goal is to conserve species and their habitats through the establishment of networks of appropriately managed and internationally important sites for migratory waterbirds.

National obligations are covered by the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), which protects the environment, particularly matters of national environmental significance (protected matters).

State obligations are met under the following legislation:

- The *National Parks and Wildlife Act 1974* covers the protection of flora, fauna and cultural heritage sites in NSW, including wetlands. Towra Point Nature Reserve Plan of Management (NPWS 2001a) is implemented under this Act.
- The *Environmental Planning and Assessment Act 1979* concerns the protection and conservation of natural areas through ecologically sustainable planning and development.

- The *Fisheries Management Act 1994* (FM Act) works with the Threatened Species Conservation Act 1995 to protect threatened aquatic species and communities, including mangroves and seagrasses.
- The *Threatened Species Conservation Act 1995* (TSC Act) covers protection and management of threatened species, populations and communities.

At a local government level, the following environmental plans are relevant:

- Sydney Regional Environmental Plan No. 17 – Kurnell Peninsula specifies zoning and planning provisions for the Kurnell Peninsula including Towra Point
- Greater Metropolitan Regional Environmental Plan 1999 No. 2 – Georges River catchment aims to maintain and improve environmental quality of Georges River and its catchment.

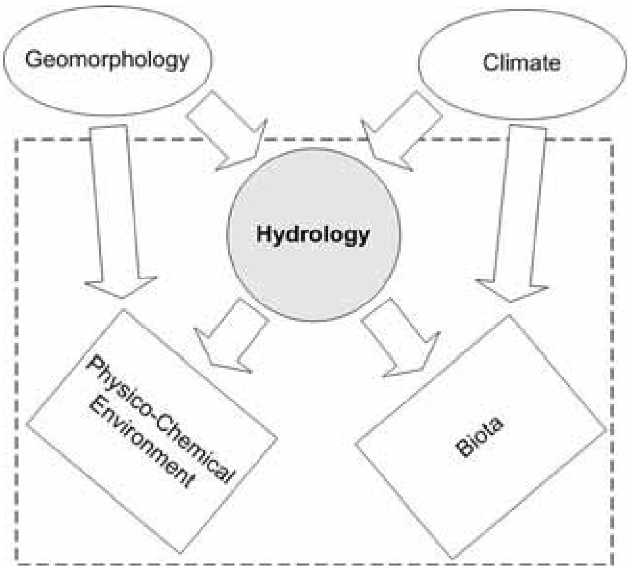
Other supporting NSW plans and regulations assisting in the protection of Towra Point Nature Reserve are:

- *NSW Ramsar Plan 2006–09* (DEC 2006a)
- *Noxious Weeds Act 1993*
- *Native Vegetation Act 2003*.

1.4 Approach taken

This ecological character description has been prepared using the *National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands* (DEWHA 2008) and steps taken are shown in Table 1.

Five essential elements were used to compile the ecological character description for the Towra Point Nature Reserve Ramsar site: hydrology, climate, geomorphology, biota and physicochemical elements (Figure 3). Each of these elements is considered an essential component of a wetland ecosystem.



Source: Mitsch and Gosselink (2000)

Figure 3: Generic conceptual model

Table 1: Steps taken in describing the ecological character of the Ramsar site

Step	Section
1 Define ecological character and its purpose.	1
2 Describe site location, area covered, listing criteria and wetland types.	2
3 Summarise ecological character of site, including a conceptual model for ecological components and processes, and list of ecosystem services.	3
4 Describe ecosystem services of site.	4
5 Describe components and processes that support ecosystem services.	5
6 Determine limits of acceptable change for key components.	5
7 Describe threats to ecological character.	6
8 Identify knowledge gaps and make recommendations for monitoring.	7
9 Identify important education, communication and public awareness messages.	7
10 Update Ramsar Information Sheet.	Attached RIS

2 Description of Towra Point Nature Reserve

2.1 Site location

Towra Point Nature Reserve, which contains Towra Point Nature Reserve Ramsar site, is located on the southern shore of Botany Bay, approximately 16 kilometres from the centre of Sydney (Figures 4 and 5). The nature reserve includes the land mass connected to Kurnell Peninsula protruding into Botany Bay and the tidal area that extends from the southern point of Woolooware Bay around to the eastern point of Quibray Bay (Figure 6).

Botany Bay is a large shallow bay measuring six kilometres north–south and eight kilometres east–west. Dredging of the bay's ocean entrance and other areas on the northern side of the bay from the 1960s increased the natural depth of Botany Bay from 2–10 metres to up to 21 metres in some areas (Roy and Crawford 1979).

Towra Point Nature Reserve is in the south-eastern part of the Botany Bay catchment (Figure 7). The sub-catchment that influences Towra Point is South Botany Bay sub-catchment, and its land use is industrial, residential and recreational. The Georges and Cooks rivers and their tributaries flow into Botany Bay, which has a tidal range of approximately 0.1–2.0 metres. The bay has a catchment area of 1100 square kilometres and a water area of 80 square kilometres (Wilton 2002). Table 2 shows the relative areas of land uses within the Botany Bay catchment at the time of Ramsar listing and at the time of writing.

The Botany Bay catchment has a high percentage of bushland. However, most of the land adjacent to Botany Bay and Georges River is urban and industrial, and runoff from these areas usually drains directly into the catchment with no filtration through bushland.

Water from the South Botany Bay sub-catchment drains into Woolooware Bay and Quibray Bay. Runoff from the industrial and residential areas of Taren Point and other surrounding suburbs drains into Woolooware Bay including runoff from playing fields, a rugby league stadium and a golf course. Only a small number of gross pollutant traps and water-quality improvement devices are in place to trap rubbish. The main source of drainage into Quibray Bay is from the Kurnell industrial area which contains the Caltex oil refinery and Kurnell Landfill Company (SSC 2004). All land uses in the catchment influence the ecological character of Towra Point to some extent.

There are more than 1.5 million residents in the severely impacted Georges River and Botany Bay catchment, and the population continues to grow (Heap et al. 2001).

Table 2: Land uses in the Botany Bay catchment

Land use	1976–1978 (%)[a]	2006–2007 (%)[b]
Parkland	4	5
Airport	No data	1
Industrial/commercial	7	8
Urban	26	30
Bushland	39	38
Water body	5	5
Rural	19	13

Source: [a] McGuinness (1988); [b] SMCMA (2007c)

Botany Bay's ecology was modified from the time the first settlers arrived; mangroves from Towra Point were used for timber, the burnt ashes were used as a source of sodium hydroxide for soap, and the cleared land was used for grazing and agriculture. The waters surrounding Towra Point were used for oyster cultivation which still continues, although on a smaller scale (Evans and Williams 2001). In addition to population growth and residential development throughout the catchment, Botany Bay became a place for heavy and noxious industries. Oil spills (there have been 31 spills between 1957 and 1987 averaging 49,000 litres) (McGuinness 1988), dredging, shoreline modification, land reclamation, land clearing and sand extraction have all had significant impacts on Towra Point, including loss of habitat and species. Alteration of the natural hydrological regime has caused increased rates of erosion and accretion which continue to impact the site. Despite these modifications Towra Point continues to support a high level of biodiversity.

2.2 Area covered by this description

The Commonwealth Government acquired 281.7 hectares of land on Towra Point in 1975 to satisfy the Japan–Australia Migratory Bird Agreement (NPWS 1989; NPWS 2001a). The land was transferred to the NSW Government and in 1982 was declared as Towra Point Nature Reserve under the *National Parks and Wildlife Act 1974*. The nature reserve was listed as a Ramsar site in 1984, and the site was covered by the provisions for protecting Ramsar sites in the *Environment Protection and Biodiversity Conservation Act 1999* when it came into force in 1999. Additions to the nature reserve in 1991 and 1996 resulted in the Ramsar site being enlarged to about 386.5 hectares (NPWS 2001a). The boundaries of the Ramsar site in 1984 and in 1998 and the area proposed for addition in 2010 are shown in Figure 5.

Further land acquisitions in 2008 have extended the area of Towra Point Nature Reserve to 603.7 hectares. That area is based on the original area of the nature reserve gazetted in 1982 and on the addition of surveyed areas of land since then. It is proposed that the additions to the nature reserve gazetted on 4 April 2008 (an area of about 217.3 hectares) be incorporated into the Ramsar site. This will include Towra Spit Island which provides important habitat for the endangered little tern and areas of mangroves and saltmarsh. Incorporation of those additions would make the total area of the Ramsar site 603.7 hectares.

This description of the ecological character of Towra Point Nature Reserve Ramsar site refers to the whole area within the Towra Point Nature Reserve as well as the areas of seagrass and associated substrate within the adjoining Towra Point Aquatic Reserve. Movement of sediment, flora and fauna is not limited by either Ramsar site or nature reserve boundary and these areas have a significant contribution to and influence on the ecological character of the Ramsar site. A distinction has been made, however, between the ecological character of the wetland at the time of Ramsar listing (1984) and at the time of writing.

2.3 Land tenure

Towra Point Nature Reserve Ramsar site is in Towra Point Nature Reserve which is managed by DECCW. Surrounding areas include Towra Point Aquatic Reserve, also managed by DECCW, which was declared in 1987 and dedicated under the FM Act. The aquatic reserve encompasses approximately 1400 hectares and is divided into a refuge and a sanctuary zone. The area was declared to protect seagrass, mangroves and marine mammals which help protect and maintain the aquatic biodiversity of Towra Point (DECC 2008b).

Land ownership on Kurnell Peninsula is mostly freehold. Land use includes industrial, residential, recreational and conservation areas.

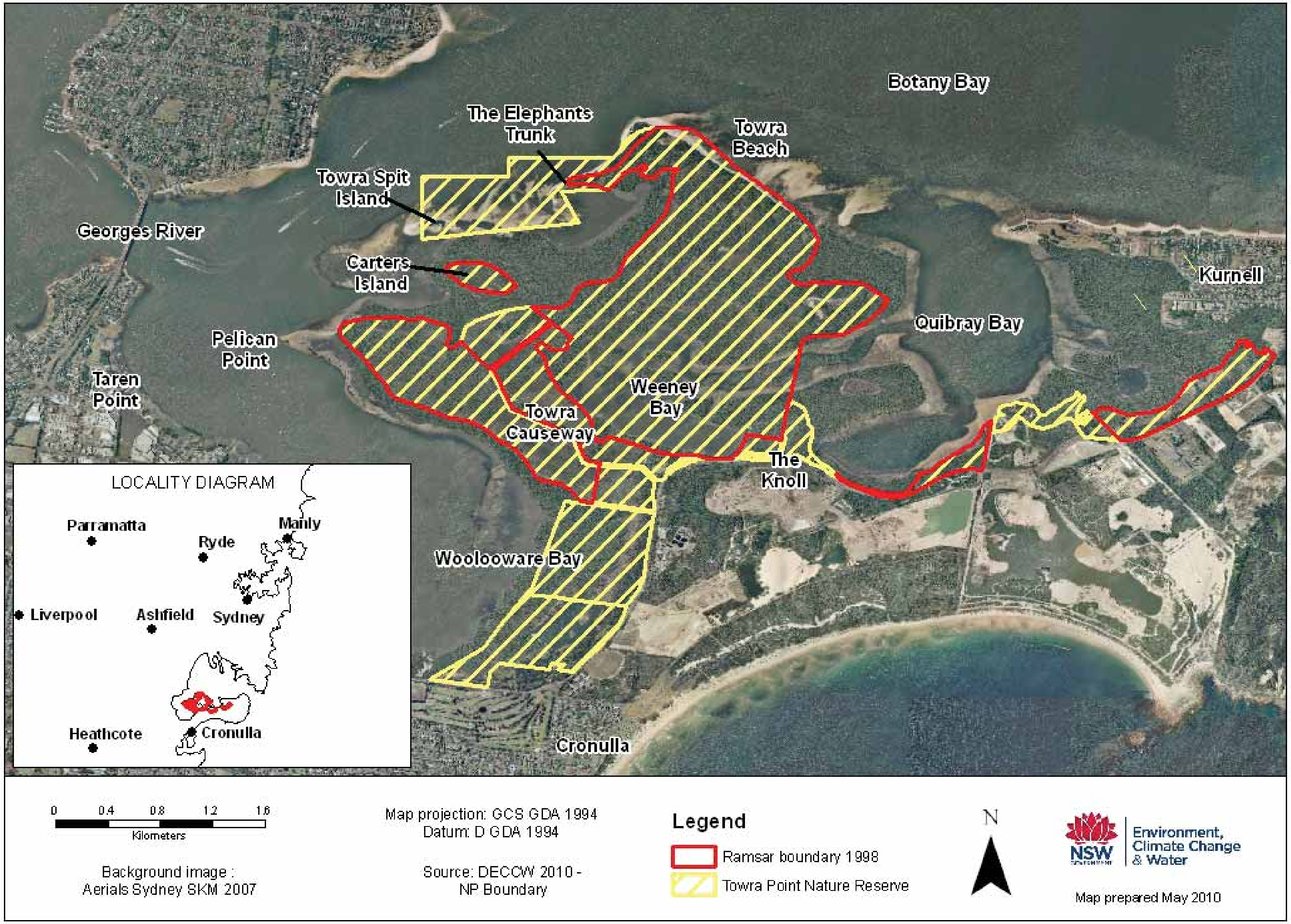


Figure 4: Boundaries of Towra Point Nature Reserve and Ramsar site

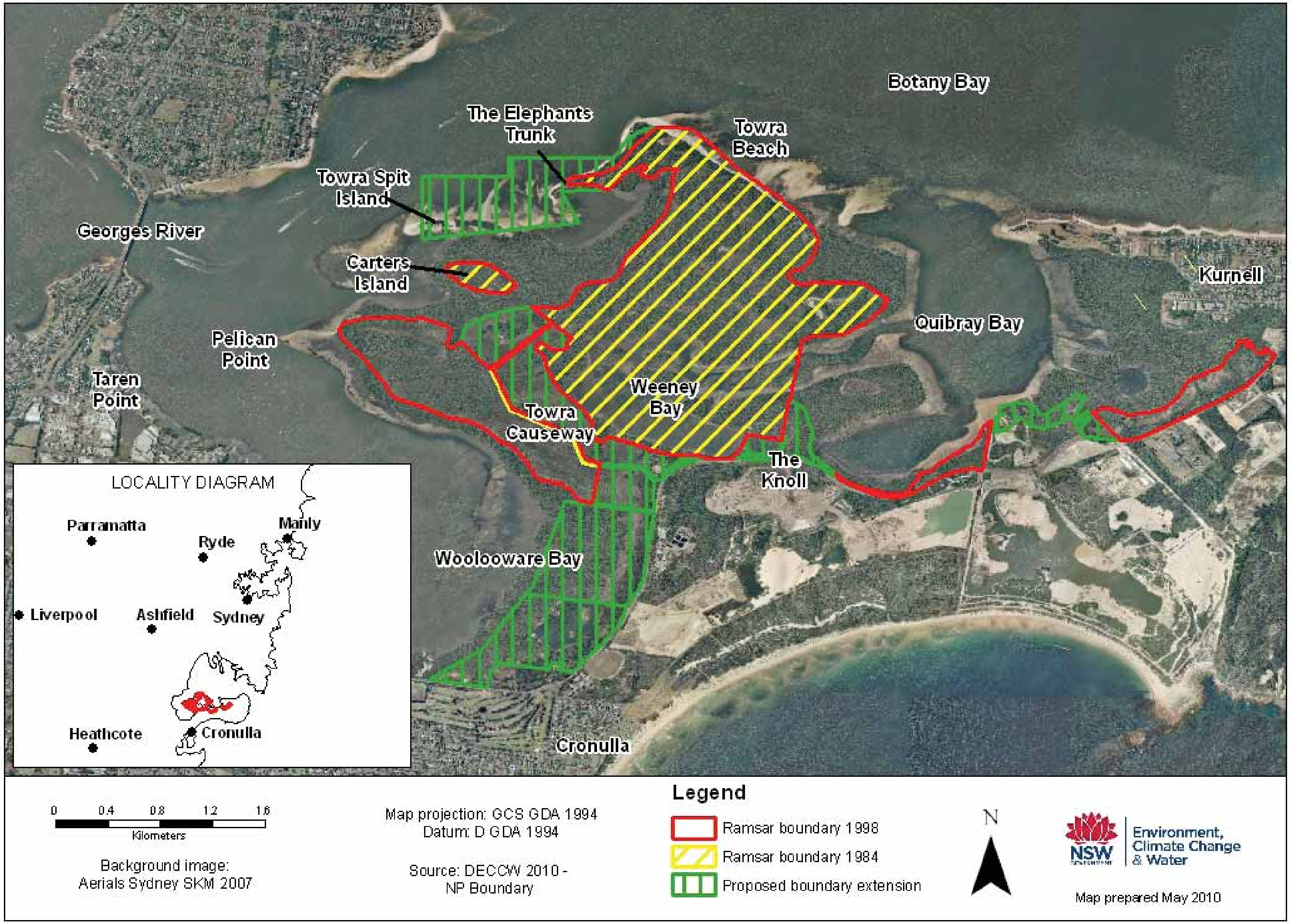


Figure 5: Towra Point Ramsar site and boundary changes

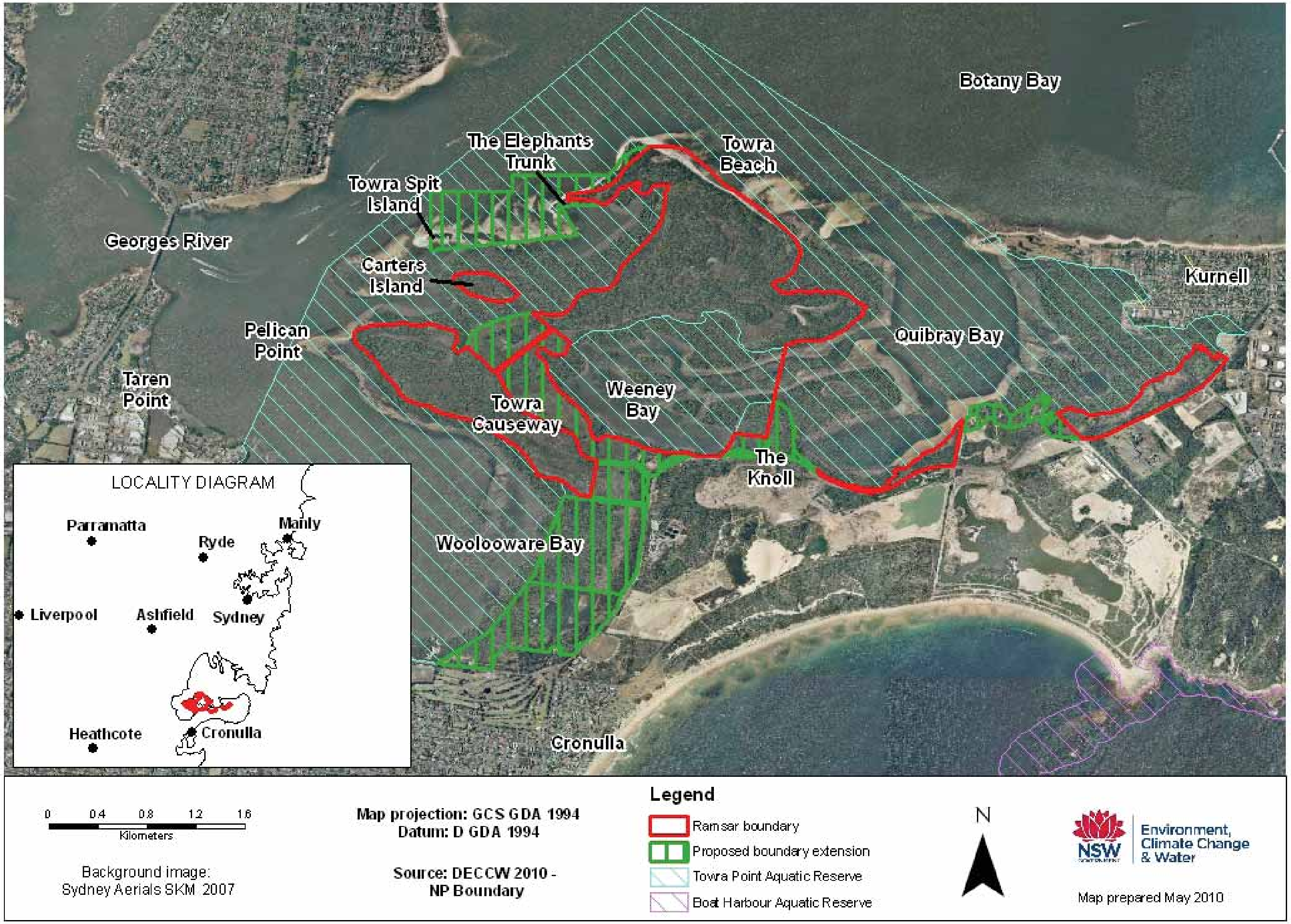
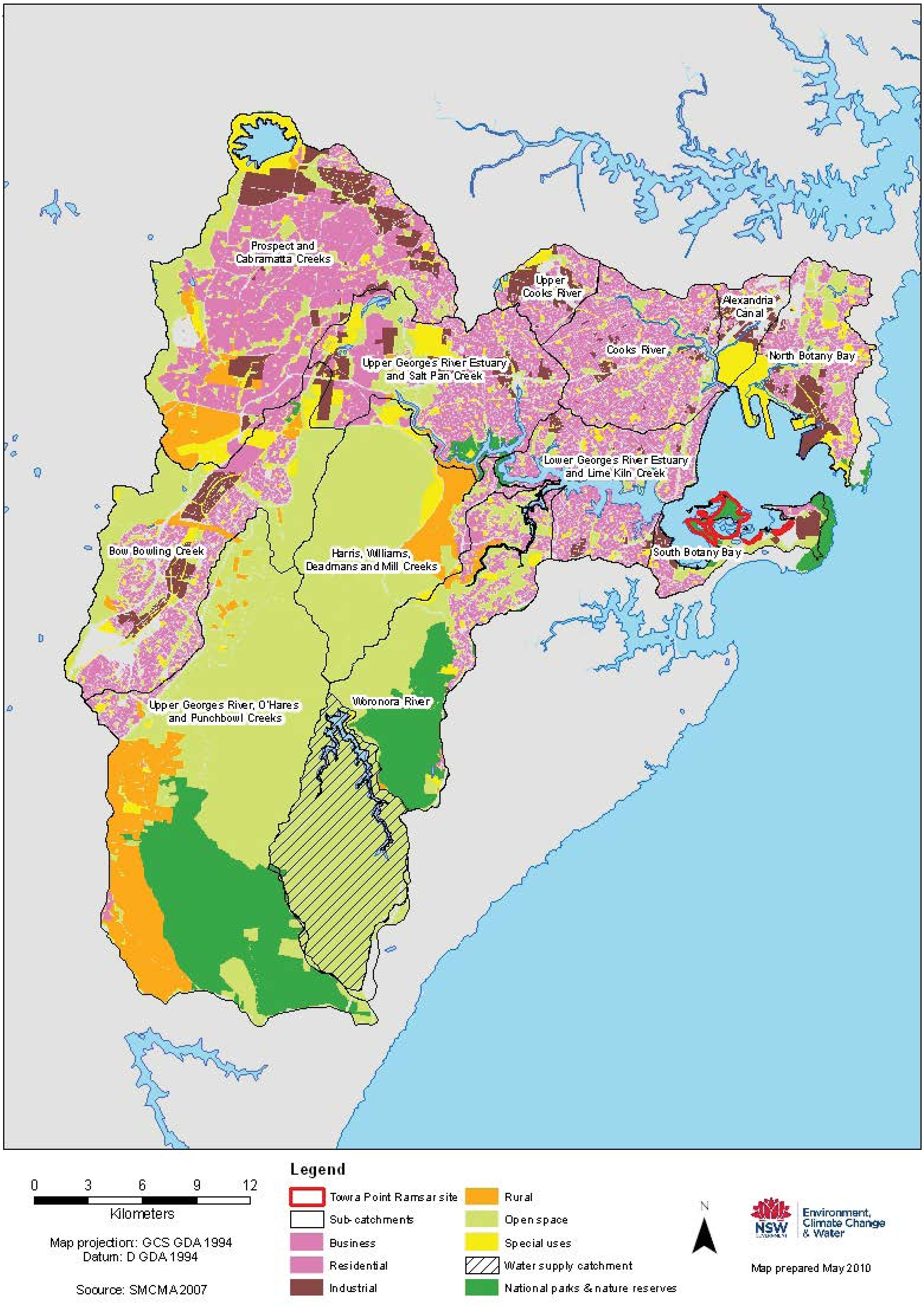


Figure 6: Towra Point Ramsar site and aquatic reserve



Source: SMCMA (2007a)

Figure 7: Sub-catchments within the Botany Bay catchment and land uses

2.4 Criteria for listing as a Ramsar site

In order for a wetland to be recognised as internationally significant it must meet at least one Ramsar listing criterion. The specific criteria that relate to a site give an indication of the benefits and services that may be lost if there were a change in the ecological character. The criteria are reviewed and updated regularly with the current criteria being adopted in 2005.

Towra Point Nature Reserve was listed as a Ramsar site in 1984 under the pre-1999 criteria 1a, 2a, 2b, 3b and 3c (NPWS 1998). These criteria translate to the current criteria 1, 2, 3 and 6:

- **Criterion 1:** A wetland should be considered internationally important if it contains a representative, rare, or unique example of a natural or near-natural wetland type found within the appropriate biogeographic region.
- **Criterion 2:** A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or threatened ecological communities.
- **Criterion 3:** 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 6:** 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.

The nine criteria for listing as a Ramsar site are given in Appendix A.

In 2009 the Ramsar site is considered to meet criteria 2, 3, 4 and 8:

- **Criterion 2:** A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or threatened ecological communities.
- **Criterion 3:** 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:** 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 8:** 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.

Reasons for changed criteria

There are several reasons for the changes in criteria. Criterion 1 is no longer met because an administrative decision was made to change the biogeographic classification from the Interim Biogeographic Regionalisation for Australia (IBRA) to Australian Drainage Divisions. Towra Point is in the Southeast Coast Drainage Division (SE Coast) which is substantially larger than the Sydney Basin bioregion under IBRA. The SE Coast stretches from the NSW–Queensland border south to the Victoria – South Australia border. In the SE Coast mangroves are common in NSW's estuaries whereas saltmarsh is more common in Victoria. Towra Point is estimated to support 6% of NSW mangroves and only 2% of NSW saltmarsh. While it is a near-natural mangrove–saltmarsh community, it is not considered to be outstanding or unique in comparison with other areas of the SE Coast.

In 1984 Towra Point Nature Reserve was listed as meeting criterion 6, as it regularly supported at least 1% of the estimated international population of eastern curlew (*Numenius madagascariensis*). The number of eastern curlew using Botany Bay (including Towra Point) has not decreased since 1984 (AWSG 2008), however the estimated international population of this species has increased (Li Zuo Wei and Mundkur 2007; WSG 2007). Therefore Towra Point now supports less than 1% of the estimated population and does not meet criterion 6. There is a possibility that Towra Point may meet this criterion again in the future for the eastern curlew or another species due to the reduction in shorebird habitat and changing populations worldwide. Therefore the applicability of this criterion should be reviewed each time the Asian Waterbird Census is published by Wetlands International (approximately every three years).

As the result of new information, it is considered that Towra Point also met criteria 4 and 8 when it was listed in 1984 and continues to do so. Therefore, in 2009, Towra Point Nature Reserve Ramsar site meets criteria 2, 3, 4 and 8. An explanation of how the site meets each criterion is given below.

Changed criteria – application to Ramsar site

Criterion 2: A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or threatened ecological communities.

Towra Point supports three nationally threatened species under the EPBC Act: magenta lilly pilly *(Syzygium paniculatum),* green and golden bell frog (*Litoria aurea),* and grey-headed flying fox *(Pteropus poliocephalus)* (Table 5). The green and golden bell frog and grey-headed flying fox are listed as vulnerable species and have been recorded at Towra Point. Towra Point also supports 23 threatened species and five endangered ecological communities under the TSC Act (Tables 6, 7 and 8) as well as 34 species listed under three international migratory bird agreements (JAMBA, CAMBA and ROKAMBA) (Table 9).

Criterion 3: 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.

In 1993 Botany Bay, including Towra Point Nature Reserve, was recognised as one of the four most important migratory wading bird sites in NSW, and Towra Spit Island was named the second most important breeding area in NSW for the little tern (*Sterna albifrons*) (NPWS 2001a). The brown honeyeater (*Lichmera indistincta*), mangrove gerygone (*Gerygone levigaster*) and wallum froglet (*Crinia tinnula*) are at the southern extent of their distribution at Towra Point (Schulz 2006). Towra Point also provides critical links for ecological connectivity for a number of species including the grey-headed flying fox and the white-fronted chat (*Epthianura albifrons*) which is now found in only two locations in Sydney, one of which is Towra Point (Schulz 2006). Other species found at Towra Point that are uncommon in the Sydney region include Lewin's rail (*Rallus pectoralis*), buff-banded rail (*Gallirallus philippensis*), restless flycatcher (*Myiagra inquieta*), little egret (*Egretta garzetta*), striated heron (*Butorides striatus*) and tawny grassbird (*Megalurus timoriensis*) (Schulz 2006). Mangrove and saltmarsh communities and adjacent seagrass beds provide critical habitat and food for juvenile fish and crustaceans, a number of which are of economic importance.

Criterion 4: 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.

Studies have shown that a higher abundance and diversity of fish species are found in areas of mangrove and saltmarsh which are adjacent to seagrass than are found in isolated communities; it is also thought that it is the area of the vegetation at Towra Point that makes it so significant (Clynick and Chapman 2002; Mazumder et al. 2006a; Jelbart et al. 2007; Saintilan et al. 2007). Some species of juvenile fish such as common silver biddy (*Gerres ovatus*), yellow fin bream (*Acanthopagrus australis*) and flat-tail mullet (*Liza argentea*) are found in high numbers and use the mangrove habitats at Towra Point exclusively for this stage in their life. Juvenile luderick (*Girella tricuspidata*) prefer Towra Point mangroves after an initial stage in the adjacent seagrass beds (Bell et al. 1984). These fish and crustaceans are vulnerable at this stage in their life cycle and Towra Point provides critical habitat for their survival (Williams 1990).

Migratory shorebirds are vulnerable due to loss of habitat along their migratory route and Towra Point is a critical stopover for replenishment of fat reserves. Each year migratory shorebirds use Towra Point from about September to April on their migration from Korea, Japan, China, Russia, Siberia and Alaska (Lane 1987). Intertidal zones along the shores of the nature reserve and adjacent areas are of significance to these birds as they offer protection from disturbance and provide a plentiful supply of food. Also of critical importance is the availability of suitable roost sites adjacent to feeding sites (Lawler 1996). The birds roost in saltmarsh, on Towra Spit Island and on oyster lease posts in Quibray and Woolooware bays (Spencer et al. 2009). Accumulation of adequate fat reserves is critical for the long northward migration; therefore a roosting site close to a feeding area makes the site suitable (Lane 1987; Lawler 1996; Laegdsgaard 2006). The little tern, endangered in NSW, has regularly used Towra Spit Island as a nesting site since its formation in 1991; the island is considered an important site for little tern conservation in NSW (Keating and Jarman 2004).

Criterion 8: 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.

Considerable evidence has verified the importance of Towra Point as a significant fish habitat as a nursery and food source for at least 25 fish species of economic importance (SPCC 1978a; Bell et al. 1984; Williams 1990; Mazumder et al. 2005, 2006b; Jelbart et al. 2007; Saintilan et al. 2007). Economically important fish species include yellowfin bream (*Acanthopagrus australis*), silver biddy (*Gerres subfasciatus*), luderick (*Girella tricuspidata*), sea mullet (*Mugil cephalus*), dusky flathead (*Platycephalus fuscus*) and sand whiting (*Sillago ciliata*). A list of all fish species recorded in Botany Bay is included in Appendix C.

Towra Point Nature Reserve Ramsar site and adjacent areas support significant areas of saltmarsh, mangroves and seagrass making it an important fish habitat. These three habitats provide protection for juvenile and migratory fish and a variety of food for many species of fish. Semi-diurnal tides allow the transport of nutrients as well as the movement of fish into different habitats; some species have been recorded in all three wetland types.

2.5 Wetland types

The wetlands at and adjacent to Towra Point Nature Reserve Ramsar site are representative of the wetlands that were found in many other parts of the Sydney region in the past, that are now rare due to land development (NPWS 2001a). The Ramsar site's size and its diversity of plant and animal species make it a unique wetland in the Sydney Basin. The site is critical in maintaining the biodiversity of the

Sydney Basin and is also an important link in the East Asian–Australasian Flyway for migratory shorebirds.

At the time of listing as a Ramsar site, Towra Point Nature Reserve included the following wetland types:

- Wetland type E: Sand, shingle or pebble shores
- Wetland type F: Estuarine waters
- Wetland type G: Intertidal mud, sand or salt flats; and
- Wetland type H: Intertidal marshes.

Due to more recent knowledge, wetland type I: intertidal forested wetlands is present and was present at the time of listing; this has been confirmed from aerial photographs taken around this time (Wilton 2002). Wetland types J: coastal brackish lagoons and K: coastal freshwater lagoons describe the character of the three lagoons which were known at the time of listing (ALS 1977).

Wetland type B: marine subtidal aquatic beds, has been included in this ecological character description to represent the seagrass beds that occur within the Ramsar site at Weeney Bay and in waters adjacent to the site.

There is distinct zonation of wetland types throughout most parts of Towra Point (Figure 8). The distribution of wetland types is influenced by the accretion to erosion ratio, tidal inundation, topography and microtopography (Clarke and Hannon 1967, 1969; Saintilan et al. 2009). Since Towra Point was listed as a Ramsar site in 1984, the area of each wetland type has changed. The biggest changes are in the areas of saltmarsh (wetland type H) and mangrove (wetland type I), both of which have decreased since 1984. Possible causes of these changes are outlined in section 5.5.1. Figure 9 shows the extent of the wetland classifications in 2007 at Towra Point.

Table 3 shows the approximate areas of each wetland type in Towra Point Nature Reserve and Towra Point Aquatic Reserve at the time of Ramsar listing.

Table 3: Areas of wetland types at time of Ramsar listing[1]

Ramsar wetland type classification	Wetland type characteristics specific to Towra Point Nature Reserve	Approximate area of wetland type at time of listing (hectares) [2]	Area of wetland type as % of total area
B	Marine subtidal aquatic beds	516 [a]	25.8%
E	Sand, shingle or pebble shores: sand spits, sand bars	Unknown	
F	Estuarine waters: permanent water of estuaries	948 [b]	64%
G	Intertidal mud, sand or salt flats: mudflats	No data	
H	Intertidal marshes: saltmarshes	141 [c 3]	7.1%
I	Intertidal forested wetlands: mangroves	395 [c 3]	19.7%
J and K	Coastal brackish lagoons and coastal freshwater lagoons	Unknown	
	Total area	**2000**	

Source: [a]: Watford and Williams (1998), [b]: NSW Maritime (2005), [c]: Wilton (2002)

1 Areas are for Towra Point Nature Reserve and Towra Point Aquatic Reserve.

2 Data for wetland types at time of Ramsar listing in 1984 was not available for all wetland types.

3 In addition to this area, mixed habitat was classified to be both wetland types H and I with an area of 55 hectares.

Terrestrial habitats are not described as wetland types under the Ramsar Convention; however, they are a significant component of the ecosystem and cover a large area – 166 hectares in 1984 and 185 hectares in 2006 (Wilton 2002; SSC 2006a).

The following sections describe each of the wetland types found at Towra Point.

Wetland type B: Marine subtidal aquatic beds

There are significant areas of seagrass meadows in Towra Point Nature Reserve Ramsar site and in the adjacent Towra Point Aquatic Reserve (Figure 10). These beds are critical in assisting the nature reserve maintain its biodiversity and abundance of species (Connolly et al. 2005a). There are three species of seagrass in Botany Bay: *Posidonia australis* (strapweed), *Zostera capricorni* (eelgrass) and *Halophila ovalis* (paddleweed). *H. ovalis* is the least abundant species around Towra Point and is found in low densities, often mixed with the other two species.

Areas of seagrass in Botany Bay have been calculated by a range of methods and at various times, but are not directly comparable due to differences in study area and methodology. Watford and Williams (1998) compared changes in the area of two species of seagrass from 1942 to 1995 (Figure 11). They estimated total seagrass area in 1984 to be 516 hectares compared to 599 hectares in 1995. However, the earlier comparative study in that paper did not calculate mixed *P. australis* and *H. ovalis*. The total area of *Z. capricorni* and *P. australis* without the mixed seagrass was found to be 474 hectares in 1995. The most recent study found a total area of 458 hectares of seagrass extending from the eastern side of Woolooware Bay to the eastern point of Kurnell headland including the seagrass within and adjacent to Towra Point Aquatic Reserve. This includes areas of mixed seagrass species (DPI 2009).

Photo: K. Brennan 2007

Figure 8: Wetland type zonation showing mangroves and saltmarsh species

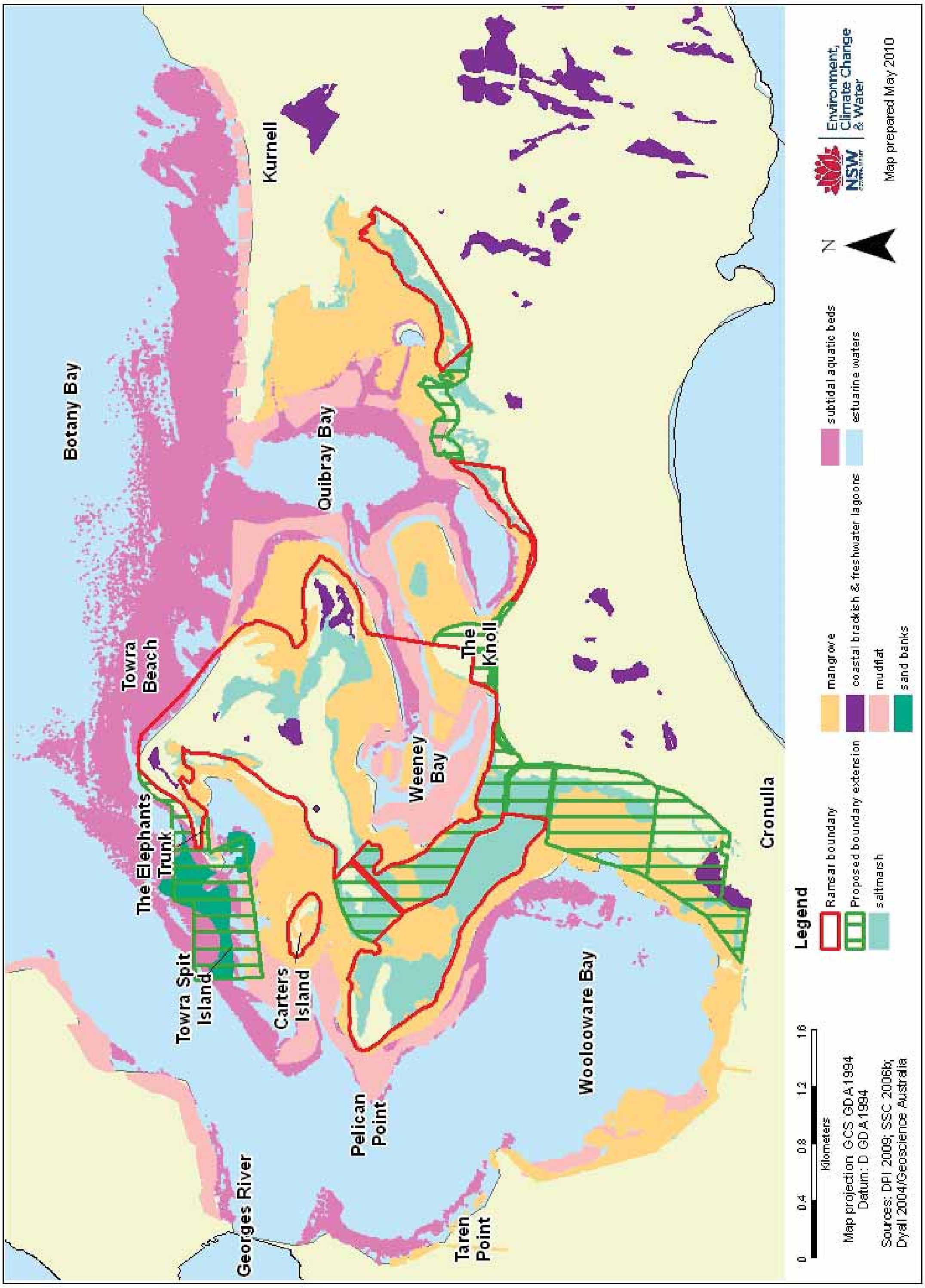


Figure 9: Wetland types of Towra Point

In 2009 the area of seagrass in Weeney Bay in the Ramsar site was about nine hectares, and comprised *P. australis* (DPI 2009). There are also extensive areas of seagrass (*P. australis* and *Z. capricorni*) around the Elephants Trunk and Towra Spit Island which are in parts of the nature reserve proposed for addition to the Ramsar site.

Some of the subtidal aquatic beds adjacent to the Ramsar site support the invasive aquatic weed caulerpa (*Caulerpa taxifolia*). The management of caulerpa, which competes with seagrasses, is discussed in section 6.

Wetland type E: Sand, shingle or pebble shores

Wind-blown marine sand and sand eroding from Towra Beach, in conjunction with tidal currents and waves, created, and continue to influence, the itinerant sand spits and bars around Towra Point (ALS 1977). The sand is quartz-rich, with carbonate concentrations generally high and organic content generally low (OzCoast and OzEstuaries 2005). Natural sand movement is continuously changing the formation of sand spits and bars around Towra Point. The change in wave dynamics due to development on the northern side of Botany Bay has increased the effect of erosion and accretion in parts of the bay, including around Towra Point (Bryant 1980; URS 2003). Sand spits are favourable roosting and nesting sites for shorebirds as they offer protection from predators and disturbance and provide a source of food in the surrounding intertidal area (SPCC 1979a; Lane 1987; Lawler 1996).

Towra Spit Island was formed in approximately 1991 when a channel separated it from the Elephants Trunk (Connell Wagner 2001). It became an important nesting site for the little tern, listed as endangered under the TSC Act, and is also an important resting and foraging site for internationally and nationally significant migratory and resident shorebirds, such as the pied oystercatcher (Figure 12). The sand spit is slowly moving and expanding in a south-westerly direction, and in 1997 it rejoined Towra Point after a large storm. The strip of sand connecting the island to the mainland was dredged in 2005 and the sand was used to replace sand eroded from Towra Beach (SMEC 2003). Towra Spit Island became isolated from the mainland as a result of this dredging which prevents land-based predators and people from accessing the nesting site. However, foxes are still able to get to the island as the surrounding waters are shallow, exposing the mudflats at low tide.

Wetland type F: Estuarine waters

The estuarine waters that surround Towra Point include Botany Bay, Georges River, Cooks River, Woolooware Bay, Quibray Bay and Weeney Bay. Habitats and species composition reflect the estuarine waters around Towra Point. Approximately 1400 hectares of water surrounding Towra Point have been dedicated as the Towra Point Aquatic Reserve by I&I NSW in order to protect mangroves and marine life.

Wetland type G: Intertidal mud, sand or salt flats

There is a variety of intertidal areas around Towra Point which support different organisms in all parts of the food chain (SPCC 1979b). The intertidal mud and sand flats extend along the shoreline from mean low water spring to mean high water spring tides. They are relatively flat with a non-vegetated zone seaward of the mangroves, and are regularly inundated (Heap et al. 2001). These flats are comprised of muddy sands that are high in organic matter (Roy and Crawford 1979) and rich in invertebrates and worms, making them favoured feeding areas for many shorebirds (Figure 13).

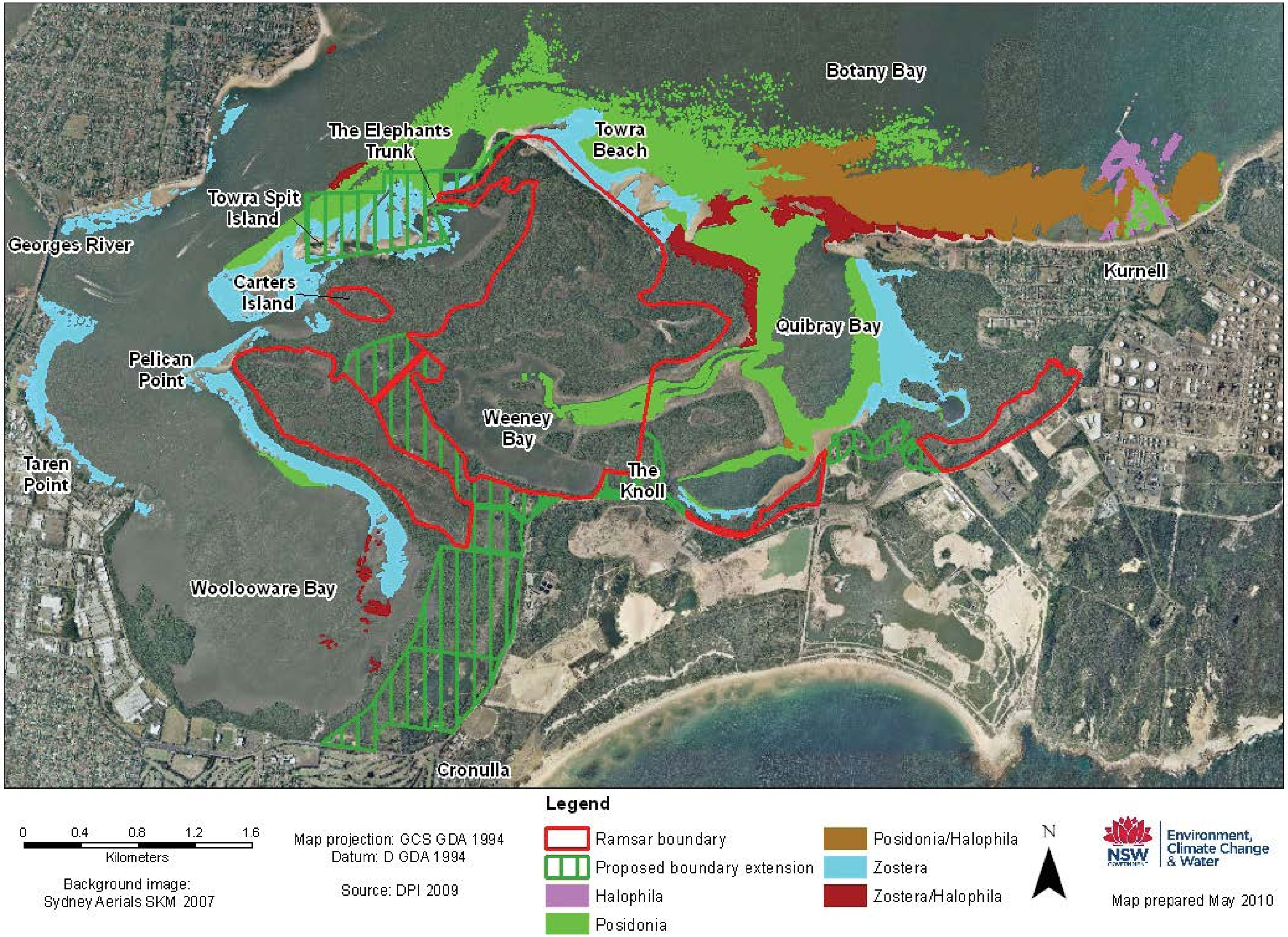
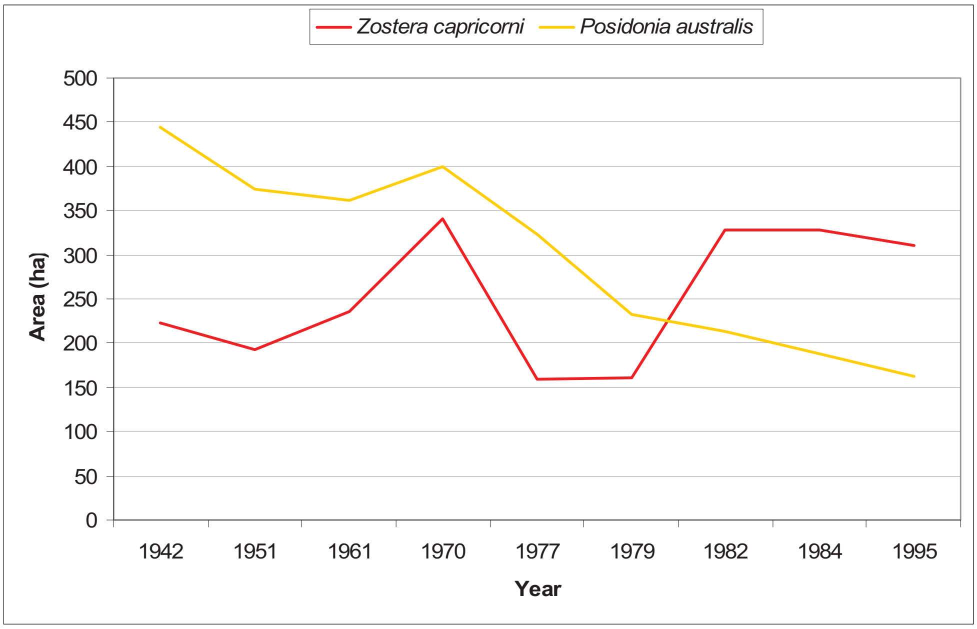


Figure 10: Distribution of seagrass in southern Botany Bay



Source: Watford and Williams (1998)

Figure 11: Changes in seagrass areas along southern shore of Botany Bay 1942–95

Photo: Phil Straw

Figure 12: Pied oystercatchers on Towra Spit Island

In Botany Bay intertidal areas were extensive before land reclamation in the northern parts of the bay in the 1970s reduced much of this wetland type (Hindwood and Hoskin 1954; SPCC 1979a; Pegler 1997). The intertidal areas at and surrounding Towra Point are therefore important in supporting the organisms that favour this habitat (see section 5.5.2).

There is no historical data on the area of intertidal mud and sand flats at Towra Point. Recent mapping determined the area of the intertidal mud flats and sand spits around Towra Point to be approximately 156 hectares at low tide (Dyall et al. 2004).

Photo: Phil Straw

Figure 13: Bar-tailed godwits foraging in the intertidal zone

Wetland type H: Intertidal marshes

Extensive saltmarsh areas were historically found along the northern side of Botany Bay prior to land clearing and reclamations for urban and heavy industrial development (Hindwood and Hoskin 1954).

In the late 1970s Towra Point supported 90% of the saltmarsh in the Sydney Basin bioregion, while in 2004 it had approximately 60% of Sydney's saltmarsh area (ALS 1977; Dyall et al. 2004). This reduction has been a motivation behind the listing of coastal saltmarsh as an endangered ecological community under the TSC Act. The saltmarsh at Towra Point is one of the largest stands in the whole of NSW (Mitchell and Adam 1989), and it is an important habitat for a number of species and provides critical benefits and services (section 4).

The saltmarsh is on the landward side of adjacent mangroves. This area is slightly higher than the mangroves, and therefore is less frequently inundated by tides than are the mangroves. Calcareous and siliceous sands are a characteristic of this zone and organic content is usually high (Roy and Crawford 1979). The main distinguishing characteristics of the saltmarsh zone are high salinity and large variations in salinity due to less frequent tidal inundation; soil salinity has a major influence on the distribution of saltmarsh species within the saltmarsh zone (Clarke and Hannon 1969, 1971).

The area of saltmarsh at Towra Point has decreased since listing in 1984 as a Ramsar site. Estimates from aerial photographs showed that in 1983 the area was 141 hectares, and in 1999 it was 88.1 hectares, a reduction of 38% (Wilton 2002) (Figures 14–16). Habitat containing both saltmarsh and mangrove species (mixed habitat) covered an additional 55 hectares in 1983 and 44 hectares in 1999. By comparing aerial imagery from 1999 to 2005, a further decline in saltmarsh can be seen.

The most recent survey found a total of 134 hectares of saltmarsh within and adjacent to the Towra Point Nature Reserve. An additional nine hectares of mixed saltmarsh and mangrove was also mapped (DPI 2009). This area cannot be compared to the study by Wilton (2002) due to different survey methods and image sources, but should be used as the most recent area for saltmarsh.

Wetland type I: Intertidal forested wetlands

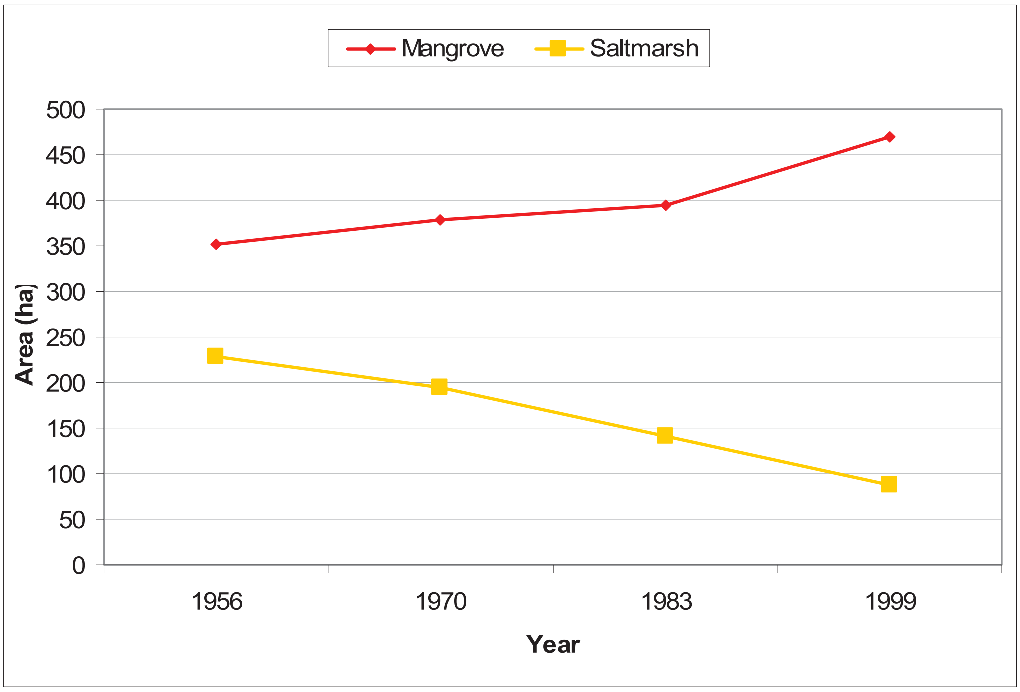
Towra Point supported 50% in the late 1970s and continues to support approximately 40% of mangroves in the Sydney region (ALS 1977; Dyall et al. 2004). There are two species of mangroves at Towra Point – the grey mangrove (*Avicennia marina*) and the river mangrove (*Aegiceras corniculatum*), with the grey mangrove the more abundant species (Clarke and Hannon 1967). Mangroves support and maintain a complex food web that is imperative for the ongoing sustainability of Towra Point Nature Reserve. Some mangroves at Towra Point are outside the Ramsar site boundary, however they are an integral part of the ecosystem.

Studies have shown that in a number of locations in south-east Australia mangroves have increased their range at the expense of saltmarsh, with greater changes in modified catchments (Mitchell and Adam 1989; Saintilan and Williams 1999, 2000; Evans and Williams 2001; Adam 2002; Wilton 2002; Laegdsgaard 2006; Mazumder et al. 2006b). Between 1956 and 1999 there was an increase of 34% in mangrove area at Towra Point, and since 1984 there has been a further increase in mangrove area (Figures 14–16). In 1983 and 1999 the area of mangroves was 395.2 hectares and 470.5 hectares respectively, an increase of 19%. Habitat containing both saltmarsh and mangrove species (mixed habitat) covered an additional 55 hectares in 1983 and 44 hectares in 1999 (Wilton 2002).

By comparing aerial imagery from 1999 and 2005, a further increase in mangrove area can be seen. The most recent survey found a total of 385 hectares of mangrove within and adjacent to Towra Point Nature Reserve. An additional nine hectares of mixed saltmarsh and mangrove was also mapped (DPI 2009). This area cannot be compared to the study by Wilton (2002) due to different survey methods and image sources, but should be used as the most recent area for mangroves.

Wetland type J: Coastal brackish lagoons
Wetland type K: Coastal freshwater lagoons

The three named lagoons at Towra Point are Towra Lagoon (Figure 17), Mirrormere and Weedy Pond. There are at least three other lagoons that are unnamed with no ecological information (Figure 18). All lagoons have been classified as Sydney Freshwater Wetlands, an endangered ecological community in NSW (SSC 2006a),



Source: Wilton (2002)

Figure 14: Area of mangroves and saltmarsh 1956–99

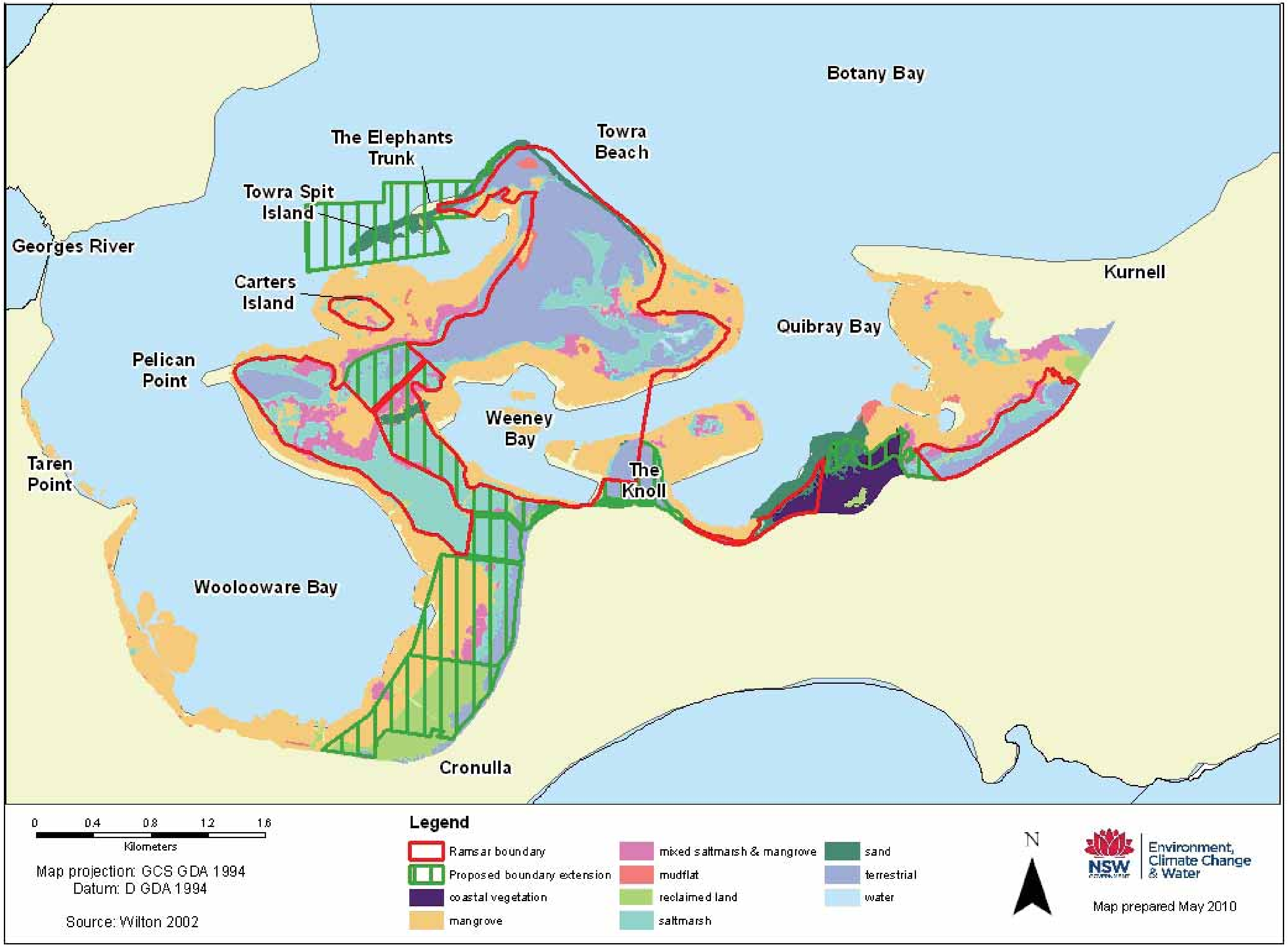


Figure 15: Wetland types in 1983

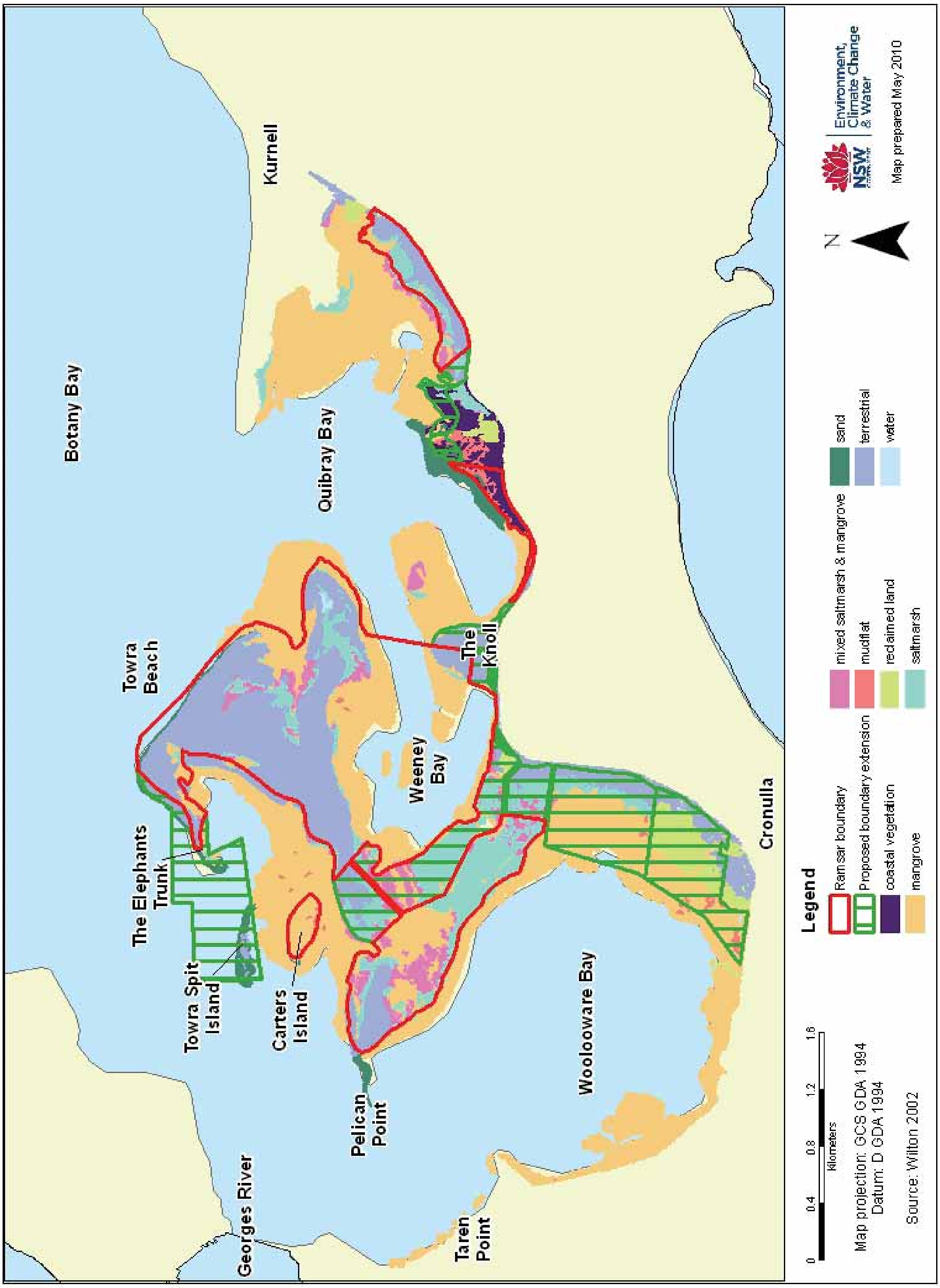


Figure 16: Wetland types in 1999

however not all lagoons are now freshwater. Wetland types J and K have been described together in this report until information is available to classify each lagoon as either a freshwater or brackish coastal lagoon.

Towra Lagoon was once the largest freshwater body on Towra Point; however, increased erosion and severe storms in 1974 and 1975 caused the intrusion of salt water into the lagoon (ALS 1977). While there have been attempts to rehabilitate the lagoon in order to restore habitat diversity, the altered wave energy as a result of morphological changes in Botany Bay is directed towards Towra Beach and continues to erode the beach which protects the lagoon.

Weedy Pond is a small wetland that can become dry for long periods until heavy rain refills it (SSEC 2008). Littoral rainforest, an endangered ecological community, surrounds Weedy Pond and Mirrormere. There is very little information on the condition and specific location of all freshwater and brackish lagoons at Towra Point. Further investigation is necessary to fill this knowledge gap. Mapping of the lagoons identified a total area of approximately seven hectares within the Ramsar site; an additional 68 hectares of Sydney Freshwater Wetlands were mapped on the remainder of Kurnell Peninsula (SSC 2006a).

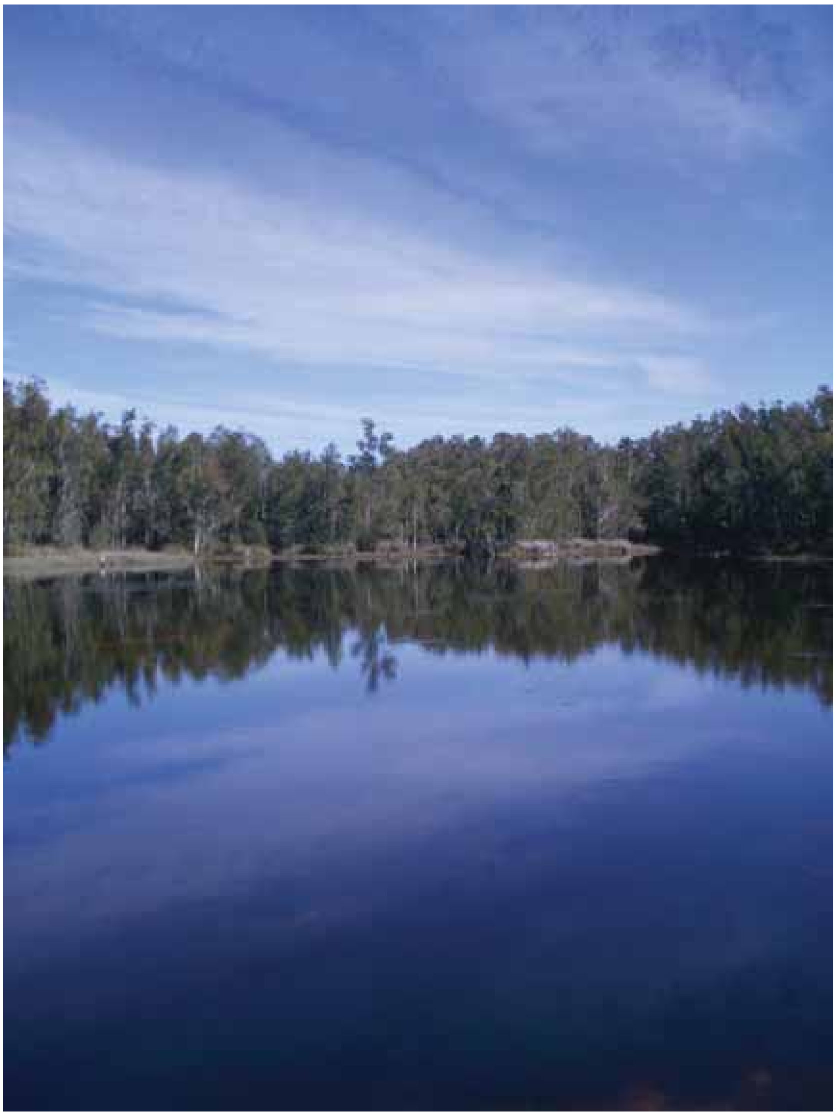


Photo: K. Brennan 2007

Figure 17: Towra Lagoon

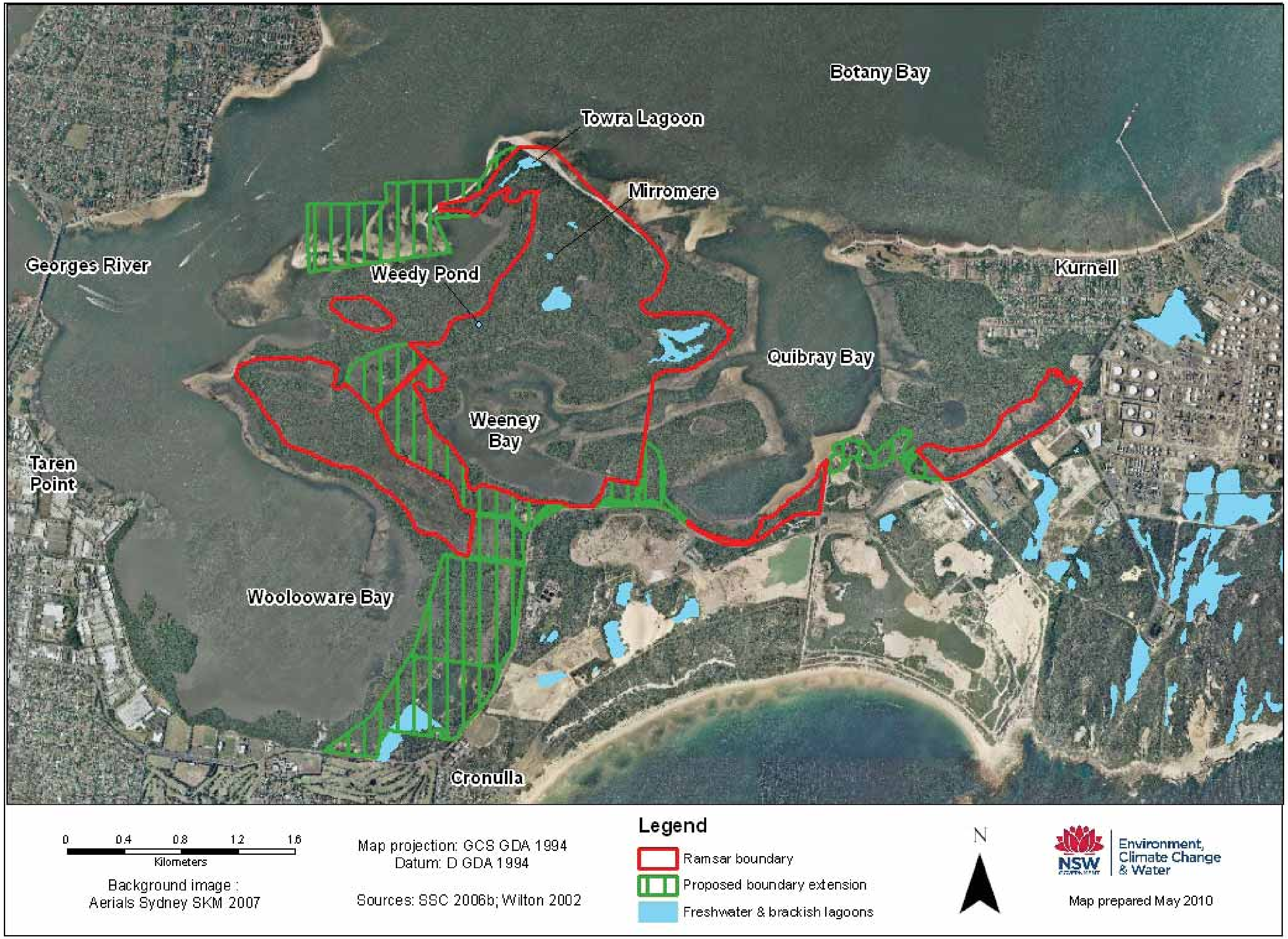


Figure 18: Known freshwater and brackish lagoon locations on Kurnell Peninsula

3 Ecological character

The ecological character of a wetland is defined by its components and process which, through their interactions, provide benefits and services. Figure 19 illustrates the links between the ecological components and processes of Towra Point.

Critical ecosystem services are listed in Table 4.

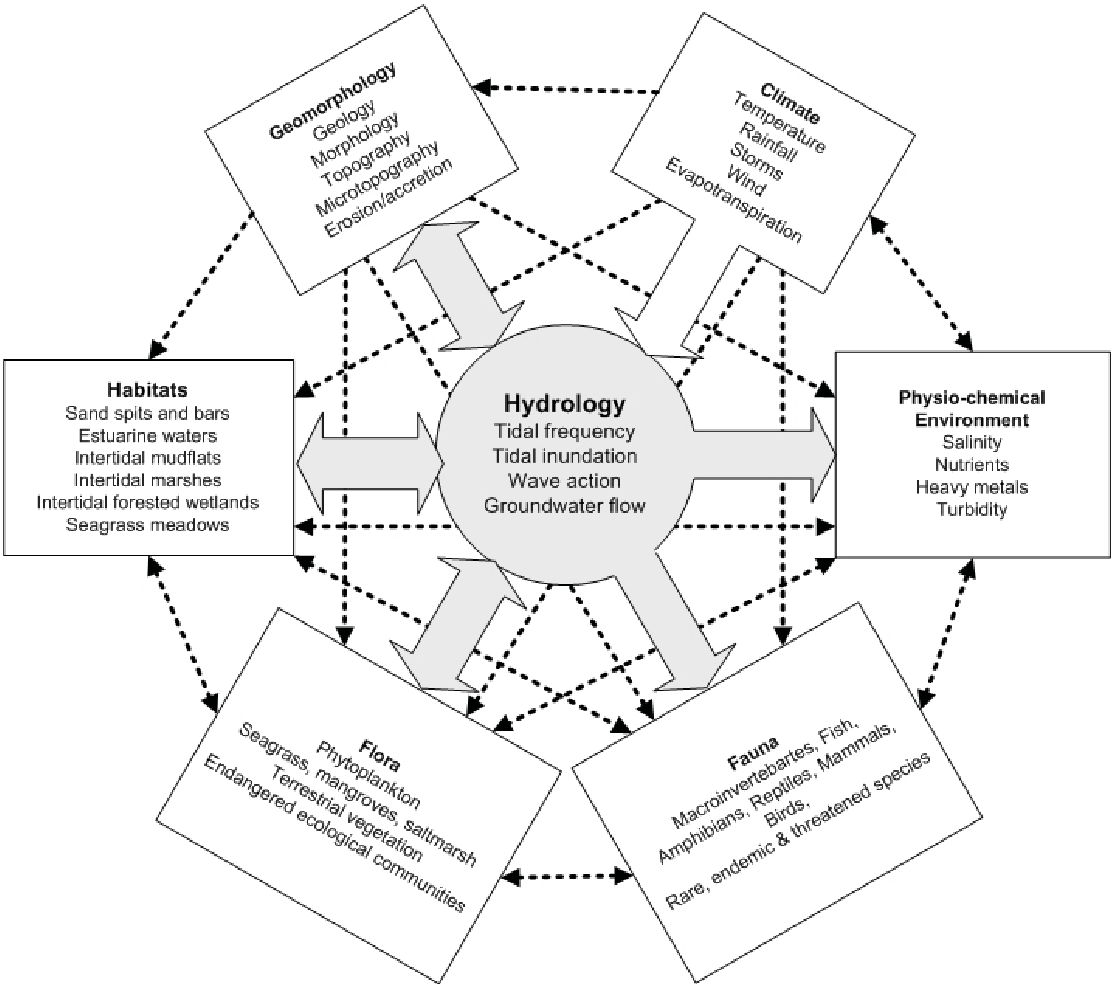


Figure 19: General conceptual model for components and processes at Towra Point

Table 4: Critical ecosystem services of Towra Point Nature Reserve

Ecosystem service		Service relating to the Ramsar site	Ramsar criteria
Provisioning	Fisheries production	Nursery habitat for commercial fish species and for commercial oyster cultivation.	3, 4, 8
	Trophic relay	Extensive food web provides numerous biological interactions and allows transfer of energy and nutrients throughout estuary.	
Regulating	Maintenance of hydrological regimes	Tidal cycle allows crabs to release larvae, which are a reliable food source for many fish and birds	1
		Retention and retardation of excess water flows, preventing flooding	
	Shoreline stabilisation and protection	Vegetation prevents erosion of marine and fluvial sands, especially in areas of site affected by tides, storms and high rainfall	1
	Pollution control	Mangroves and other vegetation types filter and trap sediments through a combination of biological activity and physical adsorption onto soil particles, preventing the flow of contaminants directly into the site's hydrological system.	1
	Science and education	As the largest wetland of its type in Sydney, Towra Point Nature Reserve attracts students of all academic levels for education and research.	1
	Aesthetic amenity	The wetlands of Towra Point are relatively pristine and the nature reserve protects some of the typical wetland types that are now rare in the area due to development. Towra Point is also one of the most important migratory bird-feeding and roosting sites in the Sydney region, and provides a pleasing view of a natural landscape in a heavily industrialised area.	1
Supporting	Hydrological processes	Towra Point wetlands maintain natural hydrological processes including evapotranspiration, runoff, infiltration and groundwater flow. Hydrology is critical in the Towra Point ecosystem, as it has a major influence on the morphology of the site and on habitat types, and determines distribution of flora and fauna species.	1
	Food webs	Mangroves and saltmarsh in Towra Point NR and seagrass meadows adjacent to the reserve are critical links in the food chain due to the large amounts of organic matter, or detritus, they produce, which is a reliable food source for invertebrates. The tidal regime in Botany Bay supports the food web at Towra Point by exporting crab and crustacean larvae from saltmarsh to intertidal and subtidal areas (outwelling) and by transporting detritus from seagrass meadows to intertidal and supratidal areas (inwelling).	1, 3
	Physical habitat	Suitable habitat for threatened species, endangered ecological communities, diverse range of shorebirds, and seagrass, mangrove and saltmarsh species growing next to each other, which enhances the area's biodiversity.	1, 2, 3, 4, 8
Supporting	Sediment trapping and stabilisation	Seagrass, saltmarsh and mangrove communities at Towra Point trap sediments; reducing both sediment loads in Botany Bay and erosion. These communities also trap contaminants which can be filtered out through the soil. Semi-diurnal tides in Botany Bay maintain good mixing of the water and suspended sediments. The high quality of the water surrounding Towra Point is evident in the health of the oysters produced in Quibray Bay. The presence of the vegetation at Towra Point supports water clarification by nutrient uptake and sediment accumulation.	1, 3

Ecosystem service		Service relating to the Ramsar site	Ramsar criteria
	Nutrient cycling	Movement of nutrients that promote the biological growth, development and maintenance of the wetland ecosystem	3
	Biodiversity	Connectivity between saltmarsh, mangrove and seagrass habitats at Towra Point is critical for maintaining species of fish and crustaceans. Towra Point is used for foraging by the threatened grey-headed flying fox, and there is a large maternal camp adjacent to Towra Point that supports the genetic diversity of the species.	1, 2, 3, 4, 8
	Special ecological, physical or geomorphic features	High levels of productivity from the combination of saltmarsh, mangrove and adjacent seagrass meadows support a high density and abundance of fish and crustaceans. Seagrass, saltmarsh and mangrove communities are important nursery habitats for fish and crustaceans, including those of commercial importance.	3, 4, 8
	Threatened wetland species, habitats and ecosystems	Towra Point supports three threatened species listed under the EPBC Act, and 23 threatened species and five endangered ecological communities under the TSC Act. Towra Point supports the largest stand of coastal saltmarsh in the Sydney Basin bioregion	1, 2, 4
	Priority wetland species	Towra Point NR and adjacent areas support 34 species of migratory birds listed under JAMBA, CAMBA and ROKAMBA. These birds use the mudflats, saltmarsh, mangrove and sand spit areas for feeding and roosting due to their high productivity and protection from predators and disturbance.	4
	Ecological connectivity	Towra Point provides important roosting, feeding and nesting sites for migratory birds, and supports significant habitat that is connected with surrounding natural areas such as Kamay Botany Bay NP, Royal NP and Georges River NP, and with Taren Point Shorebird Community. Shorebirds such as the eastern curlew and pied oystercatcher forage along the Georges River and in Port Hacking but, due to lack of suitable habitat elsewhere, return to Towra Point to roost.	2, 3, 4, 8

4 Ecosystem services

Towra Point was listed as a Ramsar site for its value in supporting threatened and endangered species and ecological communities, plants and animals at critical life stages, and fish populations. The critical benefits and services of Towra Point are, firstly, those relevant to its biodiversity value, including hydrological, nutrient cycling, food web and habitat services. Provisioning services are also of critical importance at Towra Point, as it serves as critical habitat for fish species and contributes to the local fishing industry.

The critical ecosystem services of Towra Point are described according to the categories identified in the Millennium Ecosystem Assessment (2003), with particular emphasis on provisioning services and services supporting the site's biodiversity values. The services are listed in Table 4.

4.1 Provisioning services

Towra Point is a critical habitat for fish species and contributes significantly to the finfish industry which provides food for human consumption. The oysters cultivated in Botany Bay and the Georges River are the only ones now produced in the Sydney area between the Hawkesbury and Shoalhaven rivers (DPI 2006).

4.1.1 Fisheries production

Finfish industry

The fish, crustaceans and molluscs of Botany Bay were a critical food source for the indigenous people and early settlers (ALS 1977). Due to its proximity to a growing colony and the relatively shallow and extensive waters, Botany Bay was used for fishing by the early settlers from the mid-19th century, and by 1880 a Royal Commission on Fisheries expressed concern about the declining number of fish in Botany Bay (SPCC 1979c). Commercial fishing continued in Botany Bay and for the 1977–78 financial year approximately 266 000 kg of catch was sold for approximately $280,000 (SPCC 1979c).

Changes since 1984

Towra Point Aquatic Reserve was declared in 1987 and is protected under the FM Act. Two zones have been defined: a sanctuary zone, which prohibits any form of fishing or collection of marine vegetation, and a refuge zone, which allows recreational fishing only (DECC 2008b). Commercial fishing, with the exception of lobster and abalone collection, was banned in Botany Bay and its tributaries in May 2002 as other coastal areas were exploited. This was to establish a recreational fishing haven for the exclusive use of anglers (Williams et al. 2004). The habitats at and surrounding Towra Point Nature Reserve are an important link for the commercial fishing industry to raise and protect juvenile fish, crustaceans and molluscs as they may migrate to areas that are commercially fished (Bell et al. 1984; Mazumder et al. 2005; Saintilan et al. 2007).

Oyster cultivation

The Georges River and Botany Bay system was one of the two most important areas for oyster production in NSW and was at a peak in 1971–72 with a yield of 41,068 bags (SPCC 1979c). Over half of the oysters produced in the Georges River/Botany Bay system were from Woolooware Bay, with the remainder from Quibray Bay and Georges River (SPCC 1979c), outside the Ramsar site.

Changes since 1984

The oyster industry grew due to the health and productivity of the oysters produced in the Georges River, Woolooware Bay and around Towra Point, aided by proximity to Sydney's markets (SPCC 1979c). An outbreak of Qx disease in 1994 stopped oyster farming in all areas of Botany Bay and the Georges River except for the leases in Quibray Bay and Woolooware Bay (DPI 2006). Some of the oyster leases around Towra Point have been abandoned and discarded oyster farming materials litter some parts of the nature reserve (Figure 20). During high tides, the remaining leases in Quibray and Woolooware Bay provide roosting sites for migratory birds such as the eastern curlew and bar-tailed godwit (*Limosa lapponica*) (P. Straw 2007, pers. comm.) (Figure 21). Today there are only a small number of active leases around Towra Point which are approved for cultivating Sydney rock oysters (*Saccostrea commercialis*).

4.1.2 Trophic relay

The complex food web at Towra Point provides numerous biological interactions and allows transfer of energy and nutrients to different parts of the estuary; this transfer is called trophic relay. Trophic relay can occur through tidal movement of organic material in the water column or through predator–prey interactions (Connolly et al. 2005b; Connolly 2009).

Stable isotopic analysis of carbon and nitrogen in organisms can help to determine how energy and nutrients are transferred through an ecosystem (Connolly et al. 2005b; Szymczak and Mazumder 2007). Organic material transferred from seagrass meadows into intertidal areas is used by many organisms that live in the saltmarsh and mangrove habitats (Connolly et al. 2005a, 2005b). Export of zooplankton from saltmarsh during spring tides enables transfer of energy and nutrients into otherareas (Mazumder et al. 2006a; Connolly 2009). These are two examples of trophic relay at Towra Point and a loss of these critical processes would cause loss of biodiversity (Connolly et al. 2005b).

Photo: K. Brennan 2007

Figure 20: Discarded oyster farming materials

Photo: Phil Straw

Figure 21: Eastern curlew on an oyster lease in Weeney Bay

4.2 Regulating services

The regulating services of Towra Point Nature Reserve Ramsar site include maintenance of hydrological regimes, shoreline stabilisation, biological control and pollution control.

4.2.1 Maintenance of hydrological regimes

Natural hydrological processes include rainfall, tides, evapotranspiration, runoff, infiltration and groundwater flow. Sydney is a growing city with more areas being cleared for development, and this changes some of these processes or prevents them from occurring. Water-sensitive urban design can help to minimise the impacts of development on the natural hydrological cycle.

Maintenance of natural hydrological regimes is critical for many of the components and processes of Towra Point. Crabs use the tidal cycle to release larvae which is critical to the productivity of the wetland as the larvae are a reliable food source for many fish and birds (Mazumder et al. 2006a). The vegetation communities have adapted to the tides and a change in the tidal cycle could lead to a change in ecological character of the site (Clarke and Hannon 1970).

Towra Point Nature Reserve supports recharge and discharge of groundwater. The wetland also has the ability to retain excess water and release it slowly into Botany Bay, which prevents flooding and filters some contaminants from the water. The conservation of this wetland will prevent further depletion of aquifer reserves and maintain the natural hydrological cycle.

4.2.2 Shoreline stabilisation and storm protection

The soils of Towra Point Nature Reserve include marine and fluvial sands, which are highly susceptible to erosion (Roy and Crawford 1979). The presence of vegetation prevents soil erosion, especially in areas affected by tides, storms and high rainfall. (ALS 1977).

Vegetated areas help to stabilise the seabed which reduces the effect of waves on the shoreline, and also prevent inundation of urban and industrial areas. Mangroves and seagrass trap sediment, protecting the seabed and shoreline.

Erosion at Towra Point has been intensified by dredging for the extension of the Sydney Airport runway and the container terminal at Port Botany which changed the wave patterns of the bay (SPCC 1979d; McGuinness 1988; NPWS 2001a). Erosion of Towra Beach is significant and is due to changes in the hydrological cycle in Botany Bay (SPCC 1979d).

4.2.3 Biological control of pests and disease

Towra Point supports habitat for native predators, such as the masked owl (*Tyto novaehollandiae*), white-bellied sea eagle (*Haliaeetus leucogaster*) and whistling kite (*Haliastur sphenurus*) which are often seen foraging at Towra Point and may prey on introduced rodents. Other birds such as the Australian white ibis (*Threskiornis molucca*) feed on grasshoppers.

4.2.4 Pollution control

The ability of mangroves and other vegetation types to trap sediments prevents the flow of contaminants directly into the water system. The contaminants are trapped and filtered through the soil where a combination of biological activity and physical adsorption onto soil particles removes contaminants and improves effluent water quality (Birch et al. 2004). The presence of a wetland acting as a buffer between land and water is extremely valuable for the health of the waterway. Kurnell Peninsula's land use is mostly industrial and runoff can be toxic; however, the wetland has a limit to which it can buffer the effects of such pollution. During high flow the probability of contaminated runoff is greatly increased and this places pressure on the wetland.

4.3 Cultural services

Towra Point has significant cultural services and benefits for Aboriginal and non-Aboriginal people. It provides cultural services through recreation and tourism, science and education, and aesthetics.

4.3.1 Recreation and tourism

Botany Bay and its tributaries are important and popular places for swimming, fishing and boating (SPCC 1978b). The Towra Point Nature Reserve is categorised under the plan of management for education and research only for which permits issued by DECCW are required.

No recreational activities are permitted, apart from at the day-use area on the western side of Towra Point where people can moor boats and use part of the beach. More than 500 people and 120 boats have been observed using this area over the summer months (NSW Maritime 2005). Commercial fishing is banned in the waters surrounding Towra Point, but in some parts recreational angling is allowed and these are popular fishing spots.

There are several viewing points for bird watching and nature observation outside the boundary of the nature reserve, and a horse riding facility is located adjacent to the nature reserve along the south-eastern shore of Quibray Bay.

Due to its proximity to Sydney, Kurnell Peninsula attracts a large number of regular visitors, especially to Kamay Botany Bay National Park (approximately 400,000 visitors in 2002) where Captain Cook first landed in Australia in 1770 (NPWS 2002). Towra Point is relatively concealed with limited signage which has probably helped to protect it from further degradation.

4.3.2 Science and education

DECCW encourages and supports ongoing scientific research by providing permits and access. Being the largest wetland of its type in Sydney, Towra Point Nature Reserve attracts students of all academic levels. Schools and universities use the wetland for projects, reports and theses.

In Kamay Botany Bay National Park there is an education centre from where NPWS runs educational tours and activities through its Discovery program, including a Towra Point tour every three months. The low frequency of this tour is intended to reduce disturbance and impact on the wetland. The guided tour visits areas that will have minimal impacts on the wetland and includes information about the unique and important ecosystem and the different vegetation communities and fauna species, especially the migratory shorebirds (A. Bianchi 2007, pers. comm.).

4.3.3 Aesthetic amenity

The areas surrounding Towra Point Nature Reserve are highly modified but Towra Point itself remains relatively pristine. The reserve represents some of the typical wetland types that used to be found in the area that are now rare due to development. Towra Point is also one of the most important migratory bird-feeding and roosting sites in the Sydney region, and provides a pleasing view of a natural landscape in a heavily industrialised area.

4.3.4 Aboriginal heritage

The country of the Gweagal clan of the Dharawal nation is located on the southern shore of Botany Bay and is of great significance to the Aboriginal people (Colman and Hopkins 2001). Middens, rock shelters, engravings and burial sites provide evidence that it is an important area for Aboriginal heritage and Towra Point Nature Reserve contains three known sites (NPWS 1998). Parts of Towra Point were used for food (mainly seafood) and freshwater from the ponds. Captain Cook learnt from the Aboriginals about food and land use in Botany Bay. There is still a strong association of the Aboriginal community with Towra Point and Botany Bay and, through the Discovery Program at Kamay Botany Bay National Park, others in the community are being educated about Aboriginal heritage.

The Towra Team, which consists of members of the La Perouse Aboriginal community, undertakes projects in the Kurnell area such as bush regeneration, leading Discovery Program tours and patrolling Towra Spit Island by boat during little tern nesting season. The Aboriginal community in the Botany Bay region has lost connectivity to Country since settlement, so the Towra Team helps to restore this connection and also provides training in transferable skills.

4.3.5 Non-Aboriginal heritage

Captain James Cook and his crew on the *Endeavour* were searching for fresh water when they sailed into Botany Bay in 1770. Cook explored Towra Point and mapped Towra Lagoon; Joseph Banks, Daniel Solander and other scientists took the first recorded botanical and zoological samples of Australia from Towra, Botany Bay and Kurnell (Benson and Eldershaw 2007).

Non-Aboriginal use of Towra Point began in the 1860s and caused significant changes to the area. Thomas Holt was a major landholder in the Kurnell area and used Towra Point to farm sheep and cultivate oysters (McGuinness 1988). His oyster leases in Woolooware and Quibray bays in the 1890s were the site of the first successful commercial oyster cultivation in Australia (SPCC 1979c; McGuinness 1988). The only known relic of grazing at Towra Point is a split rail fence extending from Towra Bay to Weeney Bay. However, the exotic species buffalo grass (*Stenotaphrum secundatum*) is a consequence of this past use (NPWS 2001a). Clearing of the vegetation for lumber on the Kurnell sand dunes commenced in the early 1800s, and began major sand displacement which lasted for many years (McGuinness 1988). Foundations of a civil aviation navigation facility and causeway constructed in the 1950s still remain at Towra Point.

The oyster industry is part of the cultural heritage of Towra Point, as it supported the leases of about 50 growers who employed over 300 people in 1979. In Botany Bay and the Georges River the leases were family owned, and spanned two or three generations (SPCC 1979c). The oysters produced around Towra Point were of high quality ('plate grade'), and the peak of the industry was in 1971–72 (DPI 2006). Today there are only a small number of active leases in Quibray and Woolooware bays. The vegetation at Towra Point, including adjacent seagrass, filters contaminants and suspended sediments from the water, which supports healthy oyster production (SPCC 1978a).

4.4 Supporting services

Supporting services include water cycling, nutrient cycling, food webs and habitat.

4.4.1 Hydrological processes

Towra Point is a critical wetland in the Sydney area because it maintains natural hydrological processes including evapotranspiration, runoff, infiltration and groundwater flow. Hydrology is critical in the Towra Point ecosystem and has a major influence on the morphology of the site and the habitat types, and determines both flora and fauna species distribution. Hydrological processes relevant to Towra Point Nature Reserve are discussed in section 5.4.

4.4.2 Food webs

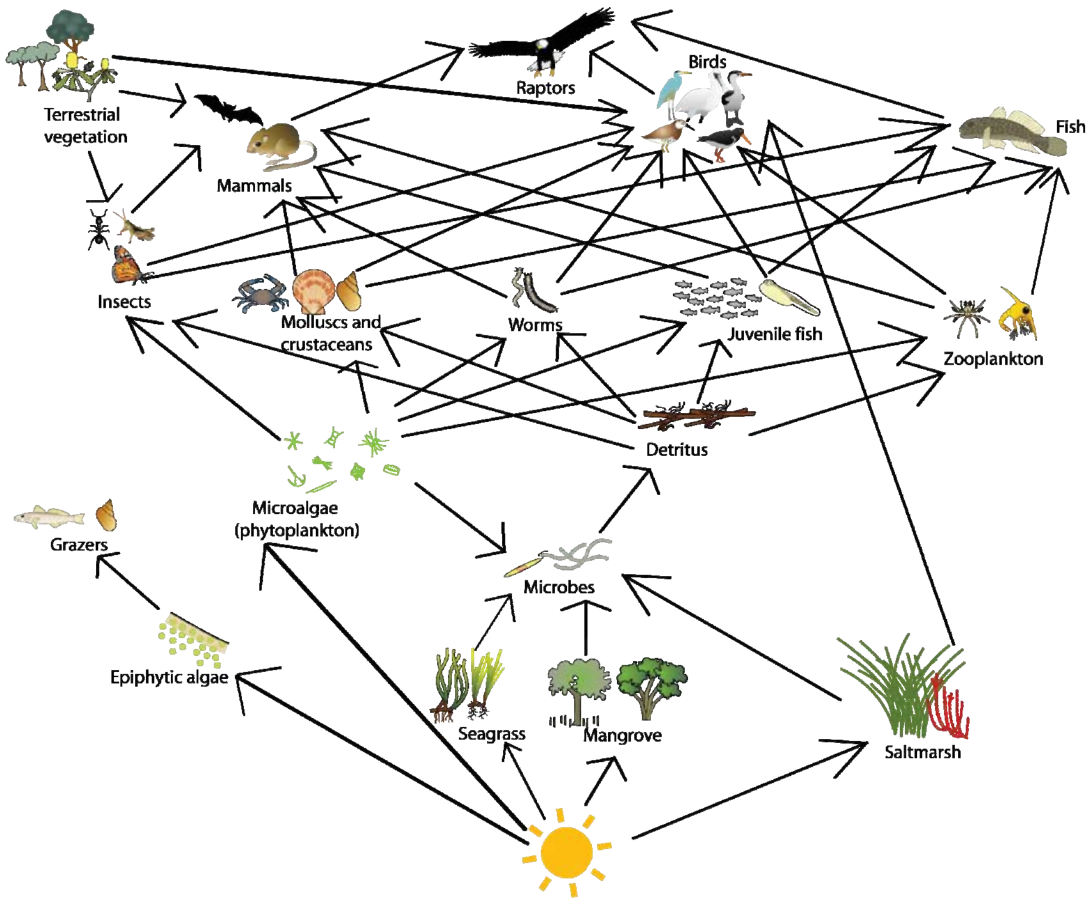
Towra Point supports a large number of interactions between organisms and the transfer of nutrients and energy, and the biodiversity of the reserve is a consequence of this. Seagrass meadows adjacent to Towra Point Nature Reserve and mangrove and saltmarsh communities are critical links in the food chain due to the large amounts of organic matter, or detritus, they produce (Connolly et al. 2005a, 2005b), which is a reliable food source for invertebrates. The food web in Figure 22 illustrates the importance of detritus on higher trophic levels.

Critical biological interactions include those involving birds and mammals, such as the grey-headed flying fox, which play an important role in seed dispersal and pollination of many native tree species (Pallin 2000), and the export of crab larvae in the spring tide which transfers energy from saltmarsh areas to Botany Bay (Mazumder et al. 2006a).

The tidal regime in Botany Bay supports the food web at Towra Point by exporting crab and crustacean larvae from saltmarsh to intertidal and subtidal areas, a process known as outwelling (Mazumder et al. 2009; Connolly 2009), and by transporting detritus from seagrass meadows to intertidal and supratidal areas, a process known as inwelling (Connolly et al. 2005a, 2005b).

4.4.3 Physical habitat

Towra Point supports remnant habitats, threatened species and endangered ecological communities which were once found throughout Sydney. Shorebirds, including little terns, have specific habitat requirements (Lawler 1996) and will only



Source: K. Brennan 2007

Figure 22: Generic food web for Towra Point Nature Reserve

use Towra Point if their requirements are met (NPWS 2003). A diverse range of shorebird species use Towra Point, which indicates that the wetland supports critical physical habitat for these birds. The physical conditions of Towra Point allow seagrass, mangrove and saltmarsh species to grow next to each other, which also enhances the biodiversity of the area (Jelbart et al. 2007; Saintilan et al. 2007).

The size of the Towra Point wetland in comparison to any other wetlands of its type in the Sydney Basin is a critical factor in maintaining suitable habitat for a large number of species (Clynick and Chapman 2002; Connolly et al. 2005a). Towra Point supports the largest stand of saltmarsh, an endangered ecological community under the TSC Act, and almost half of the mangrove community in the Sydney region (NPWS 2001a).

4.4.4 Nutrient cycling

A fine balance of nutrients maintains the healthy status of an ecosystem. The largest variation in nutrients occurs in the upper catchment of the Georges River where there are industrial and urban land uses and where there is the least amount of tidal flushing (SMCMA 2007c). Within the Botany Bay catchment, nutrients enter the water directly from surface runoff, sewage overflows and stormwater, and indirectly from groundwater discharge. Catchment land use has a major influence on the types and loads of nutrients entering the waterway. The sources of water that enter the sub-catchment containing Towra Point are mostly from residential and industrial areas with a small amount of recreational land, and the runoff has been found to be generally high in nutrients (SSC 2004).

The flora and fauna at Towra Point are critical components in nutrient cycling, especially the primary producers (phytoplankton, seagrass, mangrove and saltmarsh) which have a high nutrient requirement and convert nutrients to a more usable form for other species (SPCC 1978a).

Semi-diurnal tides in Botany Bay maintain good mixing of the water and suspended sediments. The high quality of the water surrounding Towra Point is evident in the health of the oysters produced in Quibray Bay. The presence of the vegetation at Towra Point supports water clarification by nutrient uptake and sediment accumulation. Land use has changed in the upper Georges River catchment from agriculture to residential development. This may decrease the nutrients entering the waterway, but may mean higher sediment loads due to an increase in impermeable surfaces (SMCMA 2007c). From 1997, Sydney Water Corporation began improvements to the sewer and stormwater systems of the Georges River catchment to improve water quality (SWC 2007a).

4.4.5 Primary production

Primary producers are green plants and some bacteria that rely on light for energy production through photosynthesis. Phytoplankton is one of the main primary producers in the Botany Bay and Georges River system. It is a major food source for invertebrate grazers and therefore critical in the food chain (Kunz and Richardson 2006). Towra Point Nature Reserve provides a suitable habitat for phytoplankton and other primary producers such as mangroves, saltmarsh and terrestrial vegetation. Seagrass meadows are especially known for their high productivity and also support higher levels of the food chain (West 1983; Connolly et al. 2005b).

4.4.6 Sediment trapping and stabilisation

Seagrass, saltmarsh and mangrove communities at Towra Point trap sediments; therefore they reduce both sediment loads in Botany Bay and erosion. These communities also trap contaminants which can be filtered out through the soil.

4.4.7 Biodiversity

Towra Point supports a large variety of plant and animal species (see Appendices B–E). The relatively large size of the wetland allows a greater number of species to co-exist and the different habitat types provide habitat and food for a diverse range of species (see section 5.5).

The food web illustrates the importance of the different vegetation types in providing ample food for a large number of higher order species. Intertidal areas surrounding Towra Point, including at Taren Point, consist of a different substrate which favours a more diverse range of invertebrates and, consequently, shorebird species. The proximity of seagrass to mangrove and saltmarsh areas allows trophic relay at different levels, therefore supporting biodiversity (Saintilan et al. 2007).

4.4.8 Special ecological, physical or geomorphic features

The saltmarsh community at Towra Point is listed as an endangered ecological community under the TSC Act and supports habitat for a number of birds such as the white-fronted chat. Towra Point and adjacent areas support migratory shorebirds during part of their annual migratory cycle. These birds return to this site annually to accumulate fat reserves for their northward migration and breeding. The high levels of productivity from the combination of saltmarsh, mangrove and adjacent seagrass meadows support a high density and abundance of fish and crustaceans (Jelbart et al. 2007; Saintilan et al. 2007). The importance of seagrass, saltmarsh and mangrove communities as a nursery habitat has been established for fish and crustaceans, including those of commercial importance (Bell et al. 1984; Mazumder et al. 2005).

Prior to anthropogenic changes to the northern side of Botany Bay, there were extensive mud flats and saltmarsh areas in that area for shorebirds to feed, nest and roost (Hindwood and Hoskin 1954). Land reclamation and development have destroyed those sites and shorebirds have been forced to find and compete for suitable habitat on the southern side of Botany Bay (Pegler 1997). Structures within Quibray, Weeney and Woolooware bays and along the Taren Point shoreline provide additional roost sites. Oyster leases in the bays around Towra Point are high-tide roosts for birds such as eastern curlew, whimbrel (*Numenius phaeopus*), bar-tailed godwit and cormorants. An abandoned jetty at Taren Point is an important roosting site for pied oystercatchers and an old barge in Woolooware Bay is used by ruddy turnstone (*Arenaria interpres*), common greenshank (*Tringa nebularia*) and other birds (Figures 23 and 24).

4.4.9 Threatened wetland species, habitats and ecosystems

Towra Point supports four threatened species listed under the EPBC Act, and 23 threatened species and five endangered ecological communities under the TSC Act (Tables 5, 6, 7 and 8). There are five endangered ecological communities in, and one adjacent to, Towra Point Nature Reserve (Table 8, Figure 25). Taren Point Shorebird Community is supported by habitat at Towra Point (see section 5.5.2).

Due to knowledge gaps in species occurrence, the tables give an indication only of species present. Some species, such as the bush stone-curlew (*Burhinus grallarius*), have not been recorded for over 20 years, and others, such as the curlew sandpiper (*Calidris ferruginea*), have significantly reduced in number (AWSG 2008).

4.4.10 Priority wetland species

Towra Point Nature Reserve and adjacent areas regularly support approximately 34 of the 80 species of migratory birds listed under various agreements, including JAMBA, CAMBA and ROKAMBA (NPWS 2001a) (Table 9). These birds use the mudflats, saltmarsh, mangrove and sand spit areas for feeding and roosting, and these areas provide a favourable habitat due to the high productivity of the reserve and the protection from predators and disturbance (Laegdsgaard 2006; Spencer et al. 2009). Some species have not been recorded since the 1980s, but there is insufficient information to conclude whether they have disappeared from the area or have not been detected during surveys (Appendix D).

4.4.11 Ecological connectivity

Sydney is a highly developed city in terms of urban and industrial development, and this has caused a loss and fragmentation of natural habitats. Ecological corridors are critical to assist the connectivity of natural areas to allow movement of species from one area to another and to reduce the risk of extinction of species. Corridors maintain the genetic biodiversity of an area and improve species viability (Mech and Hallett 2001). Towra Point supports significant habitat that connects it with surrounding natural areas such as Kamay Botany Bay National Park, Royal National Park, Georges River National Park, Taren Point Shorebird Community and Heathcote National Park.

Shorebirds such as the eastern curlew and pied oystercatcher forage along the Georges and Port Hacking rivers but, due to lack of suitable habitat elsewhere, return to Towra Point to roost (P. Straw 2007, pers. comm.). In the absence of connectivity to these areas species viability would diminish.

The grey-headed flying fox can forage 25 kilometres from their roost camp, and the same camps are used each year (Eby 2006). There is a large maternal camp adjacent to Towra Point that supports the genetic diversity of the species and Towra Point is used for foraging (Eby 2006; Schulz 2006). Connectivity to other native landscapes is critical for this vulnerable species.

Large birds such as the white-bellied sea eagle also rely on corridors for their home range. The connectivity between saltmarsh, mangrove and seagrass habitats at Towra Point is critical in maintaining species of fish and crustaceans (Bell and Pollard 1984; Mazumder et al. 2005; Saintilan et al. 2007).

Photo: John Dahlenburg 2007

Figure 23: Abandoned jetty at Taren Point, a roosting site for pied oystercatchers

Photo: Phil Straw 2002

Figure 24: Shorebirds roosting on an old barge

Table 5: Nationally threatened fauna and flora species under EPBC Act

Scientific name	Common name	Status*	Location recorded
Syzygium paniculatum	Magenta lilly pilly	V	In littoral rainforest along Captain Cook Drive
Litoria aurea	Green and golden bell frog	V	End of Towra causeway and Towra Lagoon
Pteropus poliocephalus	Grey-headed flying fox	V	Various locations throughout Towra Point

* E = endangered, V = vulnerable (EPBC Act)

Source: ALS (1977); DECC (2009)

Table 6: Threatened fauna under the TSC Act

Scientific name	Common name	Status*	Location recorded
Litoria aurea	Green and golden bell frog	E	End of Towra causeway and Towra swamp
Burhinus grallarius	Bush stone-curlew	E	Towra Point, Botany Bay #
Sterna albifrons	Little tern	E	Towra Point, Towra Spit Island and the Elephants Trunk
Dugong dugon	Dugong	E	Towra Point, Botany Bay
Calidris alba	Sanderling	V	Botany Bay
Calidris tenuirostris	Great knot	V	Towra Point
Charadrius leschenaultii	Greater sand-plover	V	Towra Point
Charadrius mongolus	Lesser sand-plover	V	Botany Bay
Haematopus fuliginosus	Sooty oystercatcher	V	The Elephants Trunk, Towra Point Nature Reserve, Botany Bay
Haematopus longirostris	Pied oystercatcher	V	Towra Point, various locations
Limicola falcinellus	Broad-billed sandpiper	V	Botany Bay
Oxyura australis	Blue-billed duck	V	Kurnell Lagoon
Tyto novaehollandiae	Masked owl	V	Towra Point, south-east of Mirrormere
Xenus cinereus	Terek sandpiper	V	Botany Bay
Pteropus poliocephalus	Grey-headed flying fox	V	Various locations throughout Towra Point
Scoteanax rueppellii	Greater broad-nosed bat	V	Towra Point, south-east of Mirrormere

* E = endangered, V = vulnerable (TSC Act)

Thought to be extinct in the area (Schulz 2006).

Source: ALS (1977); DECC (2009)

Table 7: Threatened flora under the TSC Act

Scientific name	Common name	Status*
Chamaesyce psammogeton	Sand spurge	E
Senecio spathulatus	Coast groundsel	E
Caladenia tessellata	Tessellated spider orchid	E
Pterostylis sp. *Botany Bay*	Botany Bay bearded orchid	E
Acacia terminalis subsp. *terminalis*	Sunshine wattle	E
Callistemon linearifolius	Netted bottle brush	V
Wilsonia backhousei	Narrow-leafed wilsonia	V
Syzygium paniculatum	Magenta lilly pilly	V

* E = endangered, V = vulnerable (TSC Act)

Source: DECC (2005)

Table 8: Endangered ecological communities under the TSC Act

Endangered ecological community	Location	Condition in 2007
Coastal saltmarsh in the NSW North Coast, Sydney Basin and South East Corner bioregions	Found on the landward side of the mangroves throughout Towra Point and along the shores of Woolooware and Quibray bays. Extensive saltmarsh on Towra causeway.	Very good condition with no weed infestation. Mangrove encroachment has been documented.
Kurnell Dune Forest in the Sutherland Shire and City of Rockdale	Fragments of this community are found on the inner part of Towra Point, at The Knoll and at Pelican Point.	Variable condition with widespread weed infestation.
Littoral Rainforest in the NSW North Coast, Sydney Basin and South East Corner bioregions	The one location within the Towra Point Nature Reserve Ramsar site boundary is in the middle of the site. There is a smaller area on the opposite side of Captain Cook Drive.	Weed infested, especially by lantana (*Lantana camara*).
Swamp Oak Floodplain Forest of the NSW North Coast, Sydney Basin and South East Corner bioregions	In areas of lower elevations within Towra Point, usually on the landward side of saltmarsh.	Moderate to good. Weed infestation by buffalo grass.
Sydney Freshwater Wetlands in the Sydney Basin bioregion	Named freshwater lagoons at Towra Point are Towra Lagoon, Mirrormere and Weedy Pond, all situated between Weeney Bay and Towra Beach. There are at least three other unnamed lagoons with no ecological information.	Moderate to good with some weed infestation and rubbish pollution. Saline intrusion has occurred in some ponds.
Taren Point Shorebird Community on the relict tidal delta sands	On a small strip of intertidal shoreline found adjacent to Towra Point, on the north-western side of Woolooware Bay at the mouth of the Georges River.	Suitable supporting habitat at present, but is at risk of disturbance due to residential and industrial development.

Source: DECC (2005); SSC (2006a); WODEC (2007)

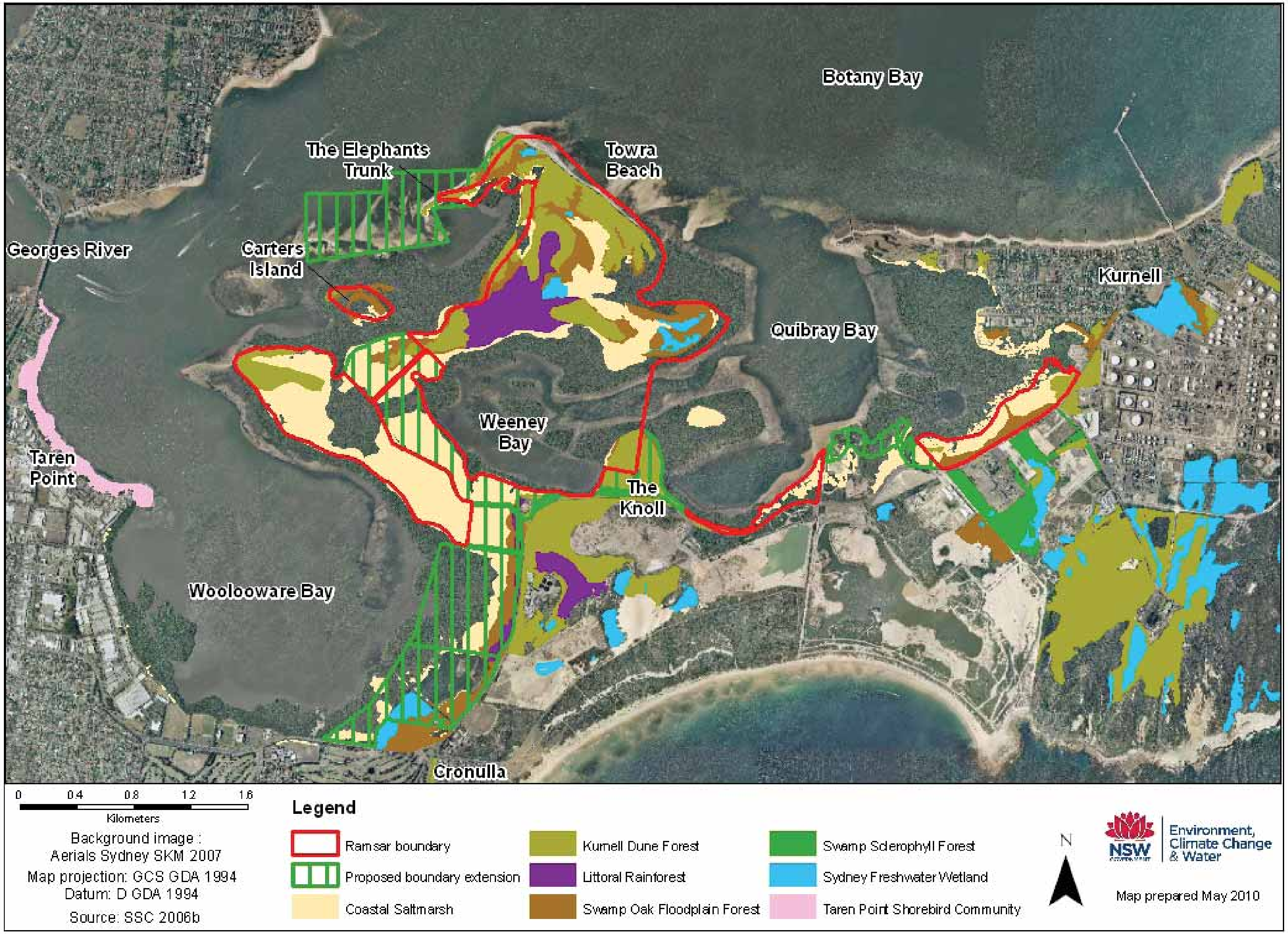


Figure 25: Endangered ecological communities

Table 9: Migratory bird species protected under international agreements

Scientific name	Common name	Protection agreement*
Egretta alba	Great egret	C
Bubulcus ibis (*Ardeola ibis*)	Cattle egret	J C
Plegadis falcinellus	Glossy ibis	C
Haliaeetus leucogaster	White-bellied sea eagle	C
Charadrius leschenaultii	Greater sand plover	C R
Charadrius mongolus	Lesser sand plover	C R
Pluvialis squatarola	Grey plover	J C
Pluvialis dominica	Lesser golden plover	J C
Numenius phaeopus	Whimbrel	J C R
Numenius madagascariensis	Eastern curlew	J C R
Numenius borealis (*Numenius minutus*)	Little curlew	C R
Limosa lapponica	Bar-tailed godwit	J C R
Limicola falcinellus	Broad-billed sandpiper	J C R
Xenus cinereus (*Tringa terek*)	Terek sandpiper	J C R
Calidris acuminata	Sharp-tailed sandpiper	J C R
Calidris ferruginea	Curlew sandpiper	J C R
Tringa hypoleucos	Common sandpiper	J C R
Tringa stagnatilis	Marsh sandpiper	C R
Tringa glareola	Wood sandpiper	J C R
Tringa incana (*Tringa brevipes*)	Grey-tailed tattler	J C R
Tringa incana	Wandering tattler	J
Arenaria interpres	Ruddy turnstone	J C R
Capella hardwickii (*Gallinago hardwickii*)	Latham’s snipe	J C R
Calidris canutus	Red knot	J C R
Calidris tenuirostris	Great knot	J C R
Calidris ruficollis	Red-necked stint	J C R
Crocethia alba (*Calidris alba*)	Sanderling	J C R
Chlidonias leucoptera	White-winged black tern	J C
Hydropogne tschegrava (*Hydroprogne caspia*)	Caspian tern	C
Sterna hirundo	Common tern	J C R
Sterna albifrons	Little tern	J C R
Sterna bergii	Crested tern	J
Apus pacificus	Fork-tailed swift	J C R
Tringa nebularia	Common greenshank	J C R

Source: ALS (1977); WSG (2007); AWSG (2008); DECC (2009)

* J = JAMBA; C = CAMBA; R = ROKAMBA

5 Components and processes

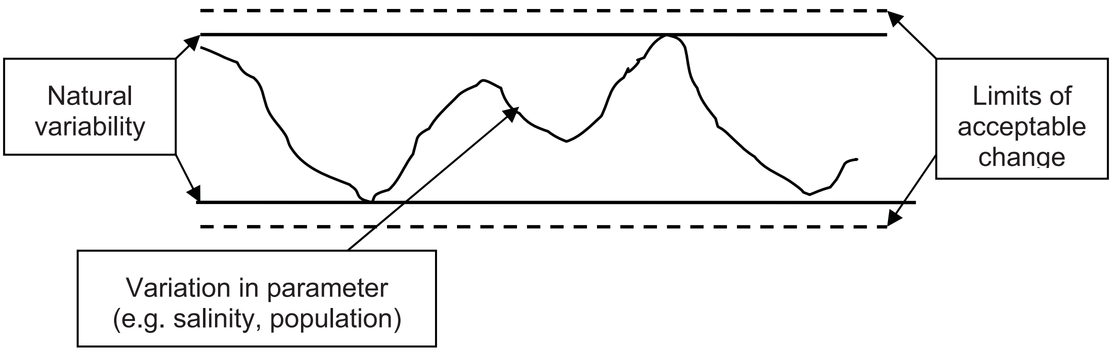
An ecosystem is defined according to its individual *components* and *processes,* and the ecosystem *benefits* and *services* are the result of interactions between the components and processes (Millennium Ecosystem Assessment 2003). It is important to monitor the components and processes of the ecosystem to ensure that these parameters do not move outside the limits of acceptable change for extended periods of time. A change in the components and/or processes may indicate a potential change in the site's ecological character. The general conceptual model illustrates how each set of parameters fits within the ecosystem and their influences.

The limits of acceptable change are values applied to particular parameters to prevent an adverse change in ecological character while allowing for natural variability. These limits may be used as a trigger for management authorities to act (Figure 26). Caution must be taken when referring to limits of acceptable change as adequate long-term data may not be available at the time of writing. It is therefore important that defined limits are updated with any new information.

In this section, components and processes that influence Towra Point Nature Reserve Ramsar site are summarised for when the site was listed in 1984. Critical components and processes are those that interact to support the critical values for which a site is listed. In the case of Towra Point Nature Reserve Ramsar site, those are primarily components and processes supporting the site's biodiversity and fisheries values, including the site's geomorphology, hydrology, physicochemical environment and biota. Those components and processes are given particular emphasis below.

Any change that has occurred to a component or process since listing is also summarised and limits of acceptable change are given for critical components and processes where adequate data exists to define them. Conceptual models are included to illustrate how each individual component and process works within the ecosystem.

This section forms a baseline assessment of the environmental condition of the wetland at the time of its listing as an internationally significant wetland and a comparison to the current condition. It also provides a baseline by which future change can be detected by management.



Source: Phillips (2006)

Figure 26: Example of natural variability and limits of acceptable change

5.1 Climate

Climate plays an important role in the regulation of the ecosystem and species have adapted to the temperate conditions at Towra Point. The Bureau of Meteorology has been collecting data since 1929 at Sydney Airport and provides long term information for the site, including temperature, rainfall and wind.

Climate change is an immediate threat to the ecological condition of Towra Point (section 6.8). El Niño and La Niña are climatic events on a broader scale that affect Towra Point by the change in the intensity of certain climate parameters such as rainfall, wind and storms.

5.1.1 Temperature

Data from the Bureau of Meteorology compiled in 1977 shows that the temperature ranges from a mean minimum of 6.2°C in July to a mean maximum of 26.2°C in January. Mean daily temperatures in winter vary from 6.2°C to 17.0°C, and mean daily temperatures in summer vary from 18.4°C to 26.2°C. The temperature at 3 pm is usually 2°C or 3°C higher than at 9 am (ALS 1977).

Temperature is an important factor for species distribution at Towra Point. High temperatures in conjunction with low rainfall, high winds and low humidity cause increased evaporation rates and therefore increased soil salinity. Extended periods of these conditions can stress the flora and fauna. Water temperature affects the solubility of oxygen and can affect the physiological processes of some species such as fish (section 6.8).

Changes in temperature since 1984

The climate monitoring station at Sydney Airport recorded temperature ranges from a mean minimum of 7.4°C in July and a mean maximum of 26.7°C in February for the period 1971–2000 (BoM 2007a). Mean daily temperatures in winter vary from 7.4°C to 19.3°C, and mean daily temperatures in summer vary from 17.0°C to 26.7°C (BoM 2007a). Global average surface temperature has increased over the past 100 years, with rates increasing by twice as much over the past 50 years (see section 6.8) (Solomon et al. 2007).

Water temperature in Woolooware Bay has been recorded by Sydney Water since 1994 and varies between 10°C and 27°C. Global ocean temperature has increased since 1955, and this has had an influence on sea level rise (Solomon et al. 2007). Water temperature is a factor in the viability of biota in the area and long term changes to overall water temperature may cause changes in the distribution of species (Bell et al. 1984).

5.1.2 Rainfall

Rainfall is a critical process in the ecosystem to recharge groundwater, offset surface and soil salinity levels, transfer nutrients and replenish soil moisture content. Rainfall is the primary freshwater source for Towra Point as it is surrounded by the marine environment of Botany Bay (SPCC 1979e). While most saltmarsh species can survive under highly saline environments, rainfall is critical for nutrient transfer and seedling growth (Clarke and Hannon 1967).

The Botany Bay area receives an annual average rainfall of 1100 millimetres, with more than 0.2 millimetres falling on 129 days of the year (ALS 1977). The highest amount of rainfall usually occurs around late autumn and early winter (March–June).

Changes in rainfall since 1984

Over the period 1971–2000 the Botany Bay area received an annual average rainfall of 1130 millimetres with more than one millimetre falling on 96 days of the year (BoM 2007a). It has been projected that winter rainfall is likely to decrease in Australia but extreme rainfall events are very likely to occur (Solomon et al. 2007) (section 6.8).

5.1.3 Storms

Due to its coastal location, Towra Point is subject to storms of varying duration and intensity throughout the year. Thunderstorms usually of short duration and higher daily rainfall occur about once a month in winter and about three times a month in summer. Occurring only four or five times a year, and not usually in winter, are storms that are associated with strong south to north-easterly winds that cause rough, high seas. These storms usually persist for a number of days and can have the most detrimental effect on Towra Point (ALS 1977).

A number of severe storms occurred in May–June 1974, August 1974 and June 1975, with waves recorded up to 7.8 metres off Botany Bay. Wave propagation in Botany Bay caused significant erosion to Towra Beach and the subsequent saltwater intrusion into Towra Lagoon (ALS 1977; McGuinness 1988; NPWS 2001a). It has been suggested that the dredging for Sydney Airport's third runway, which changed wave patterns in Botany Bay, was a factor in the erosion (ALS 1977; Roy and Crawford 1979; SPCC 1979d; McGuinness 1988; NPWS 2001a).

5.1.4 Limits of acceptable change for climate

Limits of acceptable change cannot be set for climate since the parameters cannot be managed on a local scale. Site specific data for temperature, rainfall, wind and storms should be collected and recorded for long-term monitoring of change in climate.

5.2 Geomorphology

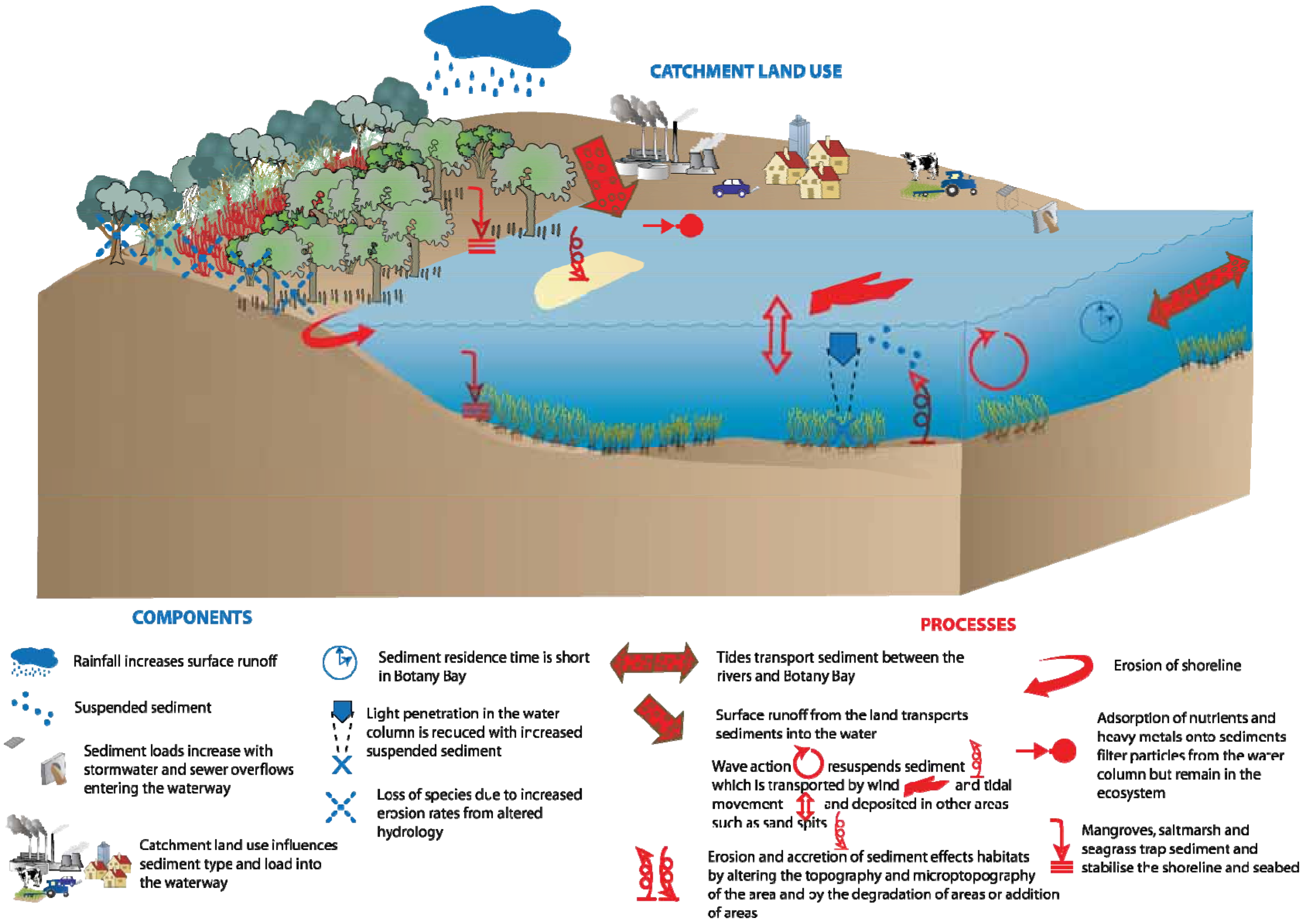
Geomorphology is the study of the characteristics, origin, and development of landforms. Critical geomorphological components and processes in Botany Bay include geology, morphology, topography and microtopography, and sedimentation. These components and processes are critical because they determine the habitats and therefore the flora and fauna species that are present. A conceptual model for the geomorphological components and processes illustrates their influences (Figure 27).

5.2.1 Geology and morphology

After the last ice age, approximately 10,000 years ago, glacial ice began to melt and slowly raised the sea level to where it stabilised 6,000 years ago (ALS 1977). The depositional events over the Holocene period (from 10,000 years ago) are described and illustrated by Roy and Crawford (1979) and summarised here.

Ten thousand years ago, sea level was about 25 metres below its current level and Towra Point did not exist, as it was the entrance for the Georges, Cooks and Hacking rivers into the ocean. Kurnell headland was separated from the rest of Kurnell Peninsula by the river mouth (Figure 28).

Further sea level rise over the following 3,000 years submerged the earlier Pleistocene sediment to form an estuary in both Botany Bay and Bate Bay and extended the rivers westward. Aeolian sand deposits from a source in Bate Bay formed a barrier between Botany Bay and Bate Bay. Dunes formed on this barrier



Source: K. Brennan 2007

Figure 27: Geomorphological components and processes at Towra Point Nature Reserve

due to the prevailing southerly winds and migrated northwards, towards Kurnell headland. Marine sand was transported through Botany Heads and deposited in the estuary, providing the sediment for future tidal deltas. Waves and tidal currents shaped Botany Bay by moving the older sediments and the new marine sand (Figures 29 and 30).

The effects of wind and waves destroyed the sand barrier and caused the reworking of sediments into beach ridges then into transgressive dunes at Kurnell. Marine sand from Botany Bay and fluvial mud from the Georges River evolved in stages to develop a levee along the southern shore of the bay and further reworking of sediments formed the basis of Towra Point. The development of Towra Point is a result of the dynamics between wind, wave and tidal processes (Figure 31).

The rising sea level raised the regional groundwater table and freshwater swamps formed in low lying areas of Towra. Muddy river-borne sediments that were deposited in low energy areas such as Woolooware and Quibray bays provided nutrient-rich sediment for the growth of mangroves and saltmarsh communities. Wind and wave action, especially from the south-east, have caused progressive erosion of Towra Beach and subsequent accretion on the western side of Towra Point where a sand spit formed. Anthropogenic alterations of the coast on the northern side of Botany Bay have changed natural wave patterns and have intensified the natural erosion and accretion on Towra Point.

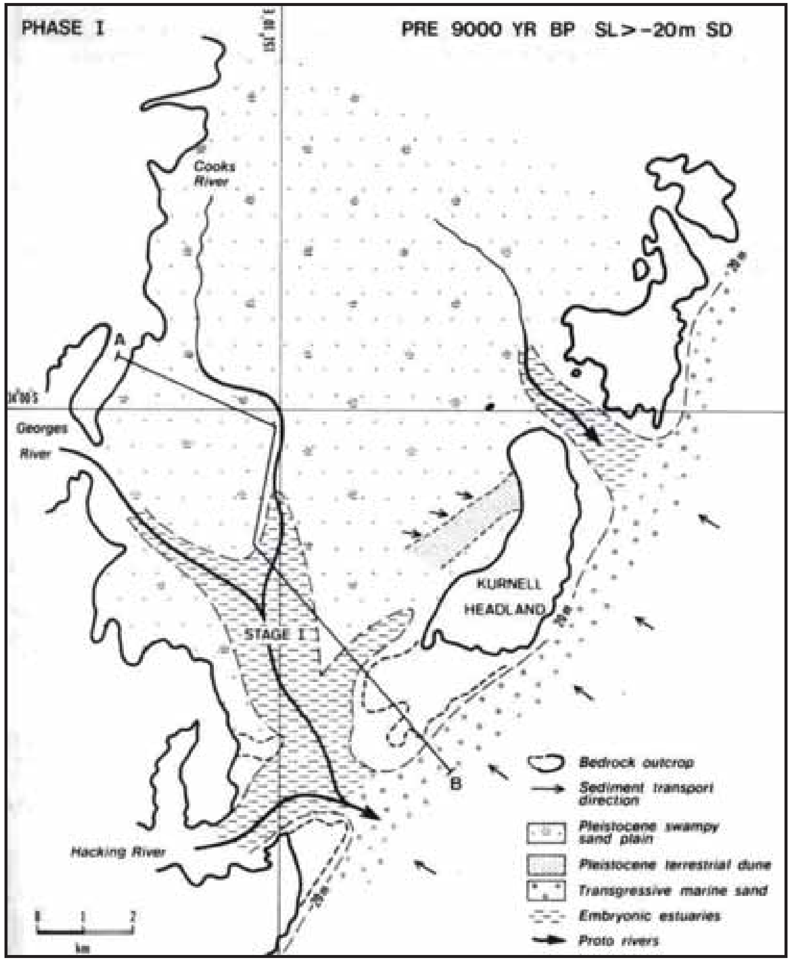
Changes in geology and morphology since 1984

Wind, wave energy and tidal currents are the most influential processes that change Towra Point's geomorphology. Anthropogenic alterations to the catchment, such as changed river flows and loads or by changing the shape of the north shore of Botany Bay, substantially change the geomorphology of the area and can change the magnitude, direction and frequency of the natural processes in the system.

Towra Spit Island was formed from Towra Point in 1991 due to erosion by wind and waves and is continuously changing shape and moving in a south-westerly direction (NPWS 1998) (Appendices F and G). Accretion of sediment caused Towra Spit Island to join the mainland at Carters Island in 1997, which gave land-based predators such as foxes and cats access to important bird roosting and nesting habitat. Severe erosion of Towra Beach, caused by natural processes but intensified by anthropogenic change, resulted in the death of fringing vegetation and saltwater inundation of Towra Lagoon in the mid 1970s. In 2004, sediment joining Towra Spit Island to Carters Island was dredged and used to restore Towra Beach and to maintain Towra Spit Island as an island.

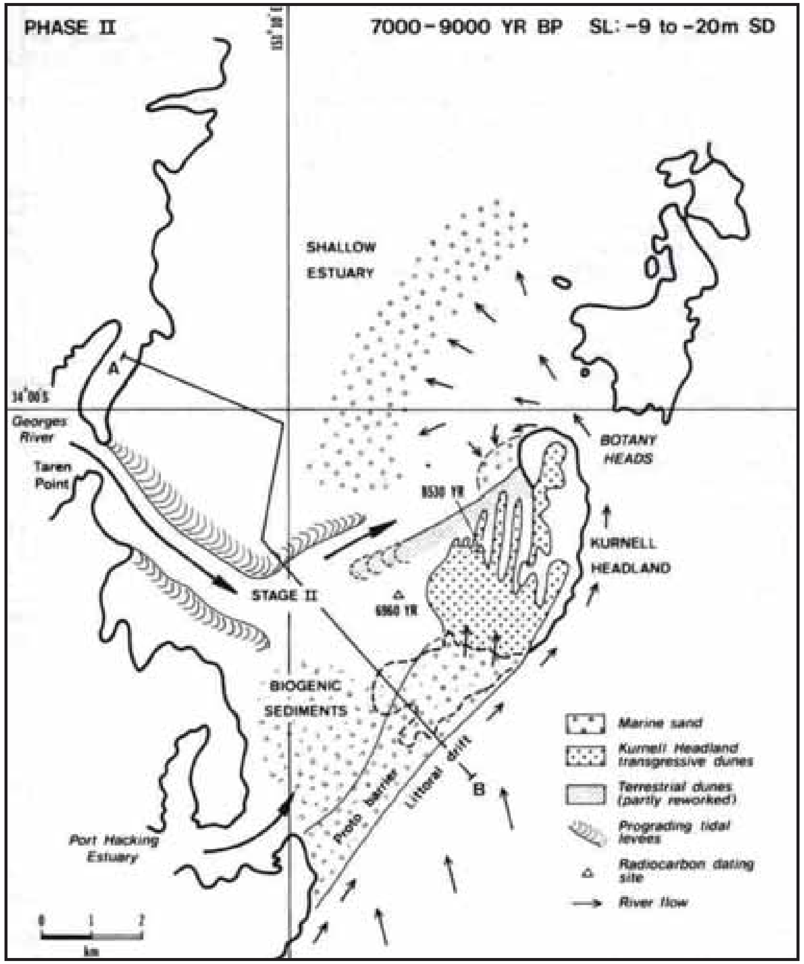
Since 1984 there have been a number of changes to the structure of Botany Bay and more are expected in the future:

- The construction of the third runway at Sydney Airport was completed in 1994. This construction claimed important migratory shorebird roosting and feeding habitat and little tern nesting site (NPWS 2001a), and decreased the tidal prism of Botany Bay. Significant seagrass meadows were destroyed by the changed wave and current patterns resulting from dredging the bay and extension of the runway and, despite recolonisation efforts, the seagrass *Posidonia australis* has not re-established on the northern side of the Bay (Watford and Williams 1998).
- Expansion of Port Botany was approved in 2005. Reclamation of 60 hectares of land and dredging 7.8 million cubic metres of Botany Bay are part of the expansion. This will change the shoreline of the bay and alter the hydrological flow regime of Penrhyn Estuary, an important shorebird site. Measures are in place to improve shorebird habitat and reduce disturbance at Penrhyn (URS



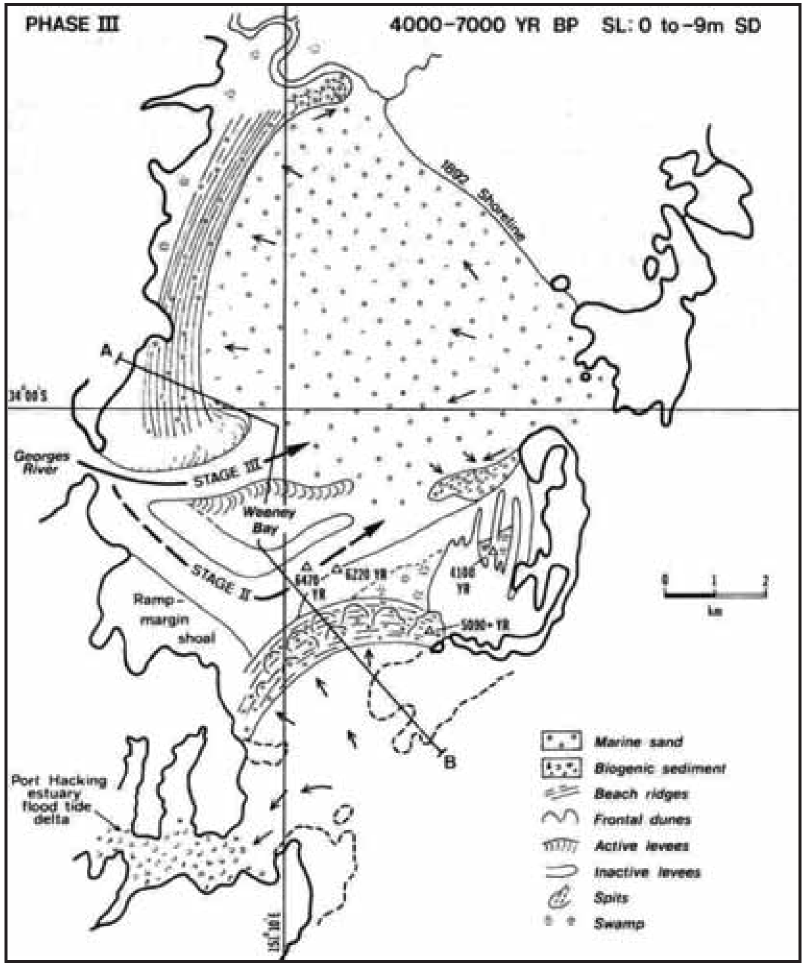
Source: Roy and Crawford (1979)

Figure 28: Botany Bay approximately 10,000 years ago



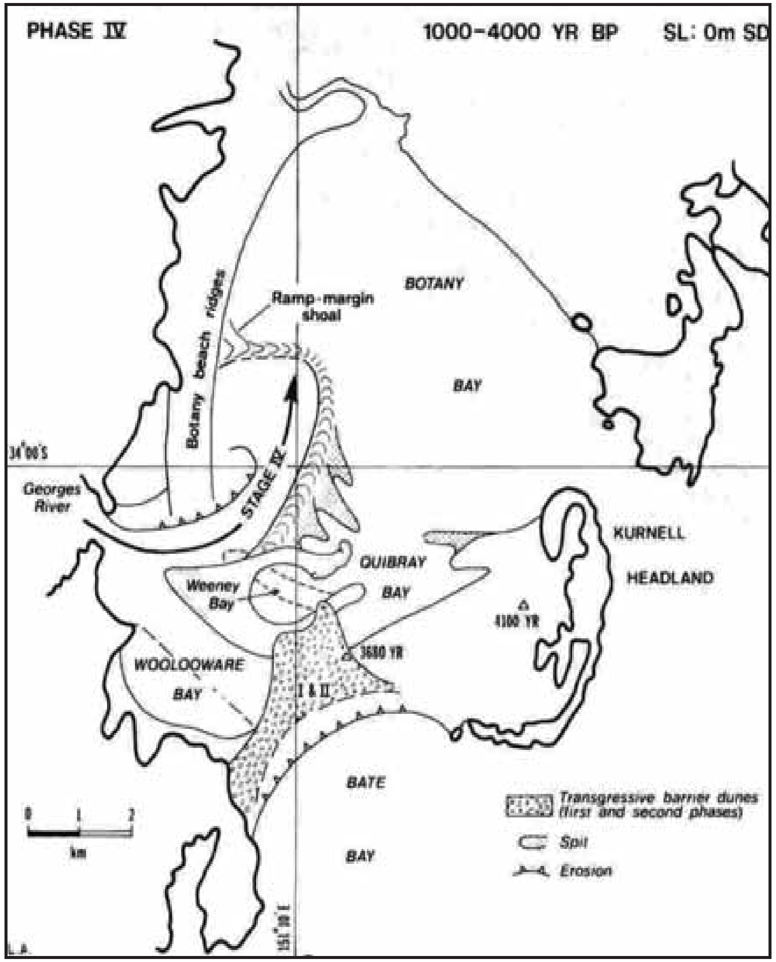
Source: Roy and Crawford (1979)

Figure 29: Botany Bay approximately 7,000–9,000 years ago



Source: Roy and Crawford (1979)

Figure 30: Botany Bay approximately 4,000–7,000 years ago



Source: Roy and Crawford (1979)

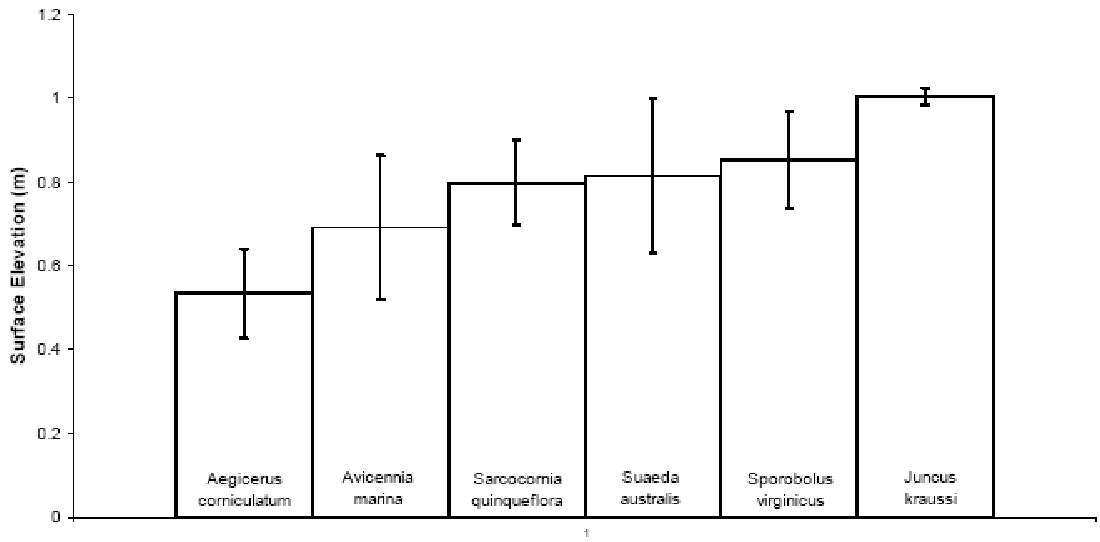
Figure 31: Botany Bay approximately 1,000–4,000 years ago

2003). However, it is largely unknown whether the site will maintain its biological diversity.

- Construction of a desalination plant on Kurnell Peninsula began in 2007. As part of this development a 7.9-kilometre long 1800-millimetre diameter pipeline will be buried in the seabed of Botany Bay for the distribution of desalinated water throughout Sydney. Environmental impact statements have stated that throughout the construction and ongoing maintenance of the pipeline, plumes of sediment generated along the pipeline path will cause loss of habitat including damage to seagrasses. Measures have been proposed to minimise impacts and monitor the site (CLT 2007; SWC 2007b).
- Energy Australia is proposing the construction and operation of two 132 kilovolt underground electrical cables to be buried in the seabed of Botany Bay to conduct electricity between the Kurnell and Bunnerong substations. An environmental assessment of the project stated that there are 82 threatened species, listed under the TSC Act and the EPBC Act, in the vicinity of the pipeline and construction will directly impact at least three of these species – black cod (Epinephelus daemelii), pipe fish (Festucalex cinctus) and seahorses. A seagrass management plan is to be prepared and implemented to minimise impacts to seagrasses (MS 2007).

5.2.2 Topography and microtopography

Towra Point is a low-lying land mass that is joined at its southern end to Kurnell Peninsula. Mangrove and saltmarsh communities fringe the area, which suggests that these areas receive regular tidal inundation (ALS 1977). Topography and microtopography are influential factors on the extent of tidal inundation; therefore these components play an important part in determining the species type and distribution at Towra Point. Saltmarsh and mangrove species can be differentiated by their elevation above sea level, which relates to their salinity tolerance. The landward progression of mangroves is limited by higher elevated areas with increased soil salinities due to less frequent tidal inundation (Clarke and Hannon 1969). Figure 32 shows the distribution of plant species at Towra Point according to topography.



Source: Hickey (2004)

Figure 32: Relationship between species distribution and surface elevation at Towra Point

There are three sections of dunes located in the interior of the northern part of Towra Point that reach a maximum height of five metres (ALS 1977). They surround an area of littoral rainforest and are listed as part of the endangered ecological community, Kurnell Dune Forest, under the TSC Act (WODEC 2007).

The shallow seabed adjacent to Towra Point, which was formed by deposition of marine and land sediment, provides a suitable environment for seagrass. Seagrass meadows occur to a maximum depth of three metres in Botany Bay; beyond this depth the growth of seagrasses is limited by reduced light penetration (Larkum 1976; ALS 1977).

Changes in topography and microtopography since 1984

Topography and microtopography are affected by the accretion and erosion of sediment. Little data is available on the change in topography of Towra Point as a whole since the time of listing as a Ramsar site. Continued erosion and sandmining of the Kurnell sand dunes south of Towra Point and erosion of Towra Beach have altered the topography of the area. While natural regimes of climate and hydrology will modify the topography and microtopography of the area, anthropogenic changes to Botany Bay will dictate the intensity and locations of these modifications.

The topography and microtopography of Towra Point are critical ecosystem components, as they define where a particular plant species can survive and influence habitat for fauna. Natural change usually occurs over a long period of time allowing species to adapt or natural processes of community succession to take place. Sudden anthropogenic change to topography and microtopography may result in a change in ecological character of the site and possible loss of species.

Sea level rise poses a significant threat as it will change the topography of the wetland. Surface Elevation Table and Marker Horizon technique is a useful method of measuring elevation trends of a wetland with respect to sea level and in determining the contributing factors of change (Rogers and Saintilan 2008). Surface elevation of Towra Point is a knowledge gap.

5.2.3 Sedimentation

Sediments in Botany Bay are of the Holocene period and predominantly consist of marine sand, mud and biogenic material (Roy and Crawford 1979):

- marine sand – fine to medium sized gains of quartz with very little stone fragments
- mud – silt and clay-sized particles derived from fluvial deposits and from the breakdown of organic matter from surrounding vegetation; typically dark grey, brown or black in colour
- biogenic material – calcareous material consisting of shells from molluscs, crustaceans and invertebrates as well as organic material.

Accretion and erosion of sediment is a critical process of Towra Point because it changes the geology, morphology and topography of the area and affects the distribution and abundance of plant and animal species. Wind, waves and currents are the natural processes that cause the movement of sediment from one area (erosion) to another (accretion) and the extent of movement and deposition is influenced by sediment type and size, water velocity, water depth and vegetation cover (Roy and Crawford 1979). Climate also has an influence on sedimentation; rainfall increases the sediment load entering from the catchment and storms increase the turbulence of the water (through waves and currents) causing greater movement of sediment. Anthropogenic changes, such as urbanisation, throughout the catchment can also contribute significant volumes of sediment to the bay.

Towra Point was formed from the accretion of Aeolian sediment from Kurnell Peninsula and alluvial sediments from the Georges River, and continues to change on this basis. Since the 1860s, the once-large dune system on Kurnell Peninsula has been cleared of vegetation, and the exposed dunes were gradually blown into Quibray Bay and onto Towra Point (Bryant 1980; McGuinness 1988; Evans and Williams 2001). Tide and wave action has moved much of the sediment from Quibray Bay around Towra Point and towards the Elephants Trunk. Sediment from the Georges River flows into Botany Bay where it is mostly flushed out into the ocean. However, some sediment is deposited in the low-energy areas such as Woolooware and Weeney bays (ALS 1977).

Key processes in plant colonisation include accretion and erosion (Clarke and Hannon 1967). Some seagrass species colonise non-vegetated seabeds in low-energy areas (West 1983). They require sufficient light penetration for photosynthesis and are therefore found to a depth of three metres in Botany Bay (Larkum 1976). Seagrasses colonised Towra Point when geomorphological and light conditions became suitable and are highly productive species (they produce a large amount of organic material) (Connolly et al. 2005b), effective in trapping sediment (West 1983). The stabilisation of sediment formed tidal mudflats high in organic matter which provided favourable conditions for mangrove growth (Saintilan et al. 2009). Mangroves are also highly productive and trap sediment; over time, with natural tidal regimes and accretion from wind-blown sand, sediment accumulated on the landward side and elevated the land higher above sea level, which reduced the frequency of tidal inundation. These conditions subsequently provided a favourable habitat for saltmarsh colonisation (Saintilan et al. 2009). Accretion and erosion that have changed the topography and microtopography of Towra Point have a major influence on the distribution and abundance of flora species and consequently on the fauna species that occur.

Accretion and erosion are natural processes, however anthropogenic alterations to the area have changed the natural movement of sediment in the catchment both spatially and temporally (Bryant 1980). Prior to these alterations, natural sand transport in Botany Bay was in a south-easterly direction. Changes to the bathymetry and shorelines of the Botany Bay catchment have altered sand movement in a westerly direction (Roy and Crawford 1979). The following list describes the anthropogenic-induced changes to the natural sedimentation process before 1984.

- Urban expansion throughout the Botany Bay catchment, mainly along the Georges River, has increased the sedimentation rate and load entering the waterway via runoff from roads and other impermeable surfaces, sewer overflows, and runoff from rural lands and development.
- The increased accretion around Towra Point may have provided increased area for seagrass and mangroves to colonise.
- Dredging of parts of Botany Bay created deep sections where water flow has been decreased and suspended sediment settled. There is reduced tidal flushing in these areas and the sediments can be toxic due to the types of industries surrounding the catchment (SPCC 1979f).
- Dredging changed the light quality and hydrodynamic regime of the area, which caused changes in the types of aquatic organisms in Botany Bay. Seagrasses are strongly limited by light (Larkum 1976; West 1983) and are no longer found in the deep dredged areas. The change in sediments altered the species

composition and richness of the benthic organisms (SPCC 1979b; Jones and Candy 1981; Dexter 1984).

- Dredging in Botany Bay and the presence of hard surfaces on the northern side of the bay have changed the natural wave pattern by refracting wave energy. This has increased the erosion rate of Towra Beach on the eastern side (Figure 33) and increased the accretion rate of the Elephants Trunk on the western side of Towra Point (URS 2003). In the mid 1970s, following dredging and severe storms, the largest freshwater lagoon at Towra Point, Towra Lagoon, was inundated by sea water, changing the ecological character of that habitat. Dredging and structural changes to the bay have caused other areas, such as Lady Robinson’s Beach at Brighton-le-Sands and Silver Beach at Kurnell, to be affected by increased rates of erosion (Bryant 1980).

Changes in sedimentation since 1984

The changes prior to 1984 have altered the natural sedimentation regime causing ongoing erosion of Towra Beach and the development of Towra Spit at the tip of the Elephant’s Trunk (ALS 1977; Roy and Crawford 1979). In about 1990 the tip separated and formed Towra Spit Island (NPWS 1998; CW 2001).

The surrounding mudflats make Towra Spit Island a favourable feeding habitat for migratory shorebirds and its isolation from the mainland offers some protection as a nesting site for the endangered little tern. In 1997 increased accretion of sediment on the south-western side of the island formed a land bridge to Carters Island, which allowed foxes, cats and people to access this important shorebird site (NPWS 1998). The land bridge was dredged in 2004 to help restore Towra Beach and to make Towra Spit an island again.

The dynamics of the area suggest that Towra Spit Island will continue to migrate in a south-westerly direction. Between 1995 and 1999 the island moved at a rate of 25 metres per year (CW 2001). The altered wave patterns will continue to erode Towra

Photo: K. Brennan 2007

Figure 33: Erosion of Towra Beach

Beach, and intense storms, such as those in 1974, could cause up to 40 metres of beach recession (SMEC 2003). Renourishment of Towra Beach with sand will be an ongoing maintenance issue for the managers of Towra Point Nature Reserve in order to preserve Towra Beach and prevent further saltwater intrusion into Towra Lagoon.

Modelling of changes in land use in the upper catchment, such as in the Liverpool and Campbelltown areas, show a decrease in the sediment loads entering the Georges River since 1984, possibly due to a reduction of rural land use, better environmental management practices or changes in rainfall patterns (SMCMA 2007c). Throughout the Botany Bay catchment, Sydney Water is in the process of improving the quality of effluent and reducing the frequency of discharges from the various sewerage treatment plants, thereby reducing nutrient and sediment loads into the water (SWC 2007a). Sutherland Shire Council monitors sediment entering the sub-catchment, which influences Towra Point, and has installed a number of gross pollutant traps and stormwater quality improvement devices. Implementation of water sensitive urban design to residential and industrial areas will decrease sediment entering the water, thereby improving water quality.

Major future changes to Botany Bay include a pipeline across Botany Bay for the distribution of desalinated water for Sydney Water, two underground electrical cables from Silver Beach to La Perouse for Energy Australia, and dredging and reclamation for the extension of container port facilities for Sydney Ports. All three projects will affect the bathymetry of Botany Bay and alter the erosion and accretion patterns that influence Towra Point.

5.2.4 Limits of acceptable change for geomorphology

The natural processes of waves, currents, wind, sediment erosion and accretion in Botany Bay will continually change the geomorphology of Towra Point. Anthropogenic structures will also continue to expand and change as will sediment loads from the catchment due to increasing population pressure. The limits of acceptable change of geomorphology should aim to maintain the natural cycle of accretion and erosion, which is difficult because these processes are continually changing (Table 10). A hydrodynamic and geochemical model of the Georges River and Botany Bay system will give an indication of the effects of future changes to the structure of the estuary or changes in sediment loads and flow.

Table 10: Limits of acceptable change for geomorphology

Critical component or process	Baseline condition 1984 and 2010	Limits of acceptable change	Confidence in LAC
Geomorphology – Towra Spit Island	Towra Spit Island is an itinerant sand spit that remains isolated from the mainland except at low tide. The intertidal habitat is an important breeding site for the little tern and feeding and roosting sites for shorebirds. Annual management of western end of Towra Spit Island is undertaken so that it is not covered by high tides between September and April.	See LACs for little terns.	Low
Sedimentation *	Towra Point sub-catchment: 340 t/yr Kurnell sub-catchment: 300 t/yr Georges River catchment: 17,000 t/yr	Knowledge gap – no LACs identified.	

* Source: SMCMA (2007c, 2009) LAC: limit of acceptable change

5.3 Hydrology

Critical hydrological processes in Botany Bay include tidal regimes, wave energy, surface runoff and groundwater dynamics. These processes are critical for the cycling of water, nutrients and chemicals and are key drivers of ecosystem geomorphology and biological diversity. Figure 34 represents the general hydrological cycle around Towra Point.

Hydrology determines the types of habitats that occur by affecting erosion and accretion, topography and microtopography, salinity, turbidity, nutrient availability, soil chemistry and moisture content. The hydrological cycle in Botany Bay is dynamic and continues to change with anthropogenic influence. Most of the plants and animals of Towra Point have adapted to the current hydrological regime. However, some species such as the green and golden bell frog have been lost in certain areas due to hydrological changes (section 5.5).

Maintenance and monitoring of a hydrological regime within natural variation is critical in maintaining the biodiversity and sustainability of the wetland. Anthropogenic alterations to Botany Bay and Kurnell Peninsula have changed how water moves throughout the system which has resulted in alteration of the ecological character of the Ramsar site since it was listed in 1984.

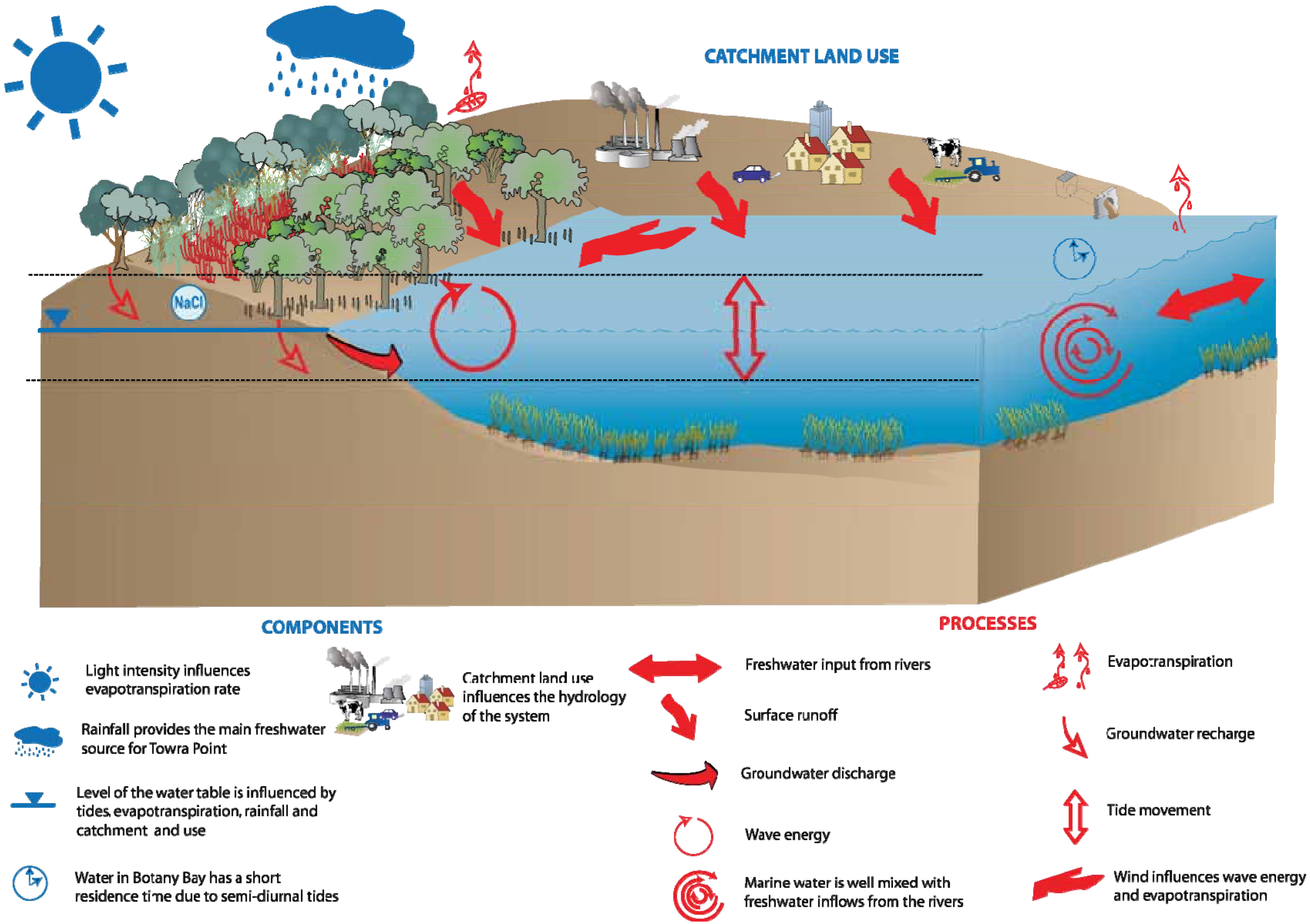
5.3.1 Tides

Botany Bay is predominantly marine with some freshwater at the surface layer from rainfall and river water (ALS 1977; Bryant 1980). Located within Botany Bay, Towra Point is influenced by the surrounding waters and the local tides and may therefore be regarded as part of a tide-dominated estuarine system.

Botany Bay experiences semi-diurnal tides of 0.1–2.0 metres; the bay is therefore well flushed (Bryant 1980; NPWS 1998). The average spring high tide is approximately 0.77 metres and the average neap high tide is 0.37 metres at Towra Point (Hickey 2004). The largest spring tide range is approximately 1.8 metres and the smallest neap tide is about 0.6 metres in the Sydney region (SPCC 1979f). The velocity of tidal or fluvial currents in Botany Bay is relatively slow, a maximum of 0.64 metres per second (Bryant 1980), which means that currents alone cannot cause movement of sediment. Wave energy is needed to suspend sediment which is then carried by currents (McGuinness 1988).

Tides and wind-driven currents direct the flow of water around the bay and have a large influence on the following components and processes:

- geomorphology – tides, in conjunction with wave energy, move sediment from one place to another. This accretion and erosion over a period of time changes the geology, morphology and topography of the area.
- groundwater – the higher the amount of tidal flooding to an area, the more influence it has on the water table. Tides affect the physical properties of the groundwater, with the critical component being salinity (Clarke and Hannon 1969).
- physicochemical environment – tides affect the ratio of sea water to fresh water within the bay and cause fluctuations in salinity. Industrial and wastewater treatment plant effluent enters Botany Bay, and the bay’s tributaries deliver excess nutrients and pollutants. Due to tidal movement, suspended sediments have a short residence time in the bay, which means that the water body is well flushed, maintaining relatively high water quality.



Source: K. Brennan 2007

Figure 34: Hydrological components and processes

- biota – the flora and fauna of Towra Point are dependent on the tidal cycles in a number of ways. The tides transport and distribute phytoplankton into and throughout the bay. Phytoplankton is a primary food source in the aquatic food chain on which zooplankton, invertebrates and fish depend. Tidal export of crab larvae from saltmarsh and tidal import of detrital material from seagrass meadows provides an important food source for fish and birds (Connolly et al. 2005b; Mazumder et al. 2006a, 2009). Shorebirds rely on high tides to replenish food (debris, worms, and crustaceans) and low tides to expose mudflats rich in food. Saltmarsh and mangrove communities rely on the tides for seed dispersal, nutrient cycling and salinity fluctuation (refer to section 5.5). Figure 35 illustrates the general distribution of plant communities with respect to tides.

Tides are influenced by topography and microtopography, with less inundation in high areas than in low areas. Plant zonation at Towra Point is influenced mostly by the tide because it determines the amount of waterlogging and the degree of salinity the plants are subject to, and assists in seed dispersal (Clarke and Hannon 1969).

A causeway was built in 1952 by the Department of Civil Aviation and runs through the centre of the saltmarsh at Towra Point. While this walkway has prevented people and vehicles from further trampling vegetation, it acts as a barrier to tidal flow through the wetland (NPWS 2001a).

Reclamations for Sydney Airport and Sydney Port Authority between 1960 and 1975 reduced the area of the bay by 2.6 square kilometres (about five per cent) (SPCC 1979f). Dredging of the bay's entrance and around the airport and container port increased the tidal prism, therefore affecting tidal velocities and water quality throughout the whole system (SPCC 1979f). This has an influence on other components and processes such as sediment and nutrient transport and distribution of species such as benthic invertebrates and macrophytes.

Changes in tides since 1984

The construction of Sydney Airport's third runway in the 1990s reclaimed more of the area of Botany Bay and future reclamations and dredging to extend the Sydney Ports site will further alter the tidal prism which will change the way water moves through the system. This may affect Towra Point by altering wave patterns and tidal inundation levels.

5.3.2 Wave action

Waves are caused by the transfer of energy from the wind to the surface of the water. Winds and storms from the south-east have the biggest impact on Botany Bay, and increase the intensity of waves (Roy and Crawford 1979; SPCC 1979d). Being a low-lying area, Towra Point has always been susceptible to waves and as a result its geomorphological shape and ecology are constantly changing through the movement of sediment by waves.

Prior to 1960, wave propagation from the south-east affected the north-west shores of Botany Bay. Following the construction of Sydney Airport's runways and development of Sydney Port, the direction of waves was changed by dredging in the north and north-east areas of Botany Bay and by expansion of hard surfaces on the northern shoreline. Waves of increased frequency and height are now directed more towards the southern shore of the bay (SPCC 1979d; McGuinness 1988). Figure 36 shows the change in wave patterns in Botany Bay before and after dredging of the entrance. The 'after' wave pattern shows the southerly shift of wave direction which has had an impact on Towra Point.

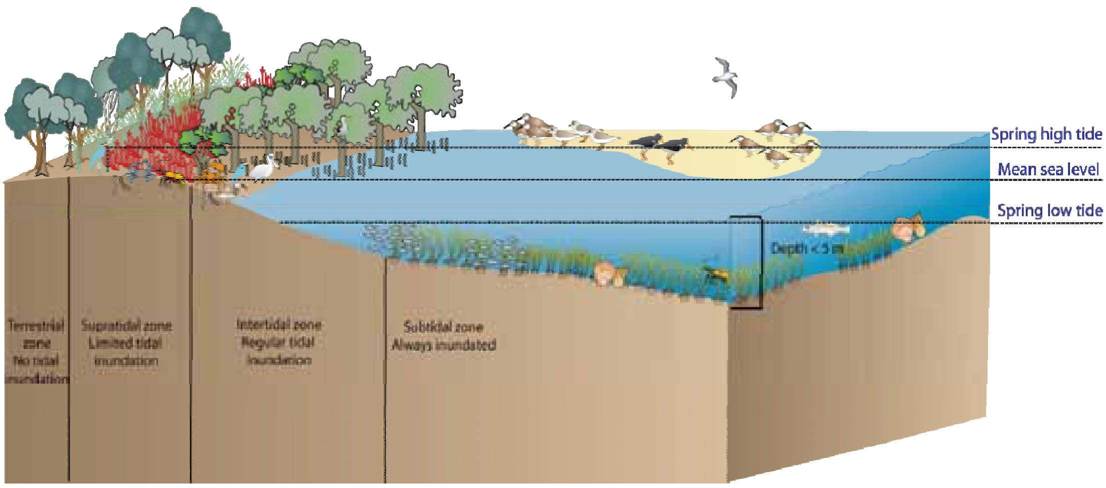


Figure 35: Tidal zones

Increased wave energy at Towra Point has caused major damage to the shores of Towra Beach due to the increasing erosion rate and vegetation recession (ALS 1977; NPWS 2001a). An increased rate of erosion, in conjunction with a number of severe storms and high tides in 1974, resulted in the intrusion of sea water into Towra Lagoon, the largest and most biologically diverse freshwater body at Towra Point (ALS 1977; SPCC 1979d; Bryant 1980; McGuinness 1988). This effect was detrimental to the presence of freshwater species, including the endangered green and golden bell frog, in Towra Lagoon as it became brackish (ALS 1977).

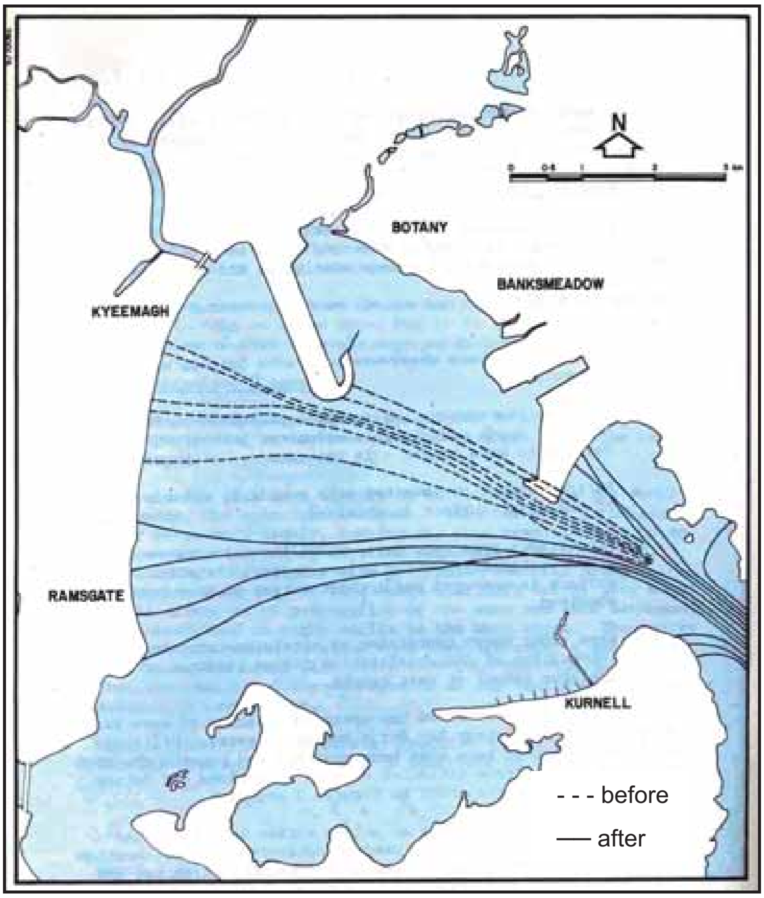
Changes in wave action since 1984

Minimisation and repair of the erosion of Towra Beach by increased wave action has been the focus of restoration since Towra Lagoon became brackish. It is possible that the shoreline of Towra Point will, in the long term, not reach dynamic equilibrium between beach erosion and accretion because the shape of Botany Bay has been changed and will continue to change through anthropogenic alterations, thus maintaining wave energy directed towards Towra Point. Regeneration of the native vegetation and removal of weeds is a continual focus for volunteer groups, NSW Maritime and DECCW. Sediment from the dredging of the Towra Spit Island land bridge was used to replenish Towra Beach in 2004, but ongoing wave action has continued to cause erosion.

Mudflats are created by the accretion of sediment in low-energy areas; however more intense waves can resuspend the sediment of mudflats and generate turbidity in the water. This has the potential to erode mudflats and therefore remove a major food source for a number of species of shorebirds and fish (Lane 1987). More frequent wave action decreases the numbers of species found in an area (Dexter 1984). Increased turbidity reduces the amount of light that is available to seagrasses which have a high light requirement.

5.3.3 Groundwater

The water table is a subsurface layer where soil and rock are saturated with water, known as groundwater. The water comes from the surface and is filtered through the soil, a process known as recharge. The height of the water table varies with elevation, soil type and vegetation cover and fluctuates with tide, rainfall, evapotranspiration and groundwater extraction. Groundwater can also move laterally through the spaces between soil particles and eventually discharge into a water body.



Source: SPCC (1979d)

Figure 36: Patterns in Botany Bay of waves from the south-east before and after entrance dredging

Tide has the greatest influence on water table fluctuations at Towra Point; the influence decreases as elevation and distance from the sea increases (Clarke and Hannon 1969). High evaporation rates in the saltmarsh zone give rise to large variations in water table level. Water table levels reach maximum height following high tide, with a lag time that increases with elevation and distance from the sea (Clarke and Hannon 1969).

Rainfall affects both water table level and salinity of the soil and groundwater. Rain over vegetated areas in the sub-catchment allows recharge of groundwater and decreases salinity. Invertebrates such as crabs and worms that burrow into the soil provide extra channels for rainfall and surface runoff into the aquifer (Robertson and Alongi 1995).

Groundwater is a critical component of an ecosystem as it provides fresh water and nutrients to plants, allows movement of water and nutrients, supports benthic communities and filters out contaminants and nutrients. It is critical in providing a source of fresh water during periods of low rainfall. Many of the plant species at Towra Point may rely on groundwater at times, including seagrass communities which may use the nutrients from the groundwater to some extent, as has been found in other NSW estuaries (Dasey et al. 2004).

The Botany Sand Aquifer is a shallow (approximately two metres deep) groundwater system that extends from Centennial Park to Botany Bay and Kurnell Peninsula, and west to Rockdale (URS 2004). It was the first aquifer to be used as a source of residential and industrial water in NSW. Botany Industrial Park drains into the northern part of the aquifer, which is the section most often used for extraction. Consequently the water is now extremely contaminated, particularly by volatile chlorinated hydrocarbons, and the aquifer now poses the biggest groundwater threat to the aquatic ecosystem (Orica 2007).

Towra Point is unlikely to be directly affected by contamination from the northern zone because Botany Bay intercepts the flow and dilutes and flushes contaminants, however no studies have been undertaken to confirm the actual impact.

Rather, Towra Point is more likely to be affected by drainage of the Botany Sand Aquifer from Kurnell Peninsula. Groundwater in the southern zone of the Botany Sands Aquifer flows in a north-westerly direction from Kurnell Peninsula and discharges into Towra Point wetland and Botany Bay. Due to the small area of the southern part of the aquifer, there is limited groundwater recharge potential (URS 2004) which makes Towra Point critical in maintaining the natural hydrological cycle.

The groundwater at Kurnell Peninsula is of low to very low salinity, and 17 registered bores and a number of unregistered bores are in use in the Kurnell residential area, mainly for gardening (URS 2004).

Caltex oil refinery is located to the east of Towra Point and has the potential to contaminate groundwater. Onsite spills and leaking underground pipes cause contamination and hydrocarbons have been found in the groundwater (URS 2004). Two sites at the refinery are monitored, with the main chemicals of concern being total petroleum hydrocarbons, benzene, toluene, ethylbenzene, xylene and lead.

Highly contaminated runoff from industries or roads in the sub-catchment has the potential to contaminate the groundwater and discharge to Botany Bay. With increasing development in the Botany Bay catchment more land is becoming sealed, hindering surface water from percolating through the soil and into the groundwater; this increases the amount of surface runoff into the waterways of Botany Bay. Towra Point wetland is critical to the recharge of groundwater via its permeable soil layers. As the surface water slowly permeate the soil, it is filtered of contaminants through adsorption. Nutrients and some toxins in the soil are broken down by bacteria which reduce the risk of groundwater contamination.

Changes in groundwater since 1984

Since 1990 Kurnell Landfill Company on Captain Cook Drive across from the Knoll has been managing construction and demolition waste from around Sydney. The groundwater is influenced by the landfill and discharges into Quibray Bay and Weeney Bay, therefore potentially exposing Towra Point wetland to landfill contaminants. Quarterly monitoring of potential contaminants in the groundwater is a requirement of the company and is submitted to Sutherland Shire Council and the NSW Government (SSC 2006b). Kurnell Landfill Company’s groundwater report for 2002 and 2006 stated that there were elevated levels of ammonia, nitrate and metals (mainly arsenic) at times. However, these compounds are a result of landfill material breakdown and do not regularly exceed guidelines (SSC 2002). Continuous monitoring of the groundwater at this site will alert authorities to any potential groundwater contamination.

Sandmining on Kurnell Peninsula has exposed the water table, therefore increasing the risk of direct contamination by surface water runoff and reducing the water table height due to evaporation. Sand mining was terminated by the NSW government in 2005 and the exposed area is being filled in with demolition waste.

A long-term change in the level of groundwater has a direct influence on surface elevation of the mangrove zone (Rogers and Saintilan 2008). A decrease in groundwater will decrease soil volume and may cause a reduction in surface elevation (Rogers et al. 2006). This has implications for the amount of tidal inundation the area receives and will affect the types of species and habitats. Surface elevation for Towra Point is a knowledge gap.

5.3.4 Limits of acceptable change for hydrology

Water quality guidelines are used to determine limits of acceptable change for groundwater on the basis that groundwater is used for irrigation and maintenance of ecosystems (ANZECC and ARMCANZ 2000) (Table 11).

5.4 Physicochemical environment

Salinity, nutrients, heavy metals and turbidity make up the physicochemical environment which influences water quality at Towra Point. Water quality 'determines the suitability of water for a particular purpose' (DEWHA 2007). Towra Point requires a standard of water quality that will sustain a diverse range of flora and fauna which is well adapted to the current environment as well as aesthetic and recreational uses from bird watching to fishing and swimming.

The physicochemical components have the potential to change the ecological character of Towra Point if they fall outside natural variations over a period of time. Other components that have a large effect on water quality include chlorophyll-a, pH and dissolved oxygen. These components are critical in the upper parts of the catchment. However, due to the well-flushed nature of Botany Bay, they are not so critical for Towra Point.

Table 11: Limits of acceptable change for hydrology

Critical component or process	Baseline condition (1984)	Limits of acceptable change	Confidence in LAC
Tide (mean sea level)	High high water: 1.07 m Mean high water springs: 0.77 m Mean high water: 0.57 m Mean high water neaps: 0.37 m Mean low water neaps: –0.33 m Mean low water springs: –0.73 m [a]	Values for high and low water springs and neaps do not fall outside mean values in more than 5 years out of 10.	Low
Wave action	Wave energy is continually eroding Towra Beach and sediment is being transported in a south-westerly direction	No increase in wave energy that would cause a permanent change from fresh to salt water in Towra Lagoon.	Medium
Groundwater	pH: 7–7.5 [b] Ammonia: 3.52–8.61 mg/L [b] Nitrate: 10.9–25 mg/L [b] Arsenic: 0.021–3.3 mg/L [b] Zinc: 0.044–0.5 mg/L [b] Copper: 0.0016 mg/L [b]	pH: 8.5 Ammonia: 0.91 mg/L [c] Nitrate: 0.7–13mg/L [c] Arsenic: 0.013 mg/L [c] Zinc: 0.008–0.015 mg/L [c] Copper: 0.0013 mg/L [b]	Low

Source: [a] Hickey (2004); [b] SSC (2002); SSC (2006b); [c] ANZECC and ARMCANZ (2000)

There are two areas of drainage that have an influence on Towra Point: one enters Quibray Bay and the other drains into Woolooware Bay. Sources of drainage are surface runoff from urban and industrial areas which has the potential to discharge contaminated waste into the wetland (SSC 2004; WODEC 2007).

Sutherland Shire Council monitored stormwater quality at a number of sites, including five sites entering Woolooware Bay and one site entering Quibray Bay during winter and summer from 1994 to 2002. Overall, water quality has improved and recommendations have been made that will ensure the continued improvement of catchment runoff. These recommendations include installation of stormwater quality improvement devices and water sensitive design for new developments.

The conceptual model in Figure 37 illustrates the influence of the components and processes of water quality on the whole ecosystem.

5.4.1 Salinity

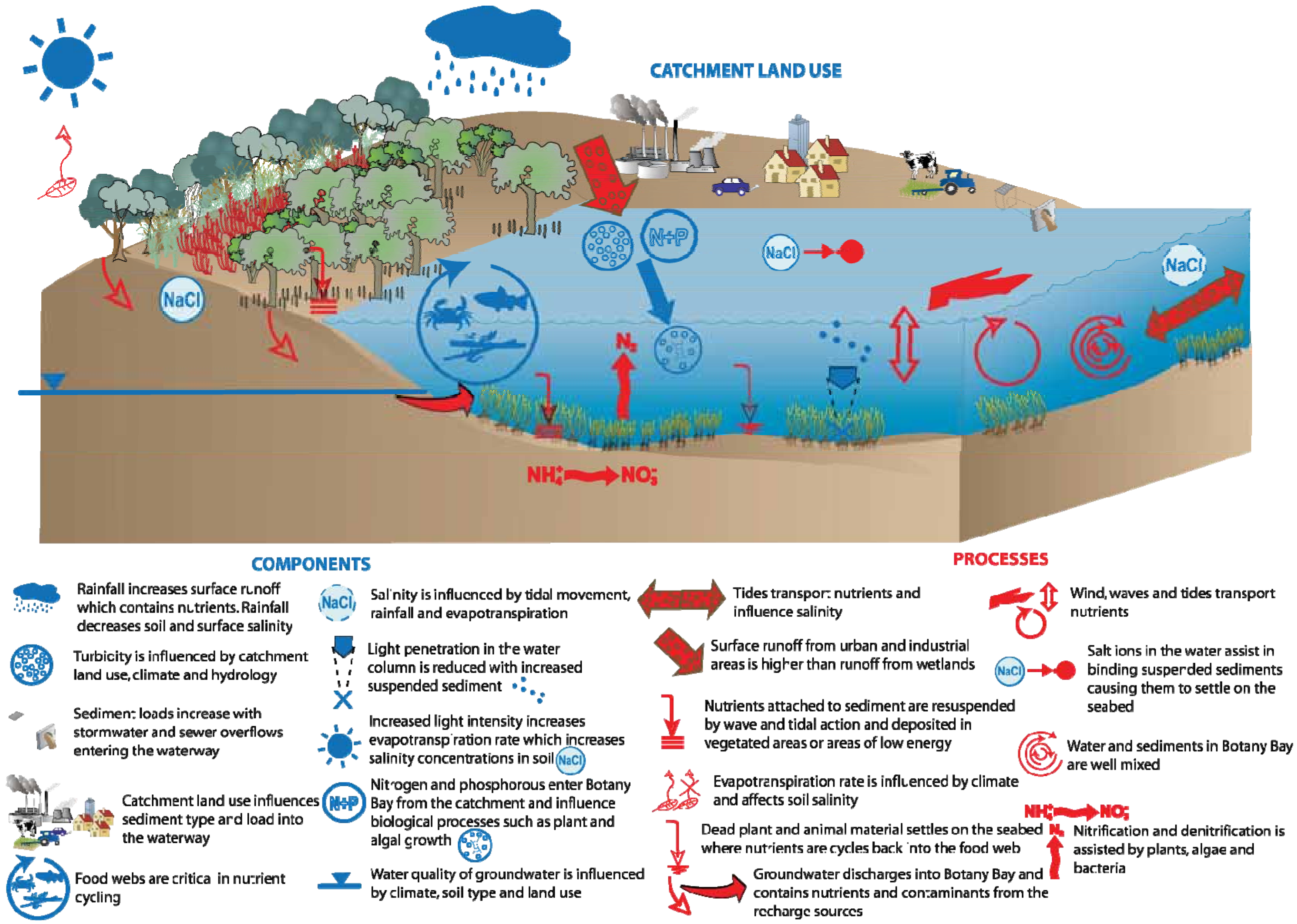
The location of Towra Point within a semi-diurnal marine embayment ensures that it is a well flushed and predominantly saline environment. The majority of fresh water is from rainfall with potentially some fluvial influence. Historically, freshwater flow from the Georges River to Botany Bay during dry weather is about 5.6 cubic metres per second and, due to tidal flushing, fresh water generally only has an influence on salinity at Towra Point after long periods of rain (ALS 1977). Typical salinity of the surrounding waters of Towra Point ranges between 20 and 35 parts per thousand (‰), with an average of about 33‰ (SMCMA 2007b).

Three freshwater lagoons are known at Towra Point. Towra Lagoon was the largest of these and supported a diverse range of fauna until seawater breached the sand barrier in 1974. The results of a survey of the lagoon in 1977 showed a very limited diversity of faunal species, with no fish recorded. After severe storms in 1975 Towra Lagoon was almost 60% sea water. By 1977 the salinity had dropped to about six per cent sea water, which is a range of 0 to 4‰ (sea water is about 35‰) with the highest salinity at the southern end of the lagoon. The other two freshwater lagoons are smaller ponds (ALS 1977).

The salinity of Botany Bay's surface water, soil and groundwater is influenced by tides, rainfall and evaporation (Figure 38). The presence of sodium and chloride ions in the water assists in binding suspended particles and metal ions, causing them to settle, therefore decreasing turbidity and increasing water clarity. High salinity of the water decreases the risk of toxigenic algal blooms (Dasey et al. 2004). The flora and fauna of Towra Point are characteristic of marine environments and plant species are partially salt tolerant. Distinct plant zonation occurs at Towra Point and the distribution of species can sometimes be attributed to salinity.

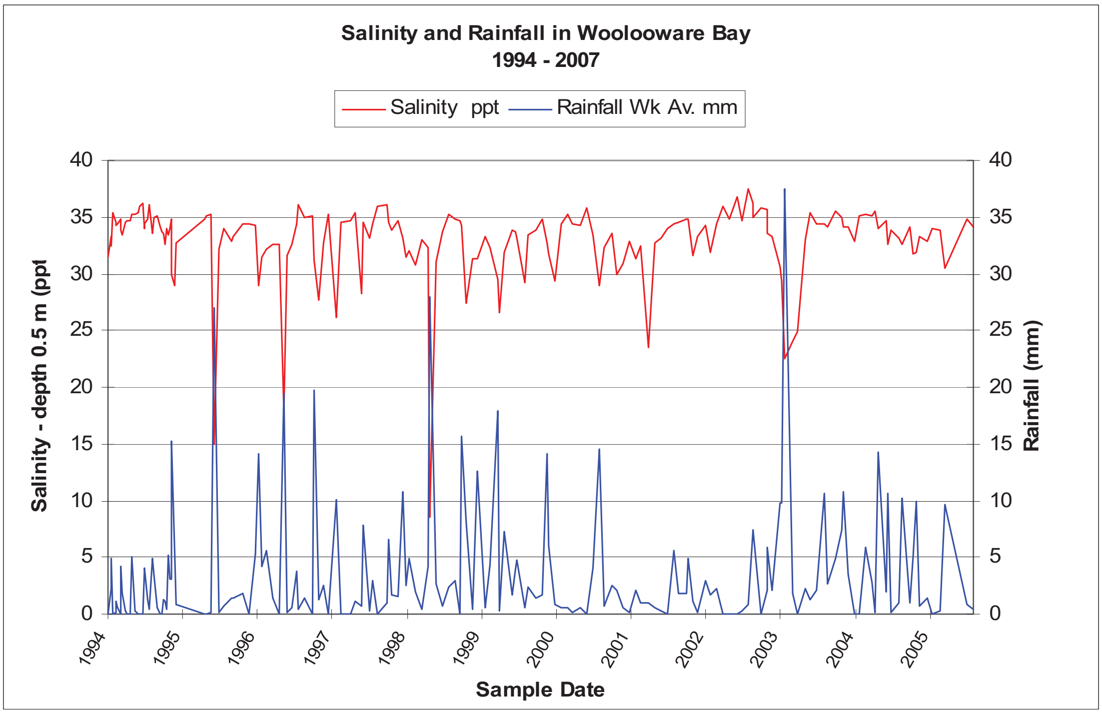
Clarke and Hannon (1970) conducted a study on the effects of salinity on plant growth and distribution. A summary of the results is below.

- Seaward expansion of sea rush (*Juncus kraussii*) and she-oaks (*Casuarina glauca*) is limited by high salinity.
- Marine couch (*Sporobolus virginicus*) grows in elevated areas in the saltmarsh zone due to a low salt tolerance.
- Streaked arrow grass (*Triglochin striata*) occurs in pools of fresh water as it is limited by salinity.
- Both the river and grey mangrove have high salt tolerance but are limited landward by salinity higher than their range of tolerance.



Source: K. Brennan 2007

Figure 37: Conceptual model for the physicochemical environment



Source: SWC (2007c)

Figure 38: Response of salinity to rainfall in Woolooware Bay

The dominant saltmarsh species at Towra Point, beaded samphire (*Sarcocornia quinqueflora*) has the highest salt tolerance of all the wetland species found at Towra Point and is not limited either seaward or landward by high salinity but by other factors including light intensity and tidal flooding (Clarke and Hannon 1970, 1971). Salinity concentrations in the soil usually reach their maximum during summer when evaporation is high and there are longer periods without rain (Clarke and Hannon 1969).

Changes in salinity since 1984

Limited records of the salinity of Towra Lagoon since 1984 indicate substantial variation. In January 1992 it was 26‰ (74% sea water) (B. Allaway, pers. comm. to B. Clarke, 1992) and in August 2007 it was 9.5‰ (27% sea water) (P. Scanes 2007, pers. comm.). Both concentrations exceed the tolerance for most freshwater species and there has been some dieback of terrestrial vegetation surrounding the lagoon.

There has been no flora or fauna survey published of the freshwater ponds since 1977 which presents a knowledge gap.

Volunteers from the Friends of Towra Point Nature Reserve, in conjunction with DECCW, NSW Maritime, I&I NSW and the former NSW Department of Infrastructure, Planning and Natural Resources (DIPNR) have made a number of attempts in the past to protect Towra Lagoon from further saltwater intrusion. However, attempts at sandbagging and use of other barriers have so far been unsuccessful due to the altered wave patterns in Botany Bay, and continuous sand replenishment of the edge of Towra Lagoon will be necessary to restore Towra Lagoon as a fresh water environment (SMEC 2003). Sea level rise, a projected outcome of climate change (Solomon et al. 2007), would increase the amount of sea water entering Towra Lagoon and prevent its recovery as a freshwater system.

Salinity of the soil at Towra Point has most likely changed as mangroves have increased their distribution landward into areas which were previously unfavourable due to high salinity and less tidal inundation.

5.4.2 Nutrients

Important nutrients in any ecosystem are nitrogen, phosphorus, carbon and, to a lesser extent, silica and iron, as these are essential for plant and animal growth. Critical nutrients to Towra Point are inorganic and organic forms of nitrogen and phosphorus. Catchment land use practices and changed hydrological regimes since settlement have elevated these nutrients in Botany Bay's waterways. Estimated loads of total nitrogen have approximately doubled since settlement (from 66 to 130 tonnes per annum) and total phosphorus and suspended sediment loads have almost tripled (5.9 to 14 and 2800 to 7600 tonnes per annum respectively) (SMCMA 2007c).

Biologically productive ecosystems such as Towra Point have a high nutrient demand and assist in the cycling of nutrients (SPCC 1978a). Excess nutrients in areas of low water flow can have detrimental effects by promoting algal growth and causing lowered dissolved oxygen and light penetration, creating a eutrophic system. Towra Point is at a low risk of becoming eutrophic due to the well flushed nature of Botany Bay. Woolooware Bay and Weeney Bay are at greatest risk of a build-up of nutrients, as they are the lowest energy areas. Areas in the upper catchment have the potential to become eutrophic and change the ecological character of the area. The main source of nutrients that have an influence on Towra Point is the Georges River (SMCMA 2007c).

The dominant sources of nutrient load into the waterways are heavily urbanised and industrialised areas (Taren Point and north and north-west areas of the catchment), sewage treatment and sewer overflow points (Georges and Cooks rivers), and agricultural land (upper Georges River). On the south-eastern shores of Quibray Bay, adjacent to the Ramsar site boundary, there is a horse-riding and stabling operation where contamination could occur as a result of excess nutrients from animal waste. High nutrient concentrations can encourage the growth of terrestrial weeds.

Land clearing and the removal of riparian vegetation exert a large influence on nutrient load to the water. Riparian vegetation prevents the direct runoff of rainfall into the water and acts as a sink for nutrients and sediments. Land clearing for rural practices and residential and industrial development can cause increased erosion of shorelines and runoff which increases the sediment and nutrient load (section 6.4).

There are three sewage treatment plants in the Botany Bay catchment that discharge treated effluent into the Georges River in wet weather, at Liverpool, Fairfield and Glenfield; Chipping Norton and the Cooks River are also key overflow points for sewage discharge (SWC 2005). Untreated discharge may occur in dry and wet weather conditions when sewage pipes become blocked, pumping stations fail or stormwater causes a breach of the system's capacity. These events deliver nutrients directly into the waterway.

Nutrients from the upper catchment are transported in the water either as dissolved forms or in sediment and are used by algae, seagrass, mangrove and saltmarsh communities. Tidal currents do not favour the growth of unattached algal groups and, therefore, this reduces the risk of eutrophication in Botany Bay.

From the data available, spikes of high concentrations of nutrients follow rain, and concentrations generally return to lower levels after a few days due to tidal flushing (SMCMA 2007b). The upper reaches of the Georges River face a greater risk of algal blooms and reduced water quality than Botany Bay due to less tidal influence.

Nitrogen

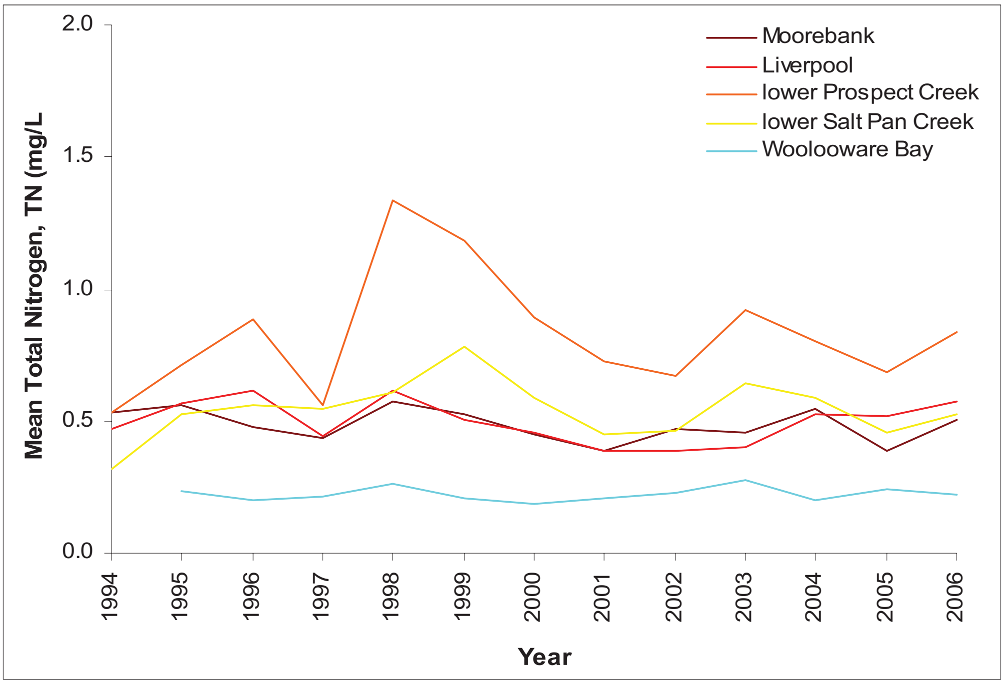
Nitrogen is present in Botany Bay in a number inorganic (nitrate, nitrite, ammonia and nitrogen gas) and organic (amino acids, proteins, urea and humic acids) forms (OzCoast and OzEstuaries 2005). Sources include runoff from rural land, stormwater and sewer overflows, runoff from urban and industrial areas, groundwater discharge and decomposition of organic matter.

Figure 39 shows the trend in nitrogen concentration at different sites along the Georges River and in Botany Bay from 1994 to 2006. The concentrations are annual averages and therefore do not adequately represent short-term variation in the system. Due to its location in a well flushed marine bay, Towra Point is less influenced by nitrogen than are the upper parts of the catchment.

Phosphorus

Inorganic orthophosphate and organic compounds containing phosphorus are dissolved in the water and are readily available for plant use (OzCoast and OzEstuaries 2005). Ionic forms of phosphorus are adsorbed onto sediment in the water, and by settling to the seabed these forms can be used by primary producers such as seagrasses. Excess phosphorus in bottom sediments has the potential to be released under anaerobic conditions and facilitate eutrophication (OzCoast and OzEstuaries 2005). There is low risk of eutrophication around Towra Point due to the high productivity of the flora and the well-oxygenated water. The main source of phosphorus is runoff from the catchment, and includes agricultural runoff, stormwater and sewer overflows, runoff from urban and industrial areas, groundwater discharge and decomposition of organic matter (SMCMA 2007c).

Figure 40 shows the trend of phosphorus concentration at different sites along the Georges River and in Botany Bay from 1994 to 2006. The data does not show short-term variation in concentration as the values are annual averages. As with nitrogen, Towra Point is not as affected by phosphorus as other areas upstream are.



Source: SWC (2007c)

Figure 39: Annual mean concentrations of total nitrogen at different sites in the Botany Bay catchment

Changes in nutrients since 1984

There is insufficient long-term data to conclude whether there has been a change in nutrient concentrations from 1984 to the present. However, there has been a significant decrease (50–60%) in total nitrogen and total phosphorus and an increase in turbidity in Woolooware Bay since approximately 1979 (Table 12). Turbidity and nutrient concentrations are dependent on a range of factors such as farm management practices, catchment land use, improvements in sewage treatment and sewer overflows, rainfall patterns, and the presence of the types and number of organisms with the ability to use nutrients.

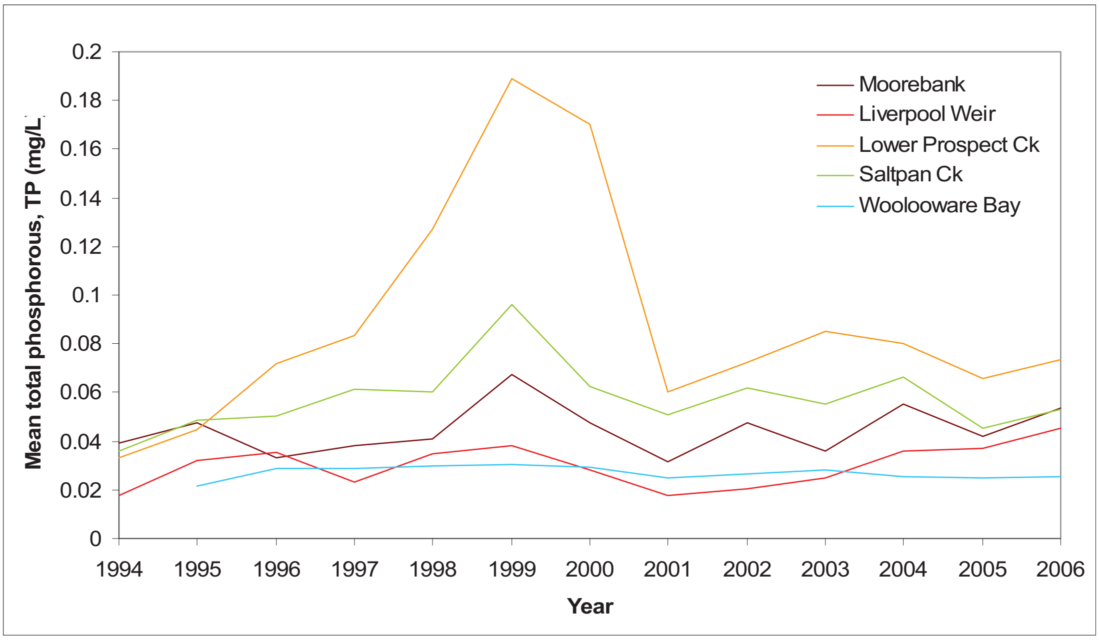
5.4.3 Heavy metals

Metals such as copper, lead and zinc are commonly found in soil and water near industrial and residential areas (SSC 2002). Wetlands assist in adsorbing these particles and filtering them out of the water. Heavy metals such as copper, iron and zinc at trace levels are required for growth by some organisms; however, excessive concentrations and the presence of other metals such as zinc and cadmium can be toxic. Heavy metals accumulate in organisms, particularly shellfish, and are passed through the food chain which may present a risk to people. In 1977 the concentrations of copper, lead and zinc around Towra Point were 1.4µg/L, 3.2 µg/L and 8.8 µg/L respectively (ALS 1977). While these values exceed the water quality guidelines for a 99% level of protection of species, they are below the 95% level of protection of species (ANZECC and ARMCANZ 2000).

Sources of heavy metals include runoff from industrial and residential areas and natural concentrations in the soil. Surface runoff increases after rainfall which subsequently increases the risk of heavy metal contamination of the water.

Changes in heavy metals since 1984

Stormwater monitoring data in Woolooware and Quibray bays indicates that there have been slight reductions in heavy metal concentrations entering the water from



Source: SWC (2007c)

Figure 40: Annual mean concentrations of total phosphorus at different sites in the Botany Bay catchment

industrial and residential sources. However, the measured levels exceed the water quality guidelines some of the time (SSC 2004) (Table 12). Sutherland Shire Council places strict requirements on industrial and residential areas by enforcing the use of stormwater quality improvement devices and water-sensitive urban design. The Caltex oil refinery and Kurnell Landfill Company both manage waste on site which greatly reduces the risk of contamination of the drainage point, Towra Point (SSC 2002, 2004).

The continued cultivation of oysters in Woolooware and Quibray bays is an indication of the low heavy metal concentrations around Towra Point (Spooner et al. 2003). The oyster leases are approved for cultivating Sydney rock oysters and are required to comply with standards set by Food Standards Australia New Zealand.

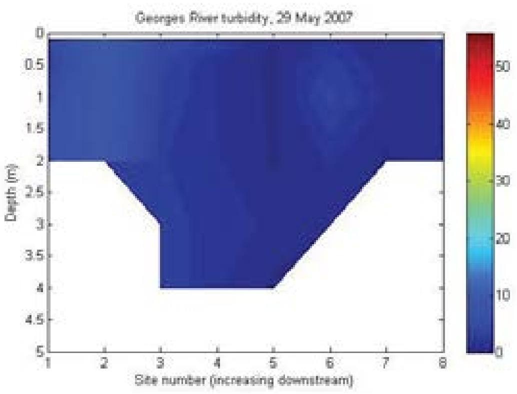
5.4.4 Turbidity

Turbidity, a measure of water clarity, is caused by suspended materials in the water column, which cause light to scatter and be absorbed rather than be transmitted to the lower parts of the water (SPCC 1979g). Suspended particles can include, but are not limited to, particulate organic carbon, phosphorus and nitrogen, and phytoplankton and metals. Increased rainfall in the catchment will increase the amount of suspended sediment entering the water column, therefore increasing turbidity. Turbidity is mostly influenced by storms, waves, high winds and catchment land use.

Turbidity in Botany Bay is highest at the river entrances and in Woolooware Bay (site 8) and there is an increase in turbidity for a number of days after rain (SPCC 1979g) (Figures 41 and 42).

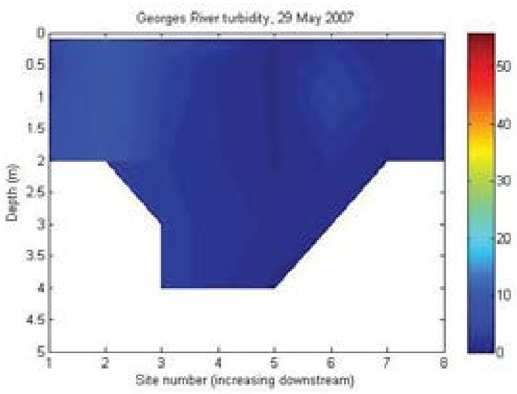
Turbidity is particularly relevant to Towra Point and surrounding seagrass meadows as it determines the conditions for seagrass growth. Increased turbidity reduces light available to seagrasses on the seabed or river bed. Seagrasses require high light intensity for survival and in Botany Bay are not found at depths of more than three metres (Larkum 1976). Pollutants and nutrients suspended in the water affect the growth of seagrass by inhibiting light for growth (section 5.5.1).

Turbid water that contains a high concentration of nutrients has the potential to cause eutrophication by providing sufficient nutrients for suspended and epiphytic algae to grow. High algal biomass then obstructs the light to benthic plants and, with the loss of benthic plants, more nutrients are available for algal uptake. This negative eutrophication loop can result in an irreversible shift in the trophic status of the



Source: SMCMA (2007b)

Figure 41: Turbidity before rain



Source: SMCMA (2007b)

Figure 42: Turbidity after rain

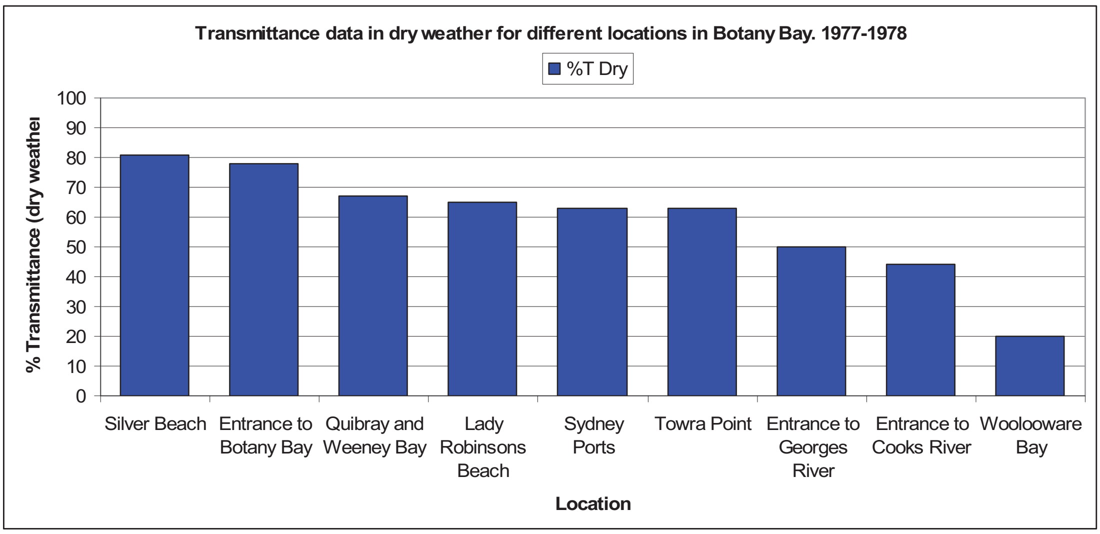
ecosystem. The settling of suspended sediments can damage gills of fish, affect crustaceans and smother benthic habitats (OzCoast and OzEstuaries 2005).

There is limited turbidity data available for the period around 1984. The State Pollution Control Commission, as part of the Environmental Control Study of Botany Bay series, sampled turbidity in Botany Bay and the Georges River, however the sampling periods are over a two month period in 1977–1978 only, and measurements taken after wet weather were not recorded for the areas surrounding Towra Point. A summary of findings states that during dry weather turbidity was defined to be 'well within acceptable limits for recreational waters' and has not significantly changed over the five years prior to 1978 (SPCC 1979g). Figure 43 is a summary of light transmittance data which suggests that the waters around river entrances have higher turbidity than locations close to the ocean entrance. This is likely due to the suspended sediment loads from the catchment and resuspended sediment in shallow areas. Therefore, Woolooware Bay is subjected to higher and more frequent turbidity than the rest of the water around Towra Point and, consequently, this limits seagrass growth. Since turbidity is a critical component because it affects the potential for seagrass growth and survival, it is a major factor in aquatic biodiversity.

Changes in turbidity since 1984

Dredging due to occur in Botany Bay includes work to bury a pipeline for desalinated water distribution and separately for two electricity cables, as well as dredging more of the northern side of Botany Bay and expansion of Sydney Ports (URS 2003; MS 2007; SWC 2007b). The predicted sediment plumes during construction of the desalinated water pipeline will have an effect on the seagrass beds adjacent to Towra Point. Although the suspended material is reported to stay within 500 metres of the dredging, the risk of seagrass mortality within the area will increase due to increased turbidity, and seagrass colonies at Silver Beach will be removed by dredging (CLT 2007). The importance of seagrass meadows and the influence of loss in seagrass area are outlined in section 5.5.1.

Increased urbanisation in the Botany Bay catchment has increased the amount of surface runoff into the waterway increasing the quantity of suspended sediments (SPCC 1979g; SMCMA 2007c). Sydney Water Corporation has commenced a number of projects to decrease the amount of stormwater runoff and sewer overflows



Adapted from SPCC (1979g)

Figure 43: Light transmittance in Botany Bay

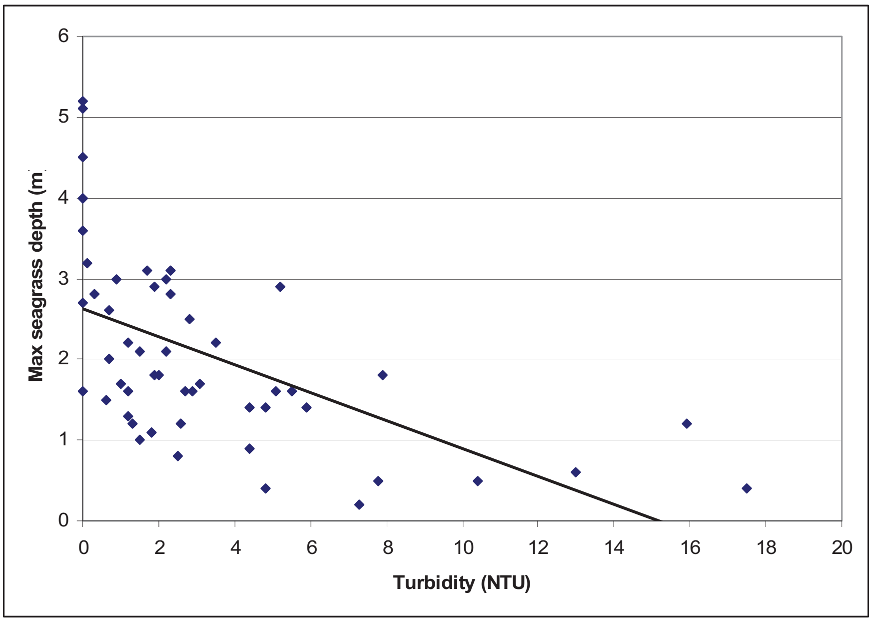
into the catchment, especially into the Georges River. Two major Sydney Water initiatives include improving the sewage system and reducing sewer overflows, and installing and maintaining stormwater quality improvement devices that help to remove litter and sediment from stormwater effluent (SWC 2007a).

One of the possible effects of climate change on turbidity may be less frequent rainfall in the south-east of Australia and an increase in the number of severe storms (Solomon et al. 2007). Longer dry periods will result in a build-up in agricultural and urban areas of sediment and contaminants, which will be delivered as large loads to the waterway relative to the current frequency and load of nutrients and contaminants. Storms may therefore increase the turbidity of the water through increased runoff loads as well as increased wave and wind action which pick up bottom sediments and keep them suspended in the water.

Turbidity values of up to 50 nephelometric turbidity units (NTU) at the mouth of the Georges River after rain have been recorded, with a decreasing trend in turbidity over time (SMCMA 2007b). Data suggests that turbidity does not exceed 8.0 NTU in the estuary and 2.6 NTU in the marine embayment to allow seagrass growth (Doherty and Scanes 2000). Turbidity of 1–2 NTU is required to maintain seagrass growth to three metres depth (Figure 44) (Doherty and Scanes 2000). Turbidity varies spatially due to hydrodynamics and temporally due to weather conditions. The recent data shows that turbidity was greatest at the top reach of the Georges River estuary, while previous reports suggest that the highest turbidity is present at the mouth of the Georges and Cooks rivers after rain (SPCC 1979g). Table 12 shows that, when comparing the two studies, turbidity is higher in 2007. However, these results are not conclusive as there is insufficient long-term data.

5.4.5 Limits of acceptable change for the physicochemical environment

A set of water quality guidelines has been outlined for natural and semi-natural water resources as part of Australia's National Water Quality Management Strategy and in relation to New Zealand's National Agenda for Sustainable Water Management. The



Source: Doherty and Scanes (2000)

Figure 44: Maximum depth of seagrass growth

guidelines are tools for land managers to prioritise monitoring and management and are not mandatory due to the large variety of ecosystems. The aim is to 'achieve sustainable use of water resources by protecting and improving their quality while maintaining economic and social development' (ANZECC and ARMCANZ 2000).

The water quality guidelines for marine water have been used in setting limits of acceptable change for water quality components at a 99% level of protection for species. Management action should only be taken after a complete assessment of the ecosystem because large fluctuations in components may occur naturally. Table 12 shows large variations in nutrient concentrations which could be a result of catchment changes and changed rainfall at the time. For example, after rain nutrients and turbidity may exceed the limit set by the guidelines. However, the ecosystem has a limited capacity to recover over time with tidal flushing. Therefore, values that are outside the limits of acceptable change should be monitored over a period of time and with reference to the corresponding local climate. Long-term trends outside limits of acceptable change will require management action.

An ecological response model developed for the Georges River and Botany Bay system will demonstrate which locations in Botany Bay, the Georges River and the Cooks River are susceptible to algal blooms, and at which times of the year blooms might occur (SMCMA 2008). Blooms occur when there is an optimum combination of

Table 12: Limits of acceptable change for the physicochemical environment

Critical compenent or process		Concentration circa 1984	Concentration circa 2007	Limits of acceptable change (water quality guidelines for marine water)
Salinity		31–35‰ [b]		
Total nitrogen (TN)		200–500 μg/L [c]	98–288 μg/L [g]	120 μg/L [e]
Oxides of nitrogen (NO_x)			2–27 μg/L [g]	Dry conditions: 5 μg/L [e] Wet conditions: 25 μg/L [e]
Ammonium (NH_4^+)			2–15 μg/L [g]	Dry conditions: 15 μg/L [e] Wet conditions: 20 μg/L [e]
Total phosphorus (TP)		20–50 μg/L [c]	12–21 μg/L [g]	25 μg/L [e]
Heavy metals	Copper	1.4 μg/L [a]	1–4 μg/L [f]	0.3 μg/L [e]
	Lead	3.2 μg/L [a]	1–2 μg/L [f]	2.2 μg/L [e]
	Zinc	8.8 μg/L [a]	8–28 μg/L [f]	7 μg/L [e]
Chlorophyll-a			0.43–25 μg/L [g]	2.2 μg/L [h] *
Turbidity at 0.5 m ** (Woolooware Bay)		2.8–7.6 NTU [d]	7.5–42 NTU [g]	8.0 NTU [h] *

Source: [a] ALS (1977); [b] Roy and Crawford (1979); [c] SPCC (1979h); [d] SPCC (1979g); [e] ANZECC and ARMCANZ (2000); [f] SSC (2004); [g] SMCMA (2007b); [h] Doherty and Scanes (2000)

* DECCW has recently analysed estuarine chlorophyll-a and turbidity data following ANZECC recommendations for setting locally relevant targets. The analyses suggest that targets of 2.2 μg/L chlorophyll and 8.0 NTU turbidity in an estuary would protect the area as a high conservation ecosystem. Values are 1.8 μg/L chlorophyll-a and 2.6 NTU turbidity for the rest of Towra Point's surrounding waters (marine conditions).

** Woolooware Bay is the most turbid of all of the bays surrounding Towra Point due to its location at the downstream end of the Georges River and estuary. Therefore, the turbidity values, especially after rainfall, will be at the upper end of the range for Towra Point. The majority of the sampling was in Woolooware Bay with few samples for other locations surrounding Towra Point (SMCMA 2007b). Seagrass growth can be a good indicator of turbidity.

environmental factors, such as nutrient load, flushing, light and temperature. By changing these factors in the model, a range of scenarios can be explored to assist catchment managers and local governments in the Georges and Cooks rivers and Botany Bay catchments to make decisions that will prevent algal blooms in the waterways under changed land or climate conditions.

5.5 Biota

The significance of Towra Point relies on the health and biodiversity of the biota that it supports. Towra Point is the largest remaining wetland of its type in the Sydney Basin biogeographic region and supports four threatened species under the Commonwealth EPBC Act and 24 threatened species and five endangered ecological communities under the NSW TSC Act. On an international scale, Towra Point provides suitable feeding, roosting and nesting habitat for migratory shorebirds during a vulnerable stage in their life cycle. There are many factors involved in sustaining the biodiversity of flora and fauna at Towra Point Nature Reserve. The components and processes that have the most influence on biota are illustrated for each component below.

5.5.1 Flora

The first scientific observations and collections of Australian flora were made from Kurnell Peninsula, including Towra Point. The native plant species therefore are culturally significant. The records of Banks and Solander include 132 plant species and provide the definitive benchmark for the native vegetation at Towra Point (Benson and Eldershaw 2007).

There is distinct plant zonation at Towra Point – the saltmarsh zone is well defined in most places from the mangrove zone and from the terrestrial zone. In a series of articles, Clarke and Hannon (1967, 1969, 1970, 1971) investigated the factors that influence plant zonation in Sydney with particular reference to Towra Point. Plant species at Towra Point have different levels of tolerance towards soil salinity and waterlogging. Tidal inundation is one of the major processes that define the boundary of a vegetation zone and is influenced by topography and microtopography, with higher elevated areas having less tidal influence. Tidal inundation, combined with wind, rain and light intensity, affects the soil salinity and therefore determines the plant species that will survive.

The critical components of wetland flora are saltmarsh, mangrove and seagrass communities. Terrestrial vegetation also plays an important role in species diversity and in the sustainability of the wetland. Much of the seagrass is not found within the Ramsar site, however it is a critical component of the Towra Point ecosystem.

Each critical component has characteristics that assist in maintaining the biodiversity of the region; however, the ecosystem relies on the presence and health of all communities and their interactions.

Seagrass

Seagrass meadows support a large diversity and abundance of fauna and are a critical component of the Towra Point ecosystem (SPCC 1978a). These seagrass meadows are largely outside the Ramsar site boundaries (except for in Weeney Bay). However, as discussed in greater detail below, interaction between the seagrass beds and mangrove/saltmarsh communities within the Ramsar site boundaries appears to contribute to the site's value for fisheries.

Once found along the northern and southern shores of Botany Bay, seagrass areas have varied due to natural and anthropogenic activity. Seagrass is protected under the FM Act due to major loss in NSW and Australia since the 1970s. The species of seagrass that surround Towra Point Nature Reserve are *Posidonia australis*, *Zostera capricorni* and *Halophila ovalis*.

The main component influencing seagrass is light availability (Larkum 1976), with turbidity being a determining factor. Seagrasses are primary producers that require shallow seabeds and high water clarity. They maintain a high productivity level within the ecosystem by producing large amounts of organic matter, important for secondary production. Their ability to release nutrients into the water supports algal epiphytes which are used by species such as fish and molluscs for grazing (SPCC 1978a; West 1983). Seagrass meadows have a high nutrient requirement and utilise nutrients from groundwater discharge areas (Dasey et al. 2004). The balance of nutrients in the water is important as excess nutrients favour the growth of algae, therefore loss of seagrass will favour algal growth (refer to section 5.5.2).

Within Botany Bay, seagrass is found to colonise seabeds to three metres in depth, which is shallow in comparison to seagrass beds in similar environments, such as Pittwater (seven metres), Port Hacking (eight metres) and Jervis Bay (nine metres). Pollution may be the limiting factor in seagrass depth in Botany Bay as the suspended sediments increase turbidity in the water (Larkum 1976).

There is a possible relationship between seagrass area fluctuations in relation to the El Niño–Southern Oscillation (ENSO) cycle. During La Niña, which is associated with greater rainfall in south-eastern Australia than during El Niño, there may be an increase in turbidity, therefore reducing seagrass area (Watford and Williams 1998). During El Niño years, there is some evidence to suggest that seagrass area increases due to a decrease in rainfall and a general increase in water quality.

Seagrasses produce more organic material than they can use; the excess is carried landward with the tide and becomes an important food source for many invertebrates and bacteria, and subsequently for fish and birds (Connolly et al. 2005b). Stable isotope analysis has established the importance of nutrients transported from seagrass meadows onto intertidal areas. Some fauna in intertidal and supratidal zones receive nutrition from seagrasses rather than mangroves and saltmarshes despite staying in the upper zones (Connolly et al. 2005a, 2005b). The presence of seagrass meadows adjacent to the mangrove and saltmarsh communities at Towra Point is a critical link in the food chain and helps to maintain the biodiversity of the wetland.

Seagrasses provide food and protection for fish and crustaceans and act as a nursery habitat for juveniles (SPCC 1978a; Bell and Pollard 1989). In addition, they stabilise the seabed, act as a buffer against wave energy and improve water quality through nutrient uptake (Larkum 1976; SPCC 1978a; West 1983). Their ecological importance is summarised below (Wood et al. 1969):

1. They act as a food source for a limited number of organisms.
2. They provide material for the detrital food chain.
3. They are host for epiphytes that may be heavily grazed.
4. They act in nutrient cycling.
5. They can bind the sediment and encourage accretion.
6. They are very productive.

A large number of fish that have been found to use the seagrass beds in Botany Bay are of commercial and recreational importance (West 1983; Bell et al. 1984; Hossain 2005), therefore loss of seagrass habitat could have economic and social impacts due to a consequential decrease in adult fish and crustaceans in the area (McGuinness 1988; Williams 1990). For example, a higher density and abundance of fish occur in areas of mangrove and saltmarsh that are adjacent to seagrass beds as opposed to areas that do not have neighbouring seagrass (Saintilan et al. 2007). Furthermore, seagrass beds in close proximity to mangrove areas support a higher density of fish than in areas further away from mangroves (Jelbart et al. 2007). A loss of seagrass area will decrease the diversity and abundance of fauna that use the entire wetland due to loss of protection and food.

Seagrass meadows trap sediments and stabilise seabeds and shorelines from waves and storms. However, they are only able to colonise areas of low energy and are affected by increased wave energy and storms. Dredging in Botany Bay has had a detrimental effect on the seagrass meadows by increasing the wave energy directed towards Towra Point and by increasing the turbidity of the water (SPCC 1978a; West 1983; Watford and Williams 1998). Smaller areas of seagrass meadows are less able to withstand wave and tidal energy. Therefore loss of sections of seagrass may have a negative effect on the whole community (Larkum 1976).

Changes in seagrasses since 1984

A number of studies show the trend of two seagrass species, *Zostera capricorni* and *Posidonia australis*, along the southern shore of Botany Bay from 1942 and 1995. The sharp decrease from around 1970 in both species coincides with dredging in the late 1960s followed by severe storms in 1974–75. The total area of both species in 1984 was approximately 516 hectares, with *Z. capricorni* covering 328 hectares and *P. australis* covering 188 hectares (Watford and Williams 1998).

The decline of both species between 1990 and 1995 corresponds to construction of Sydney Airport's third runway, where a loss of 24% of total seagrass area was identified along the southern shore of Botany Bay (Watford and Williams 1998). While there is a natural variation in seagrass area, dredging and construction have had an adverse effect. *Z. capricorni* has the ability to recolonise areas where seagrass has previously been removed provided conditions are favourable, however *P. australis* has not been found to effectively recolonise nor be successfully transplanted in Botany Bay (West 1983; Watford and Williams 1998).

Total seagrass area on the southern shore of Botany Bay from the eastern side of Woolooware Bay to Kurnell headland was 458 hectares in 2008. This area includes seagrass beds within Towra Point Aquatic Reserve and along Silver Beach at Kurnell. The composition of the seagrass beds includes 209 hectares of *P. australis*, 104 hectares of *Z. capricorni*, 13 hectares of *Halophila ovalis*, 106 hectares of mixed *P. australis* and *H. ovalis*, and 26 hectares of mixed *Z. capricorni* and *H. ovalis* (DPI 2009).

In 2009 the area of seagrass in Weeney Bay (i.e. within the Ramsar site) was about nine hectares, comprised of *P. australis* (DPI 2009). There are also extensive areas of seagrass (*P. australis* and *Z. capricorni*) around the Elephants Trunk and Towra Spit Island, which are within parts of the nature reserve proposed for addition to the Ramsar site.

Mangroves

Towra Point Nature Reserve supports 40% of the mangroves found in Sydney (Dyall et al. 2004). The size of the mangrove community is a critical factor in supporting the biota of the area, as small stands found in other areas such as Sydney Harbour are unable to maintain significant fish populations (Clynick and Chapman 2002). The largest and healthiest area of mangroves in Sydney is at Towra Point (ALS 1977).

There are two mangrove species at Towra Point: *Avicennia marina* (Figure 45) and *Aegiceras corniculatum* (Figure 46). *Avicennia marina* is the species which is dominant and most critical to the biodiversity of the wetland, and it has the greatest latitudinal distribution of all mangrove species (Clarke and Hannon 1967; Saintilan et al. 2009). Distribution of *A. marina* at Towra Point corresponds with mean high water level which is approximately 0.57 metres above mean sea level (Hickey 2004). Some mangroves are found in the saltmarsh zone, however they are limited by salinity and are restricted to the mean high water level (Clarke and Hannon 1970; Clarke and Myerscough 1993). Wilton (2002) described this as mixed habitat.

The mangrove zone undergoes the least amount of seasonal variation in soil moisture content compared with the saltmarsh zone, as it is more frequently inundated by tides (Clarke and Hannon 1967). Tidal inundation determines the limits of mangrove distribution by influencing salinity concentration and waterlogging (Clarke and Hannon 1970). The accretion to erosion ratio affects the suitability of an area for colonisation and tidal frequency also has an influence on seed dispersal and survival (Clarke and Hannon 1967, 1969; Clarke and Myerscough 1993). The saltmarsh zone is landward of the mangrove zone and is of higher elevation, and therefore is less frequently flooded by tides. Landward extension of mangroves is most likely limited due to the less frequent tidal inundation resulting in higher soil salinities and desiccation of the propagule (Clarke and Hannon 1969; Clarke and Allaway 1993; Saintilan et al. 2009).

Mangroves trap and stabilise sediment and therefore have the ability to expand into areas due to sediment accretion. They are an ecological buffer between the land and water, and trap and filter potentially contaminated sediment from the catchment, releasing the water slowly , therefore cleaning the water and preventing flooding during high rainfall. The area allows groundwater recharge and therefore assists in maintaining the natural hydrological cycle. Mangroves also protect the shoreline from erosion with their complex root system and act as a defence against waves.

Pneumatophores (aerial roots) provide a large surface area for the growth of epiphytic algae, a food source for a number of species. The substratum below mangroves at Towra Point is a suitable habitat for a diverse range of macro-invertebrates, and the shallow water and root system offer protection to fish and are an important nursery area for juveniles. A number of juvenile fish species at Towra Point use mangrove areas exclusively and one species uses mangroves after an initial stage in seagrass (Bell et al. 1984) (see section 5.5.2).

The occurrence of mangroves adjacent to seagrass and saltmarsh communities increases the diversity and abundance of species that use the area compared to areas where mangroves grow in the absence of other vegetation types (Jelbart et al. 2007; Saintilan et al. 2007). This could be a result of trophic relay between the

Photo: K. Brennan 2007

Figure 45: Grey mangrove

Photo: K. Brennan 2007

Figure 46: River mangrove

different habitats. A number of organisms that reside in the mangrove zone obtain food from the incoming tides (organic matter from seagrass meadows) (Connolly et al. 2005b), and/or from outgoing spring tides (crab larvae from the saltmarsh zone) (Mazumder et al. 2006a, 2009).

Clynick and Chapman (2002) suggested that small and fragmented areas of mangroves do not always support a significant number of juvenile fish. Their study focused on four small mangrove areas in Sydney Harbour where they found the habitat to be highly disturbed and of poor water quality, and therefore the mangroves did not provide a significant nursery habitat for juvenile fish. Towra Point on the other hand has extensive mangrove communities, and site-specific studies have shown the importance of these communities as shelter and food for juvenile fish and crustaceans (Bell et al. 1984; Mazumder et al. 2005; Saintilan et al. 2007).

Aerial photographic records since 1942 provide evidence that the total mangrove area at Towra Point has increased, and the majority of this increase is in the landward direction at the expense of saltmarsh area (Mitchell and Adam 1989; Wilton 2002). There are a number of theories about mangrove incursion into saltmarsh areas. The first theory is that a rise in sea level means that higher areas are inundated by tides, increasing the range of favourable mangrove habitat (Saintilan and Williams 1999; Wilton 2002; Saintilan et al. 2009). The second theory is based on the harvest of mangroves in the 19th century for timber, soap and to provide land for grazing, and the mangroves are now gradually reclaiming the saltmarsh areas where they once grew (Mitchell and Adam 1989). Although loss of saltmarsh habitat is occurring on a regional scale, local factors appear to have a large influence on the rate of change (Wilton 2002). The third theory concerns the height of the water table. When water table level decreases either by a period of low rainfall or by extraction, compaction of the soil results in a lowering of the ground (Rogers and Saintilan 2008). For mangrove and saltmarsh communities, this affects the amount of tidal inundation and may increase the growth of mangroves in the landward direction.

Neither historical mean sea-level rise, rainfall patterns, estuary type, catchment land use, catchment natural cover nor population pressure can account solely for the patterns in the spatial and temporal dynamics of the coastal wetlands of NSW. These possibilities are discussed in further detail in section 6.7.

Changes in mangroves since 1984

Since 1984 there has been an increase in area of mangroves at Towra Point. In 1983 and 1999 mangrove area at Towra Point was calculated from aerial photographs to be 395.2 hectares and 470.5 hectares respectively, an increase of 19% since the site was listed, gained by expansion into areas of saltmarsh (8.9%), mixed habitat (17.5%) and into the waterway (8.6%) (Wilton 2002). It is unknown whether this expansion was a result of anthropogenic or natural influences or both.

A more recent survey of mangrove area found approximately 385 hectares within and adjacent to Towra Point (DPI 2009). This data cannot be compared to the study by Wilton (2002) due to methodology and source data inconsistencies, but can be used as a baseline area for mangroves in 2008.

Saltmarsh

In the Sydney region, 60% of the saltmarsh area is at Towra Point (Dyall et al. 2004) (Figure 47). Prior to knowledge of their ecological importance and listing as an endangered ecological community under the TSC Act, saltmarsh communities were seen as wastelands and were destroyed for land development (Laegdsgaard 2006). Saltmarsh along the temperate east coast of Australia has declined since the 1940s (Saintilan and Williams 2000).

Saltmarsh contributes to the productivity of a wetland, acts as a buffer between urban and natural areas filtering out noise and pollution, allows groundwater recharge, and supports the biodiversity of the region. Coastal saltmarsh communities may also provide drought refuges for some waterbird species such as colonial species which increases the importance of Towra Point on a regional scale (Spencer et al. 2009).

There is a zonation of species in the saltmarsh. This relates to tidal inundation, microtopography, evaporation, temperature and rainfall (ALS 1977; Saintilan et al. 2009). Saltmarsh species found at Towra Point, include (Clarke and Hannon 1971):

- Beaded samphire is the most abundant species and is found on the seaward side of the saltmarsh zone. It has the highest salinity tolerance of all wetland species found at Towra Point but is limited by light intensity in competition with mangroves on the seaward side and by sea rush on the landward side. Seaward expansion is limited by frequency of tidal flooding, especially for seedling establishment (Figure 48).
- Seablite grows at slightly higher elevations on the seaward side of the zone. It has a high salt tolerance and waterlogging requirements are different for different stages in its life cycle.
- Marine couch is found on slightly higher elevated areas among the samphire and sea rush, and has a lower salt tolerance and requirement.
- Streaked arrow grass occurs in pools of rainwater or seawater and has a lower salinity tolerance than samphire and marine couch. Waterlogged conditions are a requirement for healthy growth and this species usually dies out during summer when rainfall is low and evaporation is high.
- Creeping brookweed (*Samolus repens*) is very rare at Towra Point and is only found in patches among the samphire.

Photo: K. Brennan 2007

Figure 47: Saltmarsh

- Sea rush is found on the landward side of the saltmarsh zone. It is limited seaward by high salinities and tidal flooding, and limited landward by dense leaf litter of casuarinas and competition for light.

Photo: K. Brennan 2007

Figure 48: Samphire

Saltmarsh species are limited in their seaward and landward distribution due to a number of factors. They grow best under full light, therefore their expansion is limited by light intensity which is affected by the presence of mangroves seaward and tall terrestrial trees such as casuarinas landward (Clarke and Hannon 1971). Saltmarsh seeds are unable to germinate among the root system of mangroves or in the thick leaf litter of casuarinas, which is another limit to their expansion. The height of the water table also has an influence on saltmarsh species; when it becomes high enough to submerge the plants, it restricts the amount of oxygen and light available (Clarke and Hannon 1971). Seedlings of all saltmarsh species except sea rush are dispersed by the tides (Clarke and Hannon 1970), therefore maintenance of the hydrological regime is a critical process in saltmarsh distribution and survival. Sudden changes in hydrology could have a detrimental effect on the community.

A critical component of the saltmarsh zone is microtopography, as this relates to tidal flooding (Clarke and Hannon 1969). Surface elevation is affected by the height of the water table, as a reduction in groundwater may cause soil compaction and therefore reduce elevation (Rogers et al. 2006). Tidal inundation is more frequent in areas of lower elevation which are suitable habitat for mangroves. Rainfall, wind, tidal inundation frequency and solar radiation affect soil salinity which also determines species distribution. Saltmarshes have a relatively high tolerance to salinity, which is a competitive advantage over other species.

Large areas of saltmarsh, such as those at Towra Point, contribute more to estuarine food webs than smaller areas, therefore supporting a larger, more diverse range of species (Guest and Connolly 2006). Saltmarsh communities adjacent to mangrove and seagrass support biodiversity by allowing species to use the different habitat zones (Mazumder et al. 2006a; Jelbart et al. 2007; Connolly 2009).

Saltmarsh vegetation plays an important role in productivity by supporting nutrient and energy cycling. Due to less frequent tidal flooding, the saltmarsh zone is generally drier than the mangrove zone and the soil is well oxygenated. The ammonium and nitrate produced by the process of nitrification are exported into the water for use by other organisms (Laegdsgaard 2006).

The saltmarsh vegetation is an important roost and feeding site for migratory shorebirds such as the common greenshank, curlew sandpiper, eastern curlew and red-necked stint (*Calidris ruficollis*) (Spencer et al. 2009). Its close proximity to a feeding area for these birds means that they use only a small amount of energy to move from one area to the other (Lane 1987; Lawler 1996). Saltmarsh is an important habitat for regionally significant species such as the white-fronted chat, southern emu-wren (*Stipiturus malachurus*), Lewin's rail and the white-faced heron (*Egretta novaehollandiae*) (Schulz 2006).The importance of saltmarsh in the food chain is also demonstrated by the habitat it provides for crab species, which release large amounts of larvae in the ebb tide. Certain fish species use the spring tides to access this reliable spawning and some of these fish are of commercial and economic importance. The use of saltmarsh areas by fish and birds allows nutrient cycling and energy transfer and demonstrates the ecological connectivity of the area (Mazumder et al. 2006a, 2009; Connolly 2009). The high abundance and diversity of invertebrate species in the saltmarsh zone provide food for other vertebrate fauna including insectivorous bats (Laegdsgaard et al. 2004).

There has been significant loss of saltmarsh communities in NSW, since the 1940s at least, and the community supported by Towra Point is one of the largest remaining saltmarsh areas in the state (Mitchell and Adam 1989; Saintilan and Williams 2000). Data since 1942 shows that saltmarsh area at Towra Point has declined (section 2.4). Much of the loss of saltmarsh in Sydney is due to land development; however, at Towra Point the main cause is mangrove encroachment (Wilton 2002). Mangroves are expanding landward into the saltmarsh zone for reasons yet undetermined at almost the same rate saltmarsh is disappearing (Mitchell and Adam 1989). As described above, saltmarsh species cannot compete with mangroves or terrestrial vegetation when it comes to light availability and the influence of tidal inundation prevents the expansion of saltmarsh in either direction.

Changes in saltmarsh since 1984

The area of saltmarsh at Towra Point was calculated from aerial photographs to be 141 hectares in 1983 and 88.1 hectares in 1999, a 38% decline over this period. Saltmarsh was lost to mangrove habitat (8.9%), mixed saltmarsh and mangrove (12.2%), and terrestrial habitat (7.1%), while it increased by 0.7% at the expense of terrestrial habitat. Mangrove incursion at Towra Point continues to be a threat to saltmarsh communities which are at risk of being lost as land development prevents further landward expansion. Some studies suggest that mangrove encroachment is a result of climate change; therefore, change in saltmarsh area could be an indicator of climate change (Wilton 2002; Saintilan et al. 2009).

A more recent survey of saltmarsh mapped 134 hectares within and adjacent to Towra Point (DPI 2009). This study cannot be compared to the study by Wilton (2002) due to methodology and source data inconsistencies, but should be used as the baseline area for saltmarsh in 2008.

While the harsh environment of the saltmarsh zone is unsuitable for most other species (including weeds), spiny rush (*Juncus acutus*) is a potential threat to the saltmarsh at Towra Point (DECC 2005). Removal of this weed and the propagation of sea rush are being undertaken under a DECCW contract.

Terrestrial vegetation

Terrestrial habitat at Towra Point consisted of approximately 166 hectares in 1983 and includes plant community types such as swamp oak forest, littoral strand, littoral rainforest, dune sclerophyll forest and bangalay forest with swamp oak (*Casuarina glauca*), the perennial herb *Hydrocotyle bonariensis*, tuckeroo (*Cupaniopsis anacardioides*), coast banksia (*Banksia integrifolia*) and bangalay (*Eucalyptus botryoides*) dominating their communities (ALS 1977) (Figure 49).

The magenta lilly pilly is listed as vulnerable under NSW (TSC Act) and Commonwealth legislation (EPBC Act) and has been recorded in the littoral rainforest at Towra Point Nature Reserve in 1977 and 2007 (ALS 1977; WODEC 2007). This species is under threat from weed invasion, especially by bitou bush (*Chrysanthemoides monilifera*) (WODEC 2007).

Terrestrial vegetation provides important habitat for many species as well as ecological connectivity. Hollow-bearing trees of the bangalay forest are important nesting and roosting sites for species such as the masked owl and greater broad-nosed bat (*Scoteanax rueppellii*) which are both classed as vulnerable in NSW (Schulz 2006). Coast banksias are an important food source for the vulnerable grey-headed flying-fox and a number of honeyeater species (Eby 2006; Schulz 2006).

Over 150 of the 296 species of vascular plants found at Towra Point are terrestrial vegetation types (ALS 1977) (Appendix E), which comprise and support the biodiversity of the wetland. Some of the species are rare in the Sydney area, such as swamp lily (*Crinum pedunculatum*), deciduous fig (*Ficus superba* var. *henneana*), water fern (*Blechnum camfieldii*), the common fern *Cyclosorus gongylodes*, binung (*Christella dentata*) and *Schoenoplectus subulatus* (Vahl) Lye (ALS 1977).

Changes in terrestrial vegetation since 1984

The area of terrestrial vegetation at Towra Point in 1999 was approximately 188 hectares, a 14% increase since 1984 (Wilton 2002) (Appendices F and G). This increase has been at the expense of saltmarsh (7.1%) as terrestrial vegetation has expanded seaward (Wilton 2002). A more recent survey of terrestrial vegetation mapped 185 hectares (SSC 2006b). All terrestrial areas are under threat from weed invasion (WODEC 2007). The increase in salinity of Towra Lagoon has caused loss of some surrounding terrestrial vegetation; therefore, prevention of further saltwater intrusion may encourage regrowth. A vegetation survey of Kurnell Peninsula included seven sites at Towra Point and found that the sites were in good to average condition but some parts were dominated by weeds, especially lantana. Plant species present are listed in Appendix E.

5.5.2 Fauna

The flora of Towra Point supports many fauna including threatened and migratory species.

Photo: K. Brennan 2007

Figure 49: Terrestrial vegetation

Macro-invertebrates

In the tidal zone of Towra Point, 5883 individuals of 80 species of crustaceans, polychaetes and gastropods have been recorded (ALS 1977) (Appendix B). Macro-invertebrates are distributed according to the sediment type, and small changes in benthic sediments cause changes in invertebrate species (SPCC 1979b). Major influences on species distribution, diversity and abundance include waves, temperature, rainfall and upwelling with an increase in species found in more stable, low energy areas (Dexter 1984).

Due to the differences in substratum and physical parameters of the different areas there is variation in species diversity (SPCC 1979b; Dexter 1984) (Figure 50). The difference in numbers of mollusc species between Towra Point and Weeney Bay is probably due to the softer, siltier substrate in Weeney Bay (ALS 1977). Numbers of all invertebrates are similar for Towra Point and Weeney Bay, however the types of species found in each area differ. The Woolooware Bay mud flat sampled had low numbers of all invertebrates which suggests the area may have been disturbed (ALS 1977).

Even though species diversity was low in some locations, an abundance of invertebrates was recorded, for example at Pelican Point, the Elephants Trunk and the eastern side of Towra Point, which are rich feeding grounds for shorebirds (Figure 51).

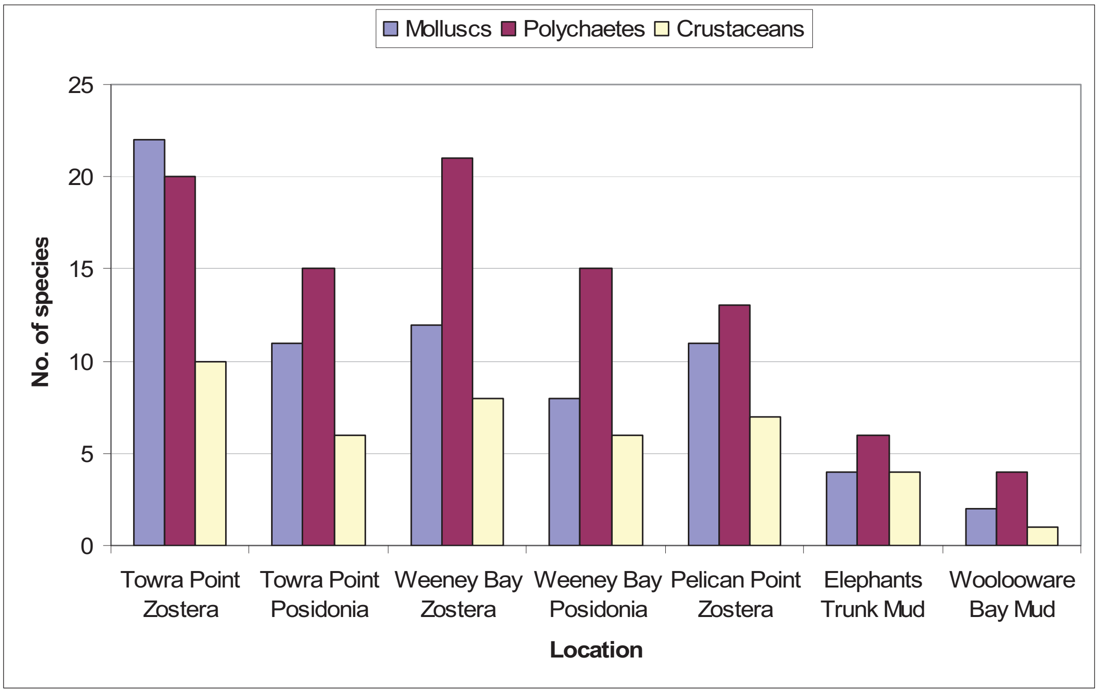
Macro-invertebrates are important components of the food web in the ecosystem at Towra Point. Mollusc, polychaete and crustacean species are part of the diet of fish and birds (Bell et al. 1984; Lane 1987). Seagrass meadows adjacent to the intertidal zone are critical as excess nutrients in the form of detritus are transported onto the mudflats with the tides and waves (Connolly et al. 2005a, 2005b).

The saltmarsh zone becomes inundated by the spring tides approximately every 14 days (Saintilan and Williams 2000). These tides are used by some crab species to export larvae into Botany Bay (Mazumder et al. 2006a, 2009; Connolly 2009). The tides are a critical process as they support the food chain, energy transport and nutrient cycling. Fish and bird species rely on the export of crab species into waterways and onto intertidal areas. Invertebrate species living in the mangrove and saltmarsh zones help to aerate and turn over the soil, thereby improving the health of plants (Lee 1998).

Macro-invertebrates are good indicators of a change in the sediments due to their association with specific substrate types and their low mobility; if the area is disturbed, the macro-invertebrates are unable to move and do not survive the disturbance. Dredging of Botany Bay in the 1970s changed the sediments and the types of organisms living in the sediments (SPCC 1979b). Oil spills are a major threat to Towra Point and cause mortality in many species. There is a high rate of mortality directly after oil spill contamination, but in a few months macro-invertebrates return to the area (Dexter 1984; McGuinness 1990; Clarke and Ward 1994) (see section 6.5).

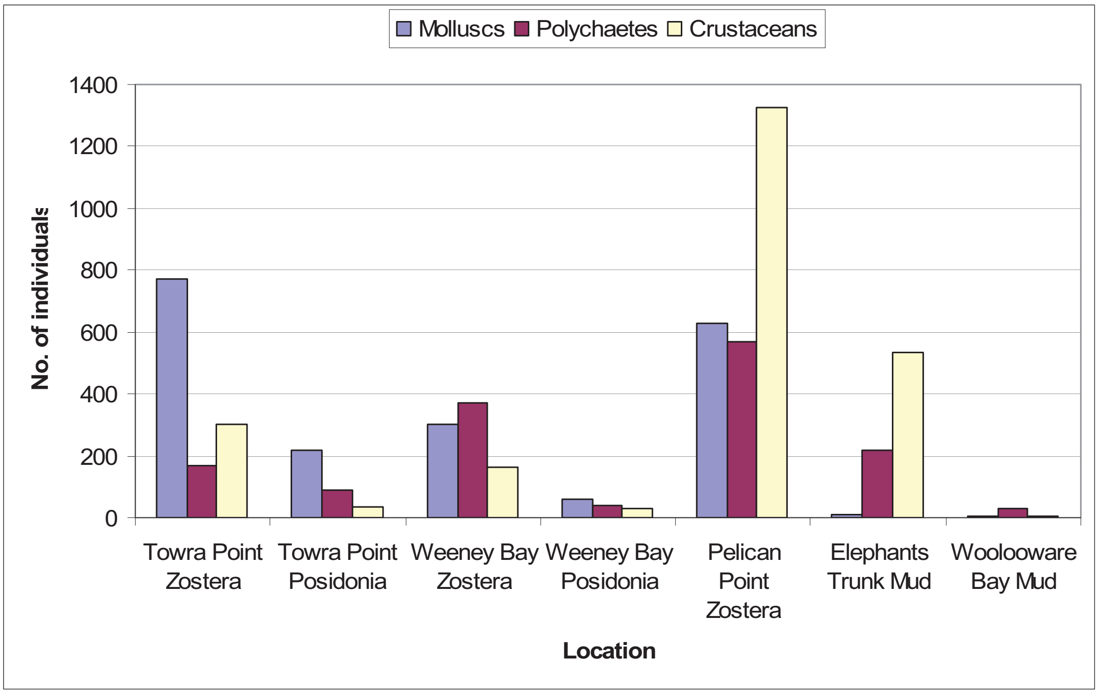
Changes in macro-invertebrates since 1984

While studies of macro-invertebrate species have been carried out around Towra Point there is a knowledge gap of total numbers of species and individuals (Robinson et al. 1983; Kaly 1988; Roach 2000). A survey of sites along the Georges River and Towra Point for decapods and molluscs (Williams et al. 2004), and studies by Mazumder et al. (2005, 2006a, 2006b) and Saintilan et al. (2007) collectively found 21 species (Appendix B). However, the studies were not specifically macro-invertebrate studies and may not represent the total macro-invertebrates at Towra Point at the time.



Adapted from ALS (1977)

Figure 50: Macro-invertebrate diversity at different locations in winter 1977



Adapted from ALS (1977)

Figure 51: Macro-invertebrate abundance in winter 1977

Loss of, or change in, habitat, and substratum especially, could cause a loss of macro-invertebrates. A change in the types and numbers of macro-invertebrates around Towra Point could mean a loss of food for some fish and birds and could therefore adversely change the ecological character of the site. Burrowing invertebrates provide channels in the soil which improves groundwater recharge efficiency (Robertson and Alongi 1995).

Fish

Many fish use the waters of Towra Point Nature Reserve and Towra Point Aquatic Reserve for food and shelter (Appendix C). Seagrass, mangrove and saltmarsh communities play an important role in the life cycle of these fish species. In the seagrass surrounding Towra Point, 5,377 individuals of 75 species were recorded in 1981, and in the adjacent mangroves 16,905 individuals of 46 species were recorded in 1984 (SPCC 1981a; Bell et al. 1984). These numbers may not accurately represent the number of species that use a particular area.

The majority of fish use the Towra Point mangroves for only part of their life cycle, usually the juvenile stage (Bell et al. 1984). Several mullet species use the waters of Towra Point as juveniles and migrate to spawning grounds off the east coast of Australia (Bell et al. 1984; B. Pease 2007, pers. comm.). There are approximately 25 species of fish that use Towra Point that are of economic or recreational importance. Freshwater eels, such as long-finned eels (*Anguilla reinhardtii*), are found in the waters around Towra Point throughout all their life stages, while others, such as short-finned eels (*Anguilla australis*), migrate from Towra Point to the tropical South Pacific to spawn (B. Pease 2007, pers. comm.). Juvenile squid have been found in the saltmarsh at Towra Point (N. Saintilan 2007, pers. comm.).

Fish occur on different levels in the food chain and are a critical link in trophic relay. By using the tides, fish are able to access both mangrove and saltmarsh habitats where they have a wide range of prey, such as crabs and macro-invertebrates (Szymczak and Mazumder 2007; Connolly 2009; Mazumder et al. 2009). These fish, such as bream (*Acanthopagrus australis*), are then preyed upon by higher order fish, such as mulloway (*Argyrosomus japonicus*), or birds, such as the white-bellied sea-eagle (Szymczak and Mazumder 2007).

The importance of wetland habitats on a global scale as a nursery habitat for juvenile fish has been well documented (SPCC 1978a; West 1983; Bell et al. 1984; Boesch and Turner 1984; Mazumder et al. 2005; Jelbart et al. 2007; Saintilan et al. 2007) and a change in ecological character in the wetland could have negative implications for these species and a negative economic impact on the fishing industry. Bell et al. (1984) found that 41% of fish species collected at Towra Point were temporary residents of the area, mainly juveniles; 77% of individuals, such as the sand whiting (*Sillago ciliata*), flat-tail mullet and the serpent eel (*Ophisurus serpens*) were temporary residents. No two species of fish had similar diets, indicating that there is a large range of food available to support a diversity of fish species (Bell et al. 1984).

Fish are sensitive to changes in their environment . The anthropogenic modifications to Botany Bay have altered the way water moves and its depth, the sediment type, wave direction and benthic organisms, which have influenced fish and prawn species and movements (SPCC 1979c). The amount of dissolved oxygen in the water is influenced by temperature and by the number of phytoplankton and other primary producers; a lack of dissolved oxygen reduces the ability of fish to survive (SPCC 1981b). Salinity and water temperature influence fish mortality, especially when changes occur quickly (Lugg 2000). Pollution and poor water quality are a threat to most fish species.

Changes in fish since 1984

After the creation of Towra Point Aquatic Reserve, waters surrounding Towra Point were protected from commercial fishing and, to some extent, recreational fishing. Commercial fishing was banned in 2002 to create an area for recreational fishing and protect fish and seagrass (Williams et al. 2004). The habitat within and adjacent to the aquatic reserve provides suitable protection and food for a large number of species, many of which are of economic or recreational importance (Bell et al. 1984; Mazumder et al. 2005).

In 2000 846 individuals of 39 fish species in the seagrass meadows surrounding Towra Point were counted, and in 2006 study 853 individuals of 13 species in the mangroves and 1208 individuals of 16 species in the saltmarsh were counted (Williams 2000; Mazumder et al. 2006b). To set limits of acceptable change, the current data may not accurately allow for the natural variation of species and further knowledge is required. However, a further loss in fish species and individuals will adversely affect the biodiversity of the area as well as negatively influence the finfish industry; the majority of fish using Towra Point are transient and migrate to other areas at different stages of their life cycle where they may be caught by commercial fishers (Bell et al. 1984).

Reptiles and amphibians

A number of studies in 1977 identified eight species of reptiles and four species of amphibians (Table 13). However, the actual number of species was predicted to be greater as the studies were carried out during the colder months (ALS 1977). None of the species recorded at the time was rare or endangered.

Changes in reptiles and amphibians since 1984

In 2006 five reptile and two amphibian species were observed during a relatively inactive period for these species due to the cold weather (Table 14) (Schulz 2006). An additional three reptile and two amphibian species have been recorded on the Atlas of NSW Wildlife (DECC 2009). These records show a shift in frog species type towards a less diverse mix; more recent surveys recorded only *Litoria* species which may be due to sampling times or methods (Schulz 2006).

There are other areas on Kurnell Peninsula which are favourable areas for reptiles and amphibians, such as the vulnerable wallum froglet. The green and golden bell frog is endangered in NSW, and Kurnell Peninsula has been identified as a key population in Sydney; some of its habitat on the peninsula has been lost due to the drying of wetlands and the frogs can be found in the remaining fragmented wetlands throughout Kurnell Peninsula (SSC n.d.; DEC 2005). These frogs can sometimes be found in swampy areas at Towra Point, Kurnell Landfill Company's site, Cronulla Sewage Treatment Plant and the Australand and Breen development sites (DEC 2005).

Mammals

There is a lack of historical data on mammals at Towra Point, as mammals in the area were not considered as threatened and many were introduced or pest species (NPWS 1989). In 1977 only one native species, the eastern swamp rat (*Rattus lutreolus*), out of seven to be living at Towra Point with an additional two (wallaby and bat species) thought to be present in the area was observed, while the rest of the mammals recorded were introduced species (Table 15); during the survey no native mammals were found, possibly due to windy and cold weather conditions (ALS 1977).

Table 13: Reptiles and amphibians in 1977

Common name	Scientific name	Number	Microhabitat
Grass skink	*Lampropholis delicata*	Numerous	Under logs and rubbish on ground, except the Teardrop where they were under bark on trees
Weasel skink	*Lampropholis mustelinum*	1	Under rubbish in wet area
Three-toed skink	*Saiphos equalis*	3	Under logs on sandy soil
Eastern blue-tongued lizard	*Tiliqua scincoides*	1	Under old roofing iron
Red-bellied black snake	*Pseudechis porphyriacus*	1 (dead)	
Marsh snake	*Hemiaspis signata*	1	Under rubbish near oyster farmer's hut
Small-eyed snake	*Unechis nigrescens*	2	Inside decaying log
Eastern long-necked tortoise	*Chelodina longicollis*	1	Hatchling which was walking along a road
Striped grass frog	*Limnodymastes peroni*	26	Under logs and on the ground
Common froglet	*Ranidella signifera*	3	Under logs and on the ground
Bleating tree frog	*Litoria dentata*	42	Under bark on standing or fallen trees, and around water bodies
Green and golden bell frog	*Litoria aurea*	6	Under bark on trees, or rubbish on ground

Source: ALS (1977)

Table 14: Reptiles and amphibians recorded since 1984

Common Name	Scientific Name	Site
Grass skink (dark-flecked sun skink)	*Lampropholis delicata*	Towra Point
Eastern blue tongued lizard	*Tiliqua scincoides*	Next to Captain Cook Drive
Red-bellied black snake	*Pseudechis porphyriacus*	Towra Point
Marsh snake	*Hemiaspis signata*	Next to Captain Cook Drive
Eastern small-eyed snake	*Rhinoplocephalus nigrescens*	Next to Captain Cook Drive
Jacky lashtail	*Amphibolurus muricatus*	Towra Point
Eastern snake-necked turtle	*Chelodina longicollis*	Towra Point
Pale-flecked garden sun skink	*Lampropholis guichenoti*	Towra Point
Green and golden bell frog	*Litoria aurea*	Towra causeway and Swamp
Bleating tree frog (Keferstein's tree frog)	*Litoria dentata*	Towra Lagoon
Jervis Bay tree frog	*Litoria jervisiensis*	Next to Captain Cook Drive
Peron's tree frog	*Litoria peronii*	Next to Captain Cook Drive

Source: Schulz (2006); DECC (2009)

Changes in mammals since 1984

A robust mammal survey is still lacking for Towra Point. The Atlas of NSW Wildlife documents incidental sightings including marine mammals, and a fauna survey in 2008 recorded 10 mammals at Towra Point (Table 16). However, both databases are incomplete for mammals.

Towra Point provides important habitat for a number of threatened mammals, such as the grey-headed flying-fox and greater broad-nosed bat. The sighting of the dugong, which is endangered in NSW, in Botany Bay in 1992 coincided with a major loss of seagrass in Hervey Bay, Queensland, due to a flood and cyclone. Dugongs are not a resident species in Botany Bay as they prefer tropical waters, but they may use the seagrass meadows as a refuge when there is inadequate food in their usual home range (Sheppard et al. 2006).

There is a grey-headed flying-fox camp on Kurnell Peninsula on site of the planned desalination plant. This camp is important for mating and raising young, and over 7,000 flying foxes can be observed from spring to autumn (Eby 2006).They have a foraging radius of about 25 kilometres from the camp and have been recorded in 14 different locations in Towra Point Nature Reserve, including Kurnell dune forest and littoral rainforest (DECC 2008a). While there has been significant habitat loss in the area for flying foxes, the existing ecological corridors on Kurnell Peninsula have enabled them to continue using the surrounding habitats for shelter and forage. The coast banksia (*Banksia integrifolia*) and eucalypt trees at Towra Point are an important source of food for this species especially due to their close proximity to the maternal camp (Eby 2006). The grey-headed flying fox plays an important role in seed dispersal and pollination (Pallin 2000).

Table 15: Introduced mammals

Common name	Scientific name
Black rat	*Rattus rattus*
House mouse	*Mus musculus*
Brown rat	*Rattus norvegicus*
Red fox	*Vulpes vulpes*
Feral cat	*Felis catus*
Rabbit	*Oryctolagus cuniculus*
Domestic dog	*Canis familiaris*

Source: ALS (1977); DECC (2008a, 2009)

Table 16: Native mammals recorded since 1984

Common name	Scientific name
Common ringtail possum	*Pseudocheirus peregrinus*
Common brushtail possum	*Trichosurus vulpecular*
Grey-headed flying-fox	*Pteropus poliocephalus*
Gould’s wattled bat	*Chalinolobus gouldii*
Chocolate wattled bat	*Chalinolobus morio*
Greater broad-nosed bat	*Scoteanax rueppellii*
Little forest bat	*Vespadelus vulturnus*
Lesser long-eared bat	*Nyctophilus geoffroyi*
Bottle-nosed dolphin	*Tursiops truncatus*
Dugong	*Dugong dugon*

Source: DECC (2008a, 2009)

Introduced mammals are a threat to the native flora and fauna of Towra Point. Foxes disperse weeds and prey on many native species. Cats and dogs threaten native species such as rats, flying foxes, birds and amphibians by disturbance and predation. Towra Point is close to urban areas and provides easy access for domestic cats and dogs, and proposed developments close to the reserve will increase this threat. The black rat (*Rattus rattus*) is a threat to the little tern colony as it preys on eggs and hatchlings (NPWS 2003).

Birds

There are at least 189 species of birds which are supported by the different wetland types at Towra Point (ALS 1977) (Appendix D). For example, cormorants, herons and raptors prey on fish in seagrass meadows and in open water; shorebirds, royal spoonbills (*Platalea regia*) and ibis feed on invertebrates in intertidal and freshwater areas; the white-fronted chat, Lewin's rail and southern emu-wren use saltmarsh areas; terrestrial vegetation is used as foraging, roosting and nesting sites; a variety of species roost on sand spits, in mangroves and saltmarsh, and on oyster lease posts in the water (Figure 52).

The variety of vegetation types at Towra Point supports a diverse range of bird species. The nectar, berries, tree hollows and insects in the terrestrial zone provide a large number of birds, such as fairy martins (*Hirundo ariel*), honeyeaters, finches and fairy-wrens, with feeding, roosting and nesting habitat (SPCC 1979a). Towra Point, though surrounded by urban and industrial land, provides a relatively large area of protection and food resources, and assists part of the ecological connectivity of other areas such as Kamay Botany Bay National Park and the Royal National Park. Birds found at Towra Point, such as the masked owl and swamp harrier (*Circus approximans*), are natural predators of some disease-carrying pests such as the black rat (Schulz 2006). The white-fronted chat used to be found in a number of locations throughout Sydney but is now found only in two places: Sydney Olympic Park and Towra Point (Birds in Backyards 2006).

Towra Point is listed as an internationally significant wetland based on a number of criteria including its importance as a migratory shorebird habitat (criterion 4) (section 2.4). Towra Point also supports a number of threatened birds under the TSC Act and supports 34 out of the 80 species of birds listed under international agreements.

Even in the 1950s, while suitable shorebird habitat in Sydney was rare, Botany Bay supported several thousand individuals on the northern and southern shores during summer (Hindwood and Hoskin 1954). The north side of Botany Bay had considerable areas of saltmarsh and intertidal mudflats (Hindwood and Hoskin 1954). Since the 1950s these habitats have declined and most of the northern side of the bay is now unsuitable for shorebirds (Pegler 1997).

Different benthic sediment types and roosting areas along the entire shoreline of Botany Bay are favourable to a variety of shorebird species (SPCC 1979a). Sedimentation also plays an important role in forming habitat, such as intertidal areas that become rich with invertebrates, and sand spits which provide roosting and nesting sites. There are important shorebird habitats in close proximity to Towra Point in addition to those in the Ramsar site, including the Taren Point endangered ecological community on the north-western side of Woolooware Bay; on the rocky reef at Boat Harbour south-east of Towra Point; and in various places along the northern side of Botany Bay (Hindwood and Hoskin 1954). Shorebirds are sensitive to disturbance and if those roosting or feeding habitats are disturbed by, for example, boats, dogs or vehicles, the birds will use Towra Point as a refuge (SPCC 1979a).

Photos: Phil Straw

Figure 52: Habitats surrounding Towra Point being used by birds

Clockwise from top left: bar-tailed godwits foraging in mud; grey-tailed tattlers at Shell Point industrial area; royal spoonbill foraging in intertidal zone; whimbrel on oyster lease; white-bellied sea-eagle roosting in mangroves; pacific golden plover on Towra Spit Island

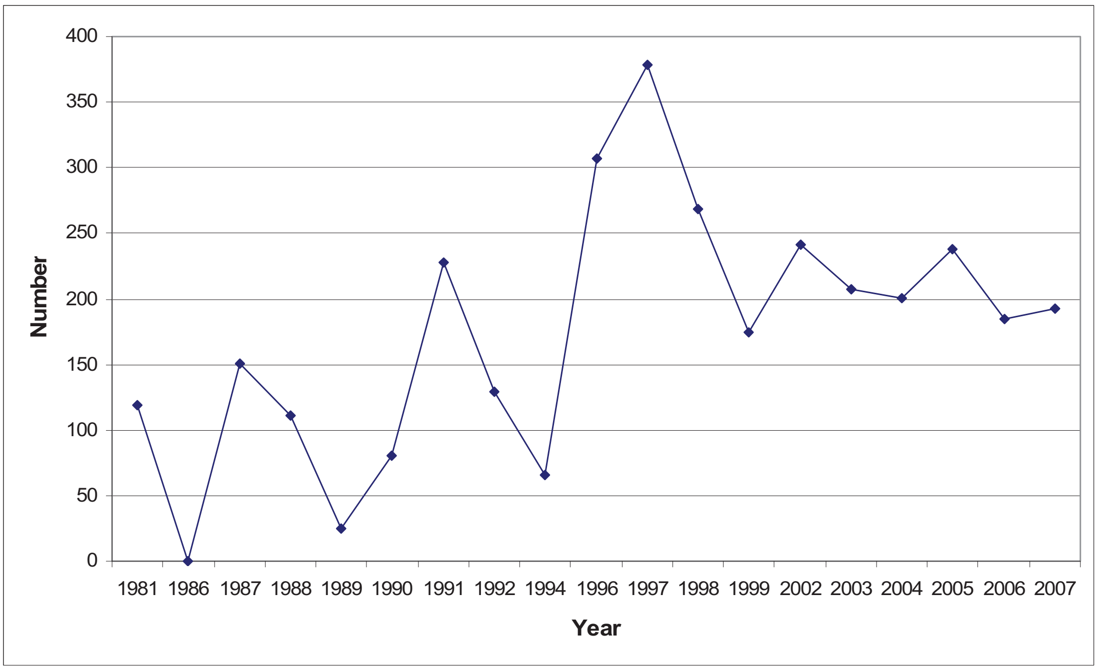
Changes in bird populations and habitats since 1984

In 1993, Botany Bay, including Towra Point, was identified as one of the four most important migratory shorebird habitats in NSW (NPWS 2001a). Towra Spit Island is the second most important little tern nesting site in NSW (NPWS 2001a). The NSW Wader Studies Group monitors shorebird populations at sites in Botany Bay. For other bird species, however, there is a knowledge gap. The Atlas of NSW Wildlife contains records of incidental sightings, and a fauna survey in 2008 recorded a number of birds (DECC 2008a, 2009). From the data available 116 species of birds have been recorded since 1984 (Appendix D). However, the results are not robust enough to set limits of acceptable change.

At the time of listing as a Ramsar site in 1984, Towra Point supported at least 1% of the estimated international population of eastern curlew. While the number of birds recorded at Towra Point has increased since then, the site no longer supports 1% of the international population due to an increase in the estimated population since 1984; 1% of the estimated population in 2002–04 was 380 individuals (Li Zuo Wei and Mundkur 2007; WSG 2007; Figure 53). Numbers of eastern curlew in Botany Bay have increased from an annual average of 131 over 1983–87 to 171 over 2004–08 (Birds Australia, unpublished data) (Table 17).

The dynamic nature of Botany Bay means that sediment is continually moving and anthropogenic changes to the natural structure of the bay have intensified and altered these movements. Towra Spit Island was formed around 1991 and joined Carters Island in 1997. While the land bridge provided extra roosting habitat for shorebirds, it was dredged in 2005 to prevent access by foxes and to replenish Towra Beach. A consequence of the removal of the land bridge was a loss of roosting habitat for shorebirds which has increased competition for space on Towra Spit Island (P. Straw 2007, pers. comm.). Foxes still remain one of the biggest threats to the birds on Towra Spit Island as they are able to access the island along the mudflats at low tide (NPWS 2003).

The only faunal endangered ecological community listed under the TSC Act is the Taren Point Shorebird Community on the north-western shoreline of Woolooware Bay. The mudflats in this area are different to those at Towra Point in sediment type and wave action (Roy and Crawford 1979), and most likely macro-invertebrates (Dexter 1984). They are a critical and unique source of food for a significant number of shorebirds (DECC 2005). Towra Point provides additional feeding and roosting areas for some of these birds, such as the bar-tailed godwit, pied oystercatcher and eastern curlew. However, birds such as the terek sandpiper (*Xenus cinereus*), ruddy turnstone and common greenshank have a strong site fidelity with the Taren Point environment and may be lost if the area degrades (SSEC 2007; WSG 2007).



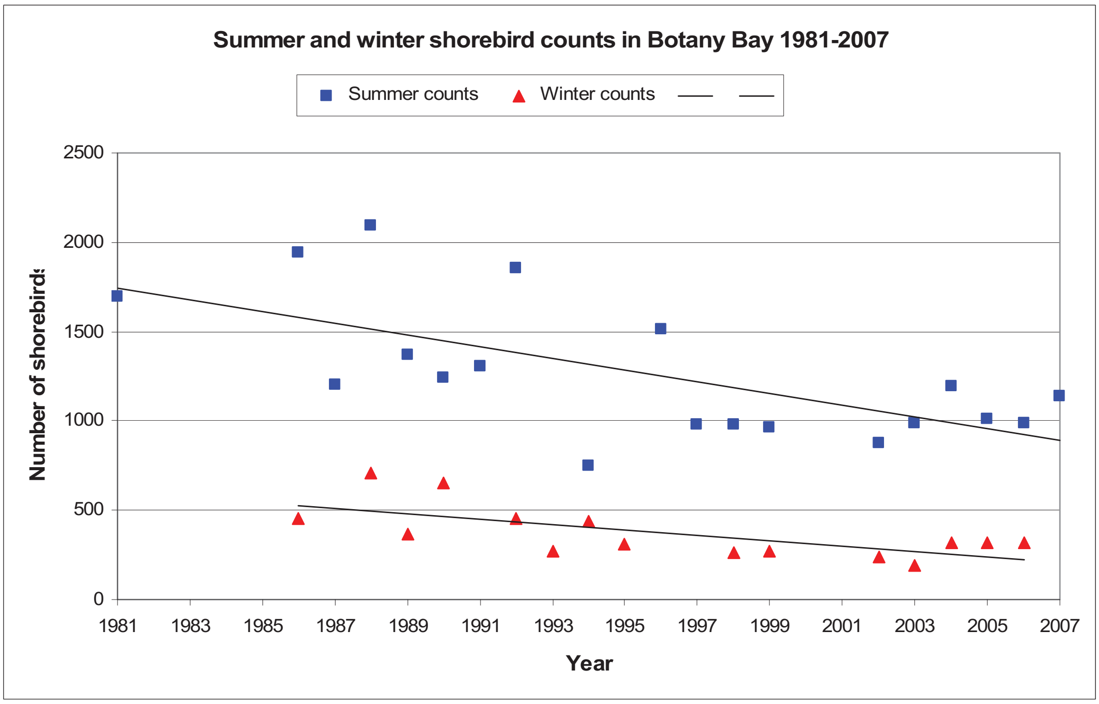
Adapted from WSG (2007) and AWSG (2008).

Figure 53: Eastern curlew numbers in Botany Bay in summer 1981–2007

Taren Point is mostly an industrial area, but future residential development would cause a loss of habitat and disturbance along the shoreline and removal of roosting sites, such as an old jetty and barge. Historically, the intertidal areas beneath the jetty and barge provided habitat for the birds that now use them as a substitute for roosting (Hindwood and Hoskin 1954; P. Straw 2007, pers. comm.). Birds such as the eastern curlew and pied oystercatcher forage around Towra Point and in the Georges River and Port Hacking. However, due to a lack of suitable roost sites in other areas, they rely on Towra Spit Island and oyster lease posts in Woolooware Bay and Quibray Bay (P. Straw 2007, pers. comm.).

The only major shorebird habitat on the northern side of Botany Bay is at Penrhyn Estuary, an artificial estuary on the western side of the Sydney container port (Pegler 1997). Penrhyn Estuary is under threat from anthropogenic disturbance, reduced flushing after the port extensions are completed and pollution from the surrounding heavy industries. The loss of shorebird habitat on the northern side of Botany Bay has placed pressure on Towra Point and Taren Point to continue to support these birds.

Bird numbers at Towra Point are highly variable from year to year and fluctuate with the seasons due to the large numbers of migratory species. The NSW Wader Study Group, with the assistance of DECCW, has collected monthly shorebird counts for Towra Point and other parts of Botany Bay since 1981. Initially counts at Botany Bay were taken to collect data for the Towra Point Nature Reserve plan of management (Morris 1985), and monitoring has continued since then. Since 1981 there have been fewer shorebirds in Botany Bay, with sharp declines in 1994 and 1995, which corresponds with habitat reclamation for Sydney Airport's third runway (Figure 54). While the total number of birds counted is decreasing, the numbers of some species, such as the eastern curlew, whimbrel and pied oystercatcher, have increased (Pegler 1997). Table 17 shows the changes in abundance of six shorebird species at Towra Point between 1983–87 and 2004–08.



Adapted from WSG (2007).

Figure 54: Shorebird numbers in Botany Bay 1981–2007

The abundance of shorebirds observed in Botany Bay over five year periods for both summer and winter has decreased significantly between 1983–87 and 2004–08 (Table 20). The annual mean number of shorebirds observed in summer (December–February), when migratory species are expected to have arrived, declined from 1668 in 1983–87 to 899 in 2004–08. The annual mean number of shorebirds in winter (June–September), when migratory species are generally in low numbers, declined from 915 in 1983–87 to 534 in 2004–08.

Little terns are listed as an endangered species in NSW (TSC Act) and, like other shorebirds, are sensitive to habitat type and disturbance. Since 1993, after their nesting site on the northern side of Botany Bay became an airport runway, Towra Spit Island became their most suitable nesting site in the Sydney area (NPWS 2003). While Towra Spit Island is outside the current Ramsar site boundaries, DECCW has proposed that it be included within the site as part of the 2010 RIS update. In addition, it is likely that the little tern nesting site is dependent upon supporting services of the Ramsar site. For example, the nesting site is susceptible to geomorphologic changes, vegetation encroachment and disturbance by people and pests, and these are limited by the buffer provided by the Ramsar site. Alternative nesting sites such as the Sydney Ports site and Penrhyn Estuary have been used in some years when Towra Spit Island was unfavourable (Keating and Jarman 2004). However, numbers of fledglings are lower there due to disturbance of the area by foxes, dogs and people (Phil Straw 2007, pers. comm.). The birds have a strong site fidelity and return to Towra Spit Island annually as a first preference (NPWS 2003).

The breeding site at Towra Spit Island is managed each year by DECCW to clear it of unsuitable vegetation and elevate certain areas to help protect the site from high tides and storms before the arrival of the little terns (Ross et al. 2003). Fox baiting prevent mortality. People are prohibited on Towra Spit Island and, during the little tern breeding season, weekend boat patrols by DECCW and the Towra Team help to

Table 17: Changes in abundance of selected shorebird species in Botany Bay

Species	Abundance at time of Ramsar listing (1983–87)	Current abundance (2004–08)
Eastern curlew	Mean no. over 5 years = 133 ± 77 (SD) [#] Towra Point supported at least 1% of global population of eastern curlew at time of Ramsar listing in 1984	Mean no. over 5 years = 171 ± 19 (SD) [&] Towra Point now supports less than 1% of global population as a result of overall increase in population
Bar-tailed godwit	Mean no. over 5 years = 609 ±189 (SD) [#]	Mean no. over 5 years = 306 ± 51 (SD) [&]
Whimbrel	Mean no. over 5 years = 14 ± 19 (SD) [#]	Mean no. over 5 years = 49 ± 9 (SD) [&]
Red-necked stint	Mean no. over 5 years = 288 ± 153 (SD) [j #]	Mean no. over 5 years = 168 ± 41 (SD) [j &]
Curlew sandpiper	Mean no. over 5 years = 221 ± 121 (SD) [j #]	Mean no. over 5 years = 4 ± 4 (SD) [j &]
Pied oystercatcher	Mean no. over 5 years = 17 ± 5 (SD) [j #] Towra Point and the southern shores of Botany Bay provide the most important breeding site for pied oystercatchers in the bay. [m]	Mean no. over 5 years = 46 ± 11 (SD) [j &] Pied oystercatchers use the southern shores of Botany Bay for breeding, as most of their suitable habitat on the northern shores has disappeared since the 1980s. [m]

Source: [g] AWSG (2008); [j] Birds Australia (unpublished data); [m] G. Ross (pers. comm.)
SD = standard deviation
* Limited data points: counts are for Botany Bay i.e. wider area than Ramsar site
[#] Mean of highest counts in summer (December–February) for 1983–87
[&] Mean of highest counts in summer (December–February) for 2004–08

control disturbance and to educate people about the significance of the site. Little tern banding and monitoring of nests, eggs and fledglings have been facilitated by DECCW since 1993 and assist in long term research and management (Keating and Jarman 2004) (Figure 55).

A deep artificial lagoon adjacent to Woolooware Bay named the H1 wetlands was used as a sandmining pit until the 1980s. The site had become a deep saline lake and was assessed as a potential shorebird habitat after infilling and vegetation clearing (SSEC 2004a). Work was carried out to make the lake shallow and to create small islands for bird habitat. Initially the site was used for feeding and roosting by a number of birds including the musk duck (*Biziura lobata*), bar-tailed godwit, eastern curlew, common greenshank, red knot (*Calidris canutus*) and sharp-tailed sandpiper (*Calidris acuminata*) (P. Straw 2007, pers. comm.). Due to a lack of management resulting in vegetation growth over the tidal mudflats, the site became unfavourable to many of the birds which abandoned the site. H1 is still used for roosting by eastern curlew and common greenshank and for nesting by pied oystercatchers and black-winged stilts (*Himantopus himantopus*) (P. Straw 2007, pers. comm.). This demonstrates the importance of ongoing management of bird habitat and how birds are sensitive to habitat. The existing suitable habitat around Towra Point is critical due to the lack of alternative areas available.

5.5.3 Limits of acceptable change for biota

The biota of Towra Point Nature Reserve is what makes the wetland internationally significant. There are large short-term natural variations in flora and fauna, such as bird numbers. However, in order to sustain the biodiversity of the area, there should be no long-term loss of species. A number of knowledge gaps have been presented in the previous sections in relation to fauna surveys, and limits of acceptable change cannot be accurately set without a more robust dataset, with the exception of birds (see below). The significance of Towra Point Nature Reserve reflects the health of the flora and fauna that it supports. Surveys of fauna and flora populations every five to 10 years would improve the accuracy of limits of acceptable change and increase the efficiency of management actions. The current condition (where known) of critical ecosystem components at Towra Point is provided in Tables 18–21.

Photo: Phil Straw

Figure 55: Banded little terns

Table 18: Limits of acceptable change for biota

Critical component, process or service		Baseline condition at time of Ramsar listing in 1984	Limit of acceptable change	Confidence in LAC	Current condition (based on most recent data)
Seagrass	*Posidonia australis*	188 ha [d]	No net loss of seagrass area	Low	209 ha [f]
	Zostera capricorni	328 ha [d]	No net loss of seagrass area	Low	104 ha [f]
	Halophila ovalis	Unknown	Knowledge gap		13 ha [f]
	Mixed *P. australis* *H. ovalis*	Unknown	Knowledge gap		106 ha [f]
	Mixed *Z. capricorni* *H. ovalis*	Unknown	Knowledge gap		26 ha [f]
Mangroves		395.2 ha [e]	No decrease in area of more than 10% over 5 consecutive years	Low	385 ha [f]
Saltmarsh		141 ha [e]	No decrease in area of more than 10% over 5 consecutive years	Low	134 ha [f]
Mixed mangrove and saltmarsh		55 ha [e]	No decrease in area of more than 10% over 5 consecutive years	Low	9 ha [f]
Macro-invertebrates		5883 individuals of 206 species [a]	Knowledge gap – insufficient information on natural variability of this component to establish LAC		Insufficient data
Fish		Unknown	Knowledge gap - insufficient data to establish LAC. If adequate habitat (mangroves, saltmarsh and seagrass) is available, fish can be considered against LAC for mangroves		Insufficient data

Source: [a] ALS (1977); [c] NPWS (1989); [d] Watford and Williams (1998); [e] Wilton (2002); [f] DPI (2009); [h] Schulz (2006)

Table 19: Limits of acceptable change for nationally endangered species

Critical component, process or service	Baseline condition at time of Ramsar listing in 1984	Limit of acceptable change	Confidence in LAC	Current condition (based on most recent data)
Magenta lilly pilly	Occurs in littoral rainforest in Towra Point Nature Reserve. Recorded from Towra Point in 1977, 1980 and 1986.	No loss of species	Medium – need to confirm presence with vegetation survey of NR	Insufficient data – no recent vegetation surveys of nature reserve undertaken
Green and golden bell frog	Six records of green and golden bell frog from 1977[a]	Species recorded every year or when surveys undertaken	Low – regular surveying to determine presence or absence not currently undertaken	Green and golden bell frog recorded from Towra Causeway and Towra Swamp since 1984 [h i]
Grey-headed flying fox	Condition in 1984 not known. Recorded from Towra Point Nature Reserve in 2006 Roosting site for species is close to Towra Point Nature Reserve.	No loss of species	Medium – need to confirm presence with regular surveys	14 records from Towra Point Nature Reserve in 2006 – average of 7 individuals per record

Sources: [a] ALS (1977); [h] Schulz (2006); [i] DECC (2009)

Table 20: Limits of acceptable change for shorebirds

Critical component, process or service	Baseline condition for Botany Bay at time of Ramsar listing (1983–87)	Limit of acceptable change	Confidence in LAC	Current condition (based on most recent data)
Abundance of shorebirds in summer (December–February)	Mean of maximum summer counts for shorebirds in Botany Bay for 1983–87 period is 1668 ± 472 (SD) [j @] Counts for shorebirds in Botany Bay have been used – not possible to restrict counts to Towra Point Ramsar site, as birds use other areas of suitable habitat in the bay. Counting effort is not always consistent between years, so annual counts vary considerably over the five year period.	Decline of no more than 50% from baseline condition for Botany Bay (1668 ± 472) in 5 consecutive years (to account for temporal variation).	Low*	Mean of maximum summer counts for shorebirds in Botany Bay for 2004–08 period is 897 ± 112 (SD) [j @]
Diversity of shorebirds in summer (December–February)	27 species recorded over 5 years 1983–87 [j]	No net loss of species over 5 consecutive years (to account for temporal variation)	Low*	26 species recorded over 5 years 2004–08 [j] Four species recorded in 1983–87 were not present in 2004–08: broad-billed sandpiper, Latham's snipe, pectoral sandpiper and oriental plover. Three species recorded in 2004–08 were not present in 1983–87: sanderling, wandering tattler and common sandpiper (*occasional records only – maximum of 1–3 individuals of each species per annum*)

Critical component, process or service	Baseline condition for Botany Bay at time of Ramsar listing (1983–87)	Limit of acceptable change	Confidence in LAC	Current condition (based on most recent data)
Abundance of shorebirds in winter (June–August)	Mean of maximum winter counts for shorebirds in Botany Bay for 1983–87 period is 604 ±148 (SD) [j] Counts for shorebirds in Botany Bay have been used – not possible to restrict counts to Towra Point Ramsar site, as birds use other areas of suitable habitat in the bay. Counting effort is not always consistent between years, so annual counts vary considerably over the five year period.	Decline of no more than 50% from baseline condition for Botany Bay (604 ± 148) (SD) in 5 consecutive years (to account for temporal variation).	Low*	Mean of maximum winter counts for shorebirds in Botany Bay for 2004–08 period is 391 ± 45 (SD) [j]
Diversity of shorebirds in winter (June–August)	23 species recorded over 5 years 1983–87 [j]	No net loss of species over 5 consecutive years (to account for temporal variation)	Low*	20 species recorded over 5 years 2004–08. [j] Four species recorded in 1983–87 were not present in 2004–08: great knot, greater sandplover, lesser sandplover and sanderling. One species not recorded in 1983–87 was present in 2004–08 – common sandpiper (*occasional record only*)
Eastern curlew	Mean of maximum summer counts over 5 years = 133 ± 77 (SD) [#] Towra Point supported at least 1% of global population of eastern curlew at time of Ramsar listing in 1984	Decline of no more than 50% from baseline condition for Botany Bay (133 ± 77) in 5 consecutive years.	Low*	Mean of maximum summer counts over 5 years = 171 ± 19 (SD) [&] Towra Point now supports less than 1% of global population as a result of increases in population elsewhere

Source: [g] AWSG (2008); [j] Birds Australia (unpublished data); [m] G. Ross (pers. comm.)

SD = standard deviation

* Limited data points; counts are for Botany Bay i.e. wider area than Ramsar site

[#] Mean of highest counts in summer (December–February) for 1982–83 to 1986–87

[&] Mean of highest counts in summer (December–February) for 2003–04 to 2007–08

[@] Abundance and diversity of shorebirds in summer are from maximum counts for five years from December 1982-February 1983 to December 1986-February 1987, and for five years from December 2003-February 2004 to December 2007–February 2008

Table 21: Limits of acceptable change for little tern (*Sterna albifrons*)

Critical component, process or service	Baseline condition at time of Ramsar listing in 1984	Limits of acceptable change	Confidence in LAC	Current condition (based on most recent data)
Little tern – breeding numbers	Towra Spit Island, formed by changes in wave action in Botany Bay in 1991, is proposed for addition to Ramsar site. Little terns regularly use Towra Spit Island for nesting. Much of their previous habitat on northern shores of Botany Bay has been destroyed by development. As Towra Spit Island did not exist at time of Ramsar listing in 1984, no baseline condition can be set.	Successful annual breeding in one out of every two years	Low–medium[#]	**2009–10** No nests, eggs, hatchlings or fledglings recorded [k #] **2008–09** 50 nests 125 eggs 65 hatchlings 50 fledglings [k #] **2007–08** 30 nests 53 eggs 27 hatchlings 21 fledglings [k #]

Source: [j] Birds Australia (unpub. data); [k] DECCW (unpublished data)

[#] Little tern counts are from Towra Spit Island i.e. outside Ramsar site's current boundaries. Little terns may sometimes nest in other areas around Towra Point which are not accessible to observers, affecting the total count in some years e.g. 2009–10. Towra Spit Island is usually preferred by little terns as it provides greater security for nesting and breeding.

Birds

Waterbird populations may undergo large annual fluctuations, reflected both in their abundance and in their diversity. Counts of shorebirds in Botany Bay have been made twice yearly (in summer and winter) since 1981 by the Australian Waders Study Group, and indicate that the number of individuals and number of species recorded is variable. For the five years 1983–87 the annual mean number of shorebirds in summer (December–February) was 1668, ranging from 1205 to 2049; and for 2004–08 the mean number was 899, ranging from 751 to 1017 (Table 20).

The diversity of shorebird species in Botany Bay also varies from year to year. The number of shorebird species recorded each year in summer ranged from 16 to 22 over 1983–87, and from 17 to 23 over 2004–08 (Table 20). Four species recorded in summer in 1983–87 (from a total of 27 species recorded over that period) were not present in 2004–08: broad-billed sandpiper, Latham's snipe, pectoral sandpiper and oriental plover. Three additional species were occasionally recorded in 2004–08 which were not present in 1983–87: sanderling, wandering tattler and common sandpiper.

The data for shorebirds collected since 1981 indicates that the total number of shorebirds recorded in Botany Bay has been declining since Towra Point Nature Reserve was listed as a Ramsar site in 1984 (WSGF 2007) (Figure 54). The decline in Botany Bay appears to be part of an overall decline in shorebird species across a wider region, as counts of individual species for south-east Australia have generally declined, such as for bar-tailed godwit, curlew sandpiper, eastern curlew (despite increasing in Botany Bay) and sharp-tailed sandpiper (Gosbell and Clemens 2006).

A limit of acceptable change for shorebirds is proposed based on studies of the reliability of monitoring data for waterbirds (Atkinson et al. 2006; Haslem et al. 2008). A limit of acceptable change needs to be sufficiently robust to account for missing data and incorporate the number of sampling events used in its determination, as well being applicable to a wide variety of species. For single sites (that is, where data is not aggregated from several counting sites) three or more counts within the monitoring period must be used in order to obtain reliable estimates of population change (Atkinson et al. 2006).

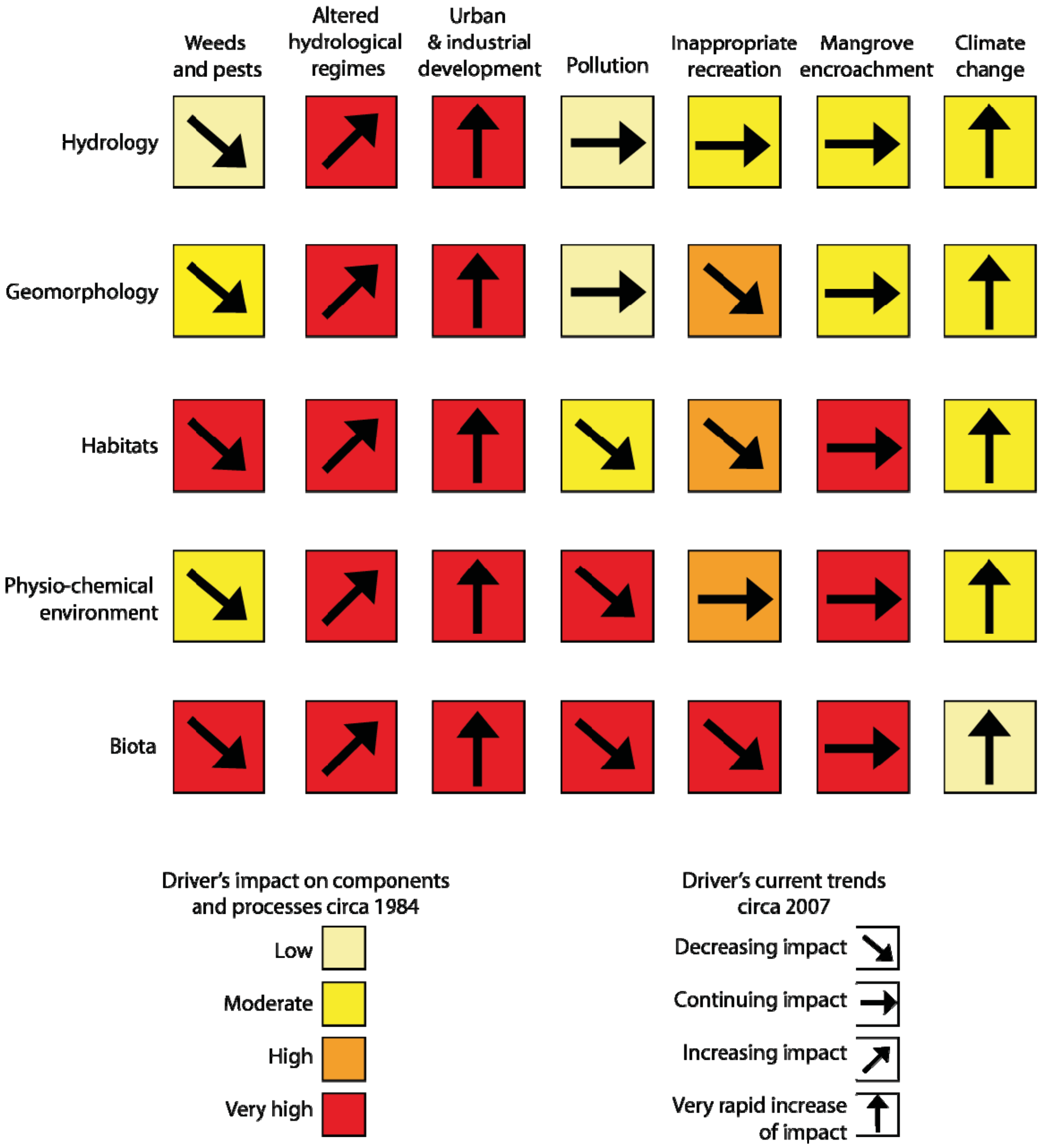
The limits of acceptable change for shorebirds at Towra Point are based on five consecutive years of counts both for total number of shorebirds and for diversity of species in Botany Bay. The counting sites in Botany Bay include Towra Point and Weeney Bay within the Ramsar site, locations close to the Ramsar site (Kurnell, H1 wetland, Quibray Bay, Taren Point and Boat Harbour), and several locations on the northen and western shores of the bay (Lady Robinson's Beach, Penrhyn Road and Riverside Drive). Tables 20 and 21 detail limits of acceptable change for shorebirds in Botany Bay, plus an assessment of the confidence of each limit of acceptable change, as follows:

- all shorebirds – summer counts of number of birds and number of species
- resident shorebirds – winter counts of number of birds and number of species
- eastern curlew
- little terns – breeding success on Towra Spit Island.

While the limit of acceptable change for shorebird diversity – no net loss of species since time of Ramsar listing – has been exceeded, further analysis is required to understand the change in species composition and to improve the confidence in this limit of acceptable change.

6 Threats to ecological character

A number of factors at Towra Point Nature Reserve and in the surrounding catchment areas threaten to adversely alter the ecological character of Towra Point. Figure 56 outlines the key threats to Towra Point and is followed by a brief description of each threat.



Adapted from Millennium Ecosystem Assessment (2003)

Figure 56: Threats to Towra Point Nature Reserve Ramsar site

6.1 Weeds

Along with pests, weeds are one of the biggest threats to Towra Point Nature Reserve and surrounding areas. Due to clearing of Towra Point for grazing and timber in the 1800s, weeds were able to colonise the area. Towra Point contains at least eight weeds listed under the *Noxious Weeds Act 1993*, four of which are weeds of national significance. As the landowner, DECCW is obliged to control weeds at Towra Point. A Weed Management Strategy has been prepared for 2007–2012 (WODEC 2007). Although a formal peninsula-wide strategy has not yet been developed, DECCW and Sutherland Shire Council are working closely with landowners to coordinate a holistic approach to management of weeds.

Towra Point is not accessible to visitors and this has helped prevent the spread of weeds. However, foxes, birds, horses, dogs, boats and vehicles can also disperse weed seeds (NPWS 2001a; WODEC 2007). Volunteer groups such as The Friends of Towra Point and Botany Bay Busy Bees, along with DECCW and NSW Maritime, are involved in bush regeneration in the area, which mainly involves weed control, which is a key activity in protecting the biodiversity of Towra Point. Volunteers from a weekend detention centre are trained in horticulture and undertake weed control and native plant propagation at Towra Point in conjunction with the Georges River Combined Council Committee (P. Annabel 2007, pers. comm.). Other groups involved in weed removal and native bush regeneration include Conservation Volunteers Australia, the Towra Team and corporate volunteers including Westpac and Toyota.

The biggest weed threats to the flora and fauna of Towra Point are bitou bush, lantana and caulerpa (*Caulerpa taxifolia*), and are described below. Other weeds of concern include spiny rush, blackberry (*Rubus* spp.), prickly pear (*Opuntia stricta*), pampas grass (*Cortaderia selloana*), African olive (*Olea africana*), African box-fern (*Lycium ferocissimum*) and asparagus fern (*Asparagus sprengeri*) (NPWS 2001a).

Bitou bush

Bitou bush is a key threatening process (TSC Act) and poses the biggest threat to coastal ecosystems in NSW, including Towra Point (DEC 2006b). This introduced species grows in dense shrubs and spreads rapidly, suffocating native plants, preventing native seed propagation and threatening biodiversity. Birds and foxes are the main vectors for dispersal, with wind and water the next most important mechanism (WODEC 2007).

Bitou bush is found throughout Towra Point with high density areas along Towra Beach, on the western side of Towra Point, along the southern shores of Quibray Bay near the horse stables and throughout the Kurnell dune forest (WODEC 2007). It is a major threat to the endangered ecological communities at Towra Point, including the small stand of littoral rainforest and Kurnell dune forest. Loss of native flora will have significant negative impacts on the native fauna of Towra Point due to loss of food and nesting areas and may lead to a loss of species. Some fauna may have adapted to the protection of bitou bush or use it as a food source in the absence of native flora and care must be taken when removing it and choosing native flora to replace it (DEC 2006b).

A State-wide threat abatement plan for bitou bush from 2006 to 2011 makes this species a top priority for management at Towra Point under the weed management strategy (WODEC 2007). DECCW is implementing this strategy and has prepared a bitou bush site management plan to assist the long-term eradication of bitou bush. Ground spraying of glyphosphate has been used as a method of broad-scale weed control in conjunction with other control measures such as hand removal of weeds and bush regeneration (Figure 57). Similar control methods are being undertaken on Kurnell Peninsula by DECCW and Sutherland Shire Council.

Lantana

Lantana is a weed of national significance and forms dense growth that eliminates native plant species and threatens biodiversity. Spread mainly by birds and insects, it has infested over four million hectares in Australia and has been named one of the world's worst weeds (ARMCANZ et al. 2000).

Lantana is widespread throughout Towra Point Nature Reserve, including the endangered ecological communities such as Kurnell dune forest and littoral rainforest (WODEC 2007). By 1990, almost 75% of vegetation at some parts of Towra Point was lantana, with a particularly bad infestation at Weedy Pond (SSEC 2004b). In 1996 the Friends of Towra Point Nature Reserve and other volunteer groups, funded by Coastcare, began lantana and other weed control strategies, and the work is ongoing. Much of the weed control technique has been removal by hand and with the use of herbicide (SSEC 2004b).

Caulerpa

Caulerpa is a seaweed native to warm, tropical waters including tropical Australia and the South Pacific. Caulerpa was first recorded in NSW in Port Hacking in April 2000 and has now been found in 13 NSW estuaries or coastal lakes, including Botany Bay (DPI 2007a). It is a Class 1 noxious species in NSW (FM Act) and it is illegal to possess or sell the species. Caulerpa has the potential to threaten other seagrasses by its invasive nature of forming dense meadows. A chemical produced by caulerpa prevents epiphytic algae growth which reduces available food for grazers (Street 2007).

Caulerpa uses light and nutrients for growth, as do other seagrasses. However, caulerpa increases in height under low light conditions thereby out-competing other seagrasses. Caulerpa may be able to use organic matter in the sediment for growth when the light is inadequate (Street 2007).

Photo: K. Brennan 2007

Figure 57: Bitou bush control

The initial introduction of caulerpa into NSW estuaries may have been the result of releasing aquarium contents into the waters and further transport is made possible by boats and fishing vessels. Caulerpa can survive out of water for up to 10 days and is a fast growing, highly adaptable species. In the surrounding waters of Towra Point Nature Reserve caulerpa grows in the seagrass meadows (Figure 58).

Recommended actions for weeds

A weed management strategy for Towra Point was prepared in 2007 (WODEC 2007). Implementation of this strategy will be followed by a review at the completion of the strategy. Ongoing weed management is critical in reducing the threat to biodiversity of the area and an integrated weed management strategy for Kurnell Peninsula, along with private landowner cooperation, is the next critical step of protection (WODEC 2007).

I&I NSW continues to monitor NSW estuaries, including Botany Bay, for the presence and distribution of caulerpa. A number of control methods have been tested, such as dredging, handpicking, smothering and salt application, the latter being the most effective. However, due to the scale of infestations, management focus has shifted to preventing further introduction of this species into new areas (DPI 2007a). Research is ongoing in several areas affected by caulerpa to further the understanding of the impacts of this invasive species on native seagrasses and habitats. Ongoing research is being undertaken in conjunction with education programs by I&I NSW to advise the community about how to prevent the spread of this invasive weed (M. Walker 2007, pers. comm.). As the surface temperature of the sea increases, temperate areas will become more favourable for growth of tropical seagrass species (Poloczanska 2006a), such as caulerpa, which may expand its distribution.

6.2 Pests

Pest animal species at Towra Point include introduced and native species, such as foxes, cats, ravens, rabbits, gulls, ants and the black rat. Foxes are the biggest threat to native birds and mammals. With Towra Point being so close to urban areas, cats also pose a threat, especially to species that use habitat fragments of urban areas to move between habitats. Ravens, gulls, rabbits, ants and rats are a threat to shorebird communities, in particular little tern and pied oystercatcher eggs and chicks (NPWS 2003).

Towra Point is listed as a high priority site for fox control due to predation on the little tern and pied oystercatcher (NPWS 2001b).

Some pest species are controlled by biological measures, such as by predation on rats, for example by swamp harriers and whistling kites. However, species-specific control measures, such as trapping and baiting to reduce numbers, are applied (NPWS 2003). A number of landowners across Kurnell Peninsula are developing an integrated weed and pest management strategy which will increase the effectiveness of control.

Recommended actions for pests

Habitat fragmentation may increase the impact of foxes due to their concentration in smaller areas. Control of foxes must be coupled with monitoring of native species and pest populations, since a reduction in foxes may increase the presence of other introduced predators such as rabbits or cats (NPWS 2001b). The most effective control measure for foxes is the use of the toxin sodium mono-fluoroacetate (1080) inside meat bait. Other control measures include trapping, shooting and den fumigation (NPWS 2001b).

Figure 58: Distribution of caulerpa in southern Botany Bay

As part of the NSW Fox Threat Abatement Plan, the Parks and Wildlife Group of DECCW conducts its fox baiting program in Kurnell Peninsula, including Towra Point, from September to March. The program is timed to coincide with the little tern and pied oystercatcher breeding seasons when foxes are the biggest threat. A proposed integrated weed and pest management strategy for the future will see DECCW, Sutherland Shire Council, other government agencies and private landowners using fox control measures throughout Kurnell Peninsula to increase the success of fox eradication (A. Bianchi 2007, pers. comm.).

During the little tern nesting period at Towra Spit Island between September and March additional control of threatening species is carried out. Species such as the Australian raven (*Corvus coronoides*) and ants are monitored and managed according to predation on eggs and chicks (NPWS 2003).

6.3 Altered hydrology

Any alteration of the natural hydrology over the entire catchment will have an effect on the ecological character of Towra Point as hydrology is a major ecosystem driver. Dredging, land reclamation, water harvesting and catchment land use will cause a change in how water moves through the system. In Towra Point Nature Reserve an analysis of the effect of the causeway through the main saltmarsh area on drainage and water flow is needed. The track was constructed in 1952 and removal or reconstruction of the track will likely change the hydrology at Towra Point and may influence other components and processes.

Dredging

Dredging in Botany Bay in the 1960s and 1970s caused ongoing detrimental effects to Towra Point by altering wave patterns. This increased the erosion rate at Towra Beach and changed sedimentation patterns. Future developments on Kurnell Peninsula have proposed dredging in Botany Bay which will again alter the bay's hydrology. There are two certain and immediate projects that involve dredging of Botany Bay; the first is a desalinated water distribution pipeline for Sydney Water and the second is two underground electricity cables for Energy Australia.

Dredging not only affects wave patterns, it changes the way in which water moves throughout the system, therefore changing the physicochemical processes and sedimentation patterns. A change in the seabed changes the benthic macro-invertebrates and plants, which affect higher trophic levels.

The seagrass meadows in Botany Bay are relatively large for the Sydney area and are sensitive to turbidity. They are a critical component of the Towra Point ecosystem as they protect the shoreline from erosion, provide shelter for juvenile fish and crustaceans and assist in nutrient and energy transfer. The proposed projects will affect this important habitat adjacent to Towra Point both directly, by dredging for the laying of pipeline and cables, and indirectly, by sediment plumes during construction and future maintenance. Sediment plumes have been modelled for the desalination plant pipeline (CLT 2007). Seagrasses stabilise the seabed and reduce the effects of waves, and a reduction in seagrass area could have a deleterious effect as the effects of waves on the area increase (Larkum 1976).

The environmental assessment for the Botany Bay cable project for Energy Australia states that 80 threatened species are within six kilometres of the cable site, one of which, the black cod, resides in the area. Therefore, dredging may cause loss or change of habitats and may lead to loss of species (MS 2007).

Inappropriate water use

Groundwater extraction, sandmining and water harvesting can be carried out sustainably. However, inappropriate water use is a major threat to Towra Point and surrounding areas.

Sandmining since the 1930s has exposed the southern part of Botany Sands Aquifer, increasing the risk of groundwater contamination and increasing the rate of evaporation of the groundwater. Groundwater-dependent wetlands throughout Kurnell Peninsula are now rare, possibly due to a lowering of the height of the water table. The loss of wetland habitats has reduced the biodiversity of the area, as wetlands are favourable to many bird, fish, and frog and turtle species.

Changes in the way water is extracted from the system, either by groundwater extraction or water harvesting, will alter the surrounding environment and threaten the organisms in the area.

Recommended actions for altered hydrology

Careful consideration and planning of proposals to change the hydrology of the Georges River and Botany Bay must be taken. Modelling the effects of future proposals gives an estimate of the extent of change and must not be underestimated. Where possible, alternative options to alteration of hydrological regimes should be investigated thoroughly.

6.4 Urban and industrial development

The Georges River and Botany Bay catchment area is home to approximately 1.5 million people with future growth predicted (Colman and Hopkins 2001). Urban expansion and industrial development poses a major threat to ecological communities, as it places pressure on all aspects of the natural environment. Development increases the area covered by hard surfaces, which increases runoff into the waterway. Loss of bushland and permeable surfaces affects natural hydrological regimes, such as groundwater recharge, and increases water flows, especially after rainfall. The loss of these areas prevents infiltration of runoff through the soil, which increases sediment, nutrient and contaminant load and volume of water into the waterway, thereby reducing water quality.

Clearing of land for urban and industrial development causes loss of habitat for native plants and animals which can have a significant detrimental effect on the many threatened species in the catchment, and fragmentation of bushland and reserves hinders movement of species and reduces genetic biodiversity. While some developers revegetate after clearing and building, if inappropriate plants are used, species may be lost.

Taren Point Shorebird Community is an endangered ecological community protected under the TSC Act. However, the adjacent lands are privately owned and are under pressure for residential development and construction of recreational facilities. The shorebird community is under severe threat if residential development is approved, as loss of habitat and increased disturbance is likely. The benthic fauna at Taren Point and Shell Point are unique to the area and are specific feeding habitats for a number of shorebird species (DECC 2005). Site managers are under pressure to remove an old jetty and barge; these structures are important roosting sites for a number of shorebirds. Loss or degradation of this habitat may result in loss of species, and increase competition for and pressure on habitat at Towra Point.

Recommendations for urban and industrial development

Best practice for development includes the maintenance of habitat corridors; prevention of habitat loss and revegetation of pre-development flora is critical in the protection of biodiversity. Water-sensitive urban design improves an ecosystem's ability to cope with increasing population pressures. Sutherland Shire Council has applied a stormwater management development control plan to improve water quality for new and existing developments. The implementation of stormwater quality improvement devices throughout the catchment will reduce pollution entering the waterway. Other programs such as Sydney Water's 'SewerFix' will increase the capacity of wastewater treatment plants and improve the quality of sewer overflows (SWC 2007a). Community education and awareness plays an important role in protecting the environment by increasing the value people place on natural areas and reducing some of the negative impacts they cause.

Suitable bird habitat away from disturbance should be established before the clearance of existing structures or development of sensitive areas. For example, if development along Taren Point were to occur, alternative habitat for birds may include high tide roost posts and structures in Woolooware Bay (P. Straw 2007, pers. comm.). Protection of existing mudflats and intertidal areas is critical for the biodiversity of the area as they support many species of fish, macro-invertebrates and birds.

6.5 Pollution

Towra Point Nature Reserve is in a severely impacted catchment (Heap et al. 2001). Although most of the catchment is bushland, parkland or rural, urban and industrial areas are located adjacent to the waterway, and the industries in the catchment, such as the Caltex oil refinery and Kurnell Landfill Company, are potential sources of major pollution. The permeable soils and shallow water table makes the Botany Sands Aquifer vulnerable to contamination which poses a threat to the ecological character of Towra Point. Surface water may be affected by hydrocarbon contamination of groundwater at the oil refinery and nutrient and metals contamination from the landfill site as well as from urban and industrial runoff. Pollution from the oil refinery and landfill are contained on site and strict monitoring and reporting measures are a requirement. However, the potential to affect Towra Point is high due to drainage patterns of the sub-catchment and proximity to the wetland.

Sydney Ports is located on the northern side of Botany Bay, east of Sydney Airport. In the 2006–07 financial year, more than 1,600 trading vessels, including at least 240 tankers, visited Botany Bay, the majority of which were container and bulk liquid carrying vessels (SPC 2007). These vessels have the potential to bring introduced or pest species into Botany Bay and increase the risk of an oil spill.

A wharf which extends one kilometre north-west from Silver Beach into Botany Bay was built in 1956 for the Caltex oil refinery to transport crude oil from ships to the refinery. About 50% of airline fuel required at Sydney Airport is transported from the wharf via an underground pipeline. Between 1957 and 1988, 31 spills of more than one barrel (169 litres) were recorded, including a spill of 95 tonnes (95 kilolitres) in 1979 (Figure 59) (McGuinness 1988). There is a risk of oil pollution at Towra Point from faulty pipes or spills from oil tankers. Due to the ecological importance of Towra Point and NSW regulations, contingency plans, adequate equipment, trained staff and an oil spill response atlas are provided in the event of an emergency (Caltex 2007). Sydney Ports Corporation is responsible for responding to oil and chemical spills in Botany Bay and NSW Maritime conducts training courses and maintains the database.

A fish kill is 'any sudden and unexpected mass mortality of wild or cultured fish' and can result from natural causes, such as disease or change in salinity, or by anthropogenic influences, such as a change in the physicochemical environment caused by pollution (Lugg 2000). There are three records of fish kills in Botany Bay before 1984 (McGuinness 1988) (DPI 2007b):

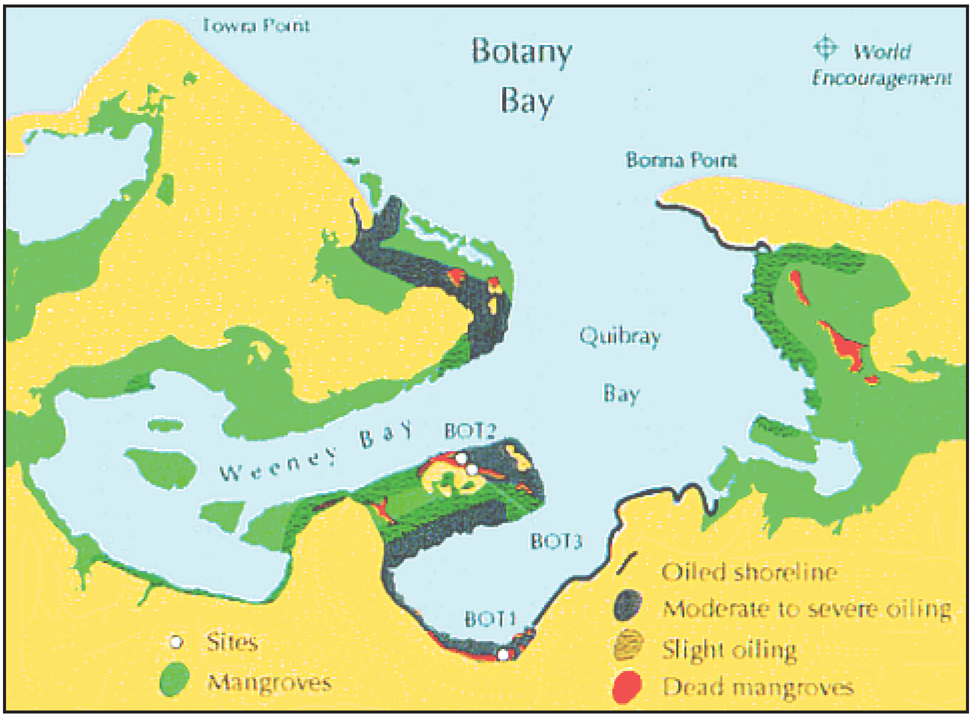
- in 1972, caused by an unknown source (it was presumed to be low temperature)
- in 1973, caused by a cyanide leak into the Cooks River
- in 1979, caused by a 95-tonne oil spill from the *World Encouragement*.

It is likely that there were other fish kills which were not recorded. Reporting of fish kills since 1984 has increased and the NSW Fisheries Fish Kill database has seven fish kills between 1998 and 2004 recorded. Causes of these kills are mostly unknown, however some were due to undersized by-catch dumped from fishing vessels or fish washed ashore by strong winds (DPI 2007b).

Other forms of pollution that are a risk to Towra Point include surface runoff from the catchment and sewer overflows. Excess nutrients and toxic chemicals have an influence on any ecosystem, including higher risk of algal blooms and eutrophication and poisoning of plants and animals from high levels of copper, zinc and lead. Towra Point is affected by runoff from urban and industrial areas which regularly exceed water quality guidelines for ammonia, total nitrogen, suspended solids, copper and lead (SSC 2002, 2004). The northern side of Botany Bay is heavily industrialised by polluting industries. However, due to the nature of the aquifer and the semi-diurnal tidal patterns, impacts on Towra Point have so far been minimal.

Recommended actions for pollution

Prevention of pollution is most effective at the source. Therefore, if industries and land owners in the catchment improve effluent and runoff quality, the threat of pollution will be reduced. Water-sensitive urban design and stormwater quality



Source: Duke and Burns (1999)

Figure 59: Oil spill from the *World Encouragement* in 1979

improvement devices assist in filtering out sediments and pollutants from runoff. Sydney Water is improving wastewater treatment plants along the Georges River, and some councils are increasing the number of gross pollutant traps and water sensitive urban design features within their jurisdiction. Kurnell Landfill Company and Caltex oil refinery have strict regulations on effluent quality and must report results quarterly. In the event of an oil spill, contingency plans are in place to reduce the effect on the area and training exercises are organised and coordinated by NSW Maritime.

6.6 Inappropriate recreation

The Botany Bay area is a popular place for recreation, including fishing, swimming, boating, bird watching and bike riding (SPCC 1978b). Certain activities, such as destruction of habitat and disturbance of important bird habitat, have a negative effect on the biota at Towra Point (NPWS 2001a). Motorbike riding, boating, use of four-wheel drive vehicles, and horse-riding can damage native vegetation and spread weeds. Litter and fires are also a risk related to inappropriate recreation. There is only one area at Towra Point available for recreation which is located on the western side of Towra Point, where permanent buoys are located to allow boats to moor without damaging seagrasses due to anchoring. The rest of the nature reserve is accessible by permit only.

Shorebirds are particularly sensitive to disturbance, some more than others (Blumstein et al. 2003), and people, dogs, horses, vehicles and boats may cause the site to become unfavourable for these birds (NPWS 2003). Towra Spit Island is an important nesting site for little terns and a roosting site for other migratory shorebirds between September and April (NPWS 2003). Signage on the island and boat patrols by rangers and volunteers prevent disturbance of the site. Increasing urban and industrial development in the area threaten to change habitats and put pressure on shorelines. For areas around Taren Point and Shell Point, development and increased disturbance along the shoreline could risk the loss of large numbers of shorebirds which may not find other suitable habitat in Botany Bay (P. Straw 2007, pers. comm.).

Recommended actions for inappropriate recreation

Kurnell Peninsula has historically been used by heavy industries and many people, even within Sydney, do not know of Towra Point or of its international significance, which may have protected it from disturbance and inappropriate activities so far. Increased signage and education about the importance of Towra Point Nature Reserve are recommended, which may reduce the threat of inappropriate activities and place an increased value on the area.

Towra Spit Island is patrolled on weekends during the little tern breeding season by DECCW and the Towra Team to prevent public access and educate people about the importance of the site. It is recommended that the monitoring continues every year for the protection of shorebirds.

6.7 Mangrove encroachment

Aerial photographic records since 1942 have shown a change in mangrove and saltmarsh area in a number of estuaries in south-east Australia; there has been an increase in mangrove area and a decrease in saltmarsh area over this period in at least twenty-eight locations in south-east Australia including Towra Point (Figure 60). Mangrove encroachment has been described as the main cause of saltmarsh decline in south-east Australia (Saintilan and Williams 2000). From 1956 to 1999 at Towra Point, mangrove area increased by 34% and saltmarsh area decreased by 62%

(Wilton 2002). There are three factors which may have the most influence on mangrove and saltmarsh distribution:

- sea level rise;
- sedimentation and subsidence; and
- nutrient and sediment loads.

Sea-level rise

As sea level rises, more areas will be inundated. The response of mangrove and saltmarsh communities to these changes will most likely be to move in a landward direction to maintain optimal ecological conditions (Mitchell and Adam 1989; Harty 2004). Saltmarshes have maintained a zone almost free of other wetland types due to the extremely saline environment that they tolerate. However, if there were increased tidal inundation, reduction of soil salinity and increase of soil moisture would favour the growth of mangroves which would out-compete saltmarshes for light (Clarke and Hannon 1971). Landward migration of saltmarshes will be prevented at Towra Point by urban and industrial development unless buffer zones are developed (Saintilan and Williams 1999; Wilton 2002; Harty 2004).

Sedimentation and subsidence

Mangroves stabilise and accumulate sediment, which increases habitat for them to colonise and allows them to increase their distribution. The effect of accumulation of sediment on surface elevation is dependent on rainfall, level of the water table and has been related to the ENSO cycle. An increase of sedimentation does not always relate to an increase in surface elevation. During periods of low rainfall, low plant productivity and a reduced water table the soil is likely to subside, and the effects of accretion will be reduced. ENSO correlates with periods of low rainfall and drought conditions which may influence mangrove encroachment due to subsidence of the soil (Rogers et al. 2006).

Photo: K. Brennan 2007

Figure 60: Mangroves in the saltmarsh zone (mixed habitat)

Nutrient and sediment loads

Since 1941 the Georges River and Botany Bay catchment has undergone intense growth in urban and industrial development. The replacement of native vegetation with hard surfaces has increased the amount of sediment and nutrients directly entering waterways. While Towra Point is at the lower end of the catchment and Botany Bay is well flushed, the increase in sediment loads from the catchment has an influence on the wetland. A study of 28 estuaries in south-east Australia showed a trend towards a higher level of mangrove encroachment in more modified urban and industrial catchments (Saintilan and Williams 2000). Growth of mangrove and saltmarsh species improves with increased nutrient concentration of the soil to a certain amount, with their optimum growth requirements higher than the average soil nutrient level (Clarke and Hannon 1970). Therefore an increase in dissolved nutrients provides optimum levels for growth for both species. However, mangroves out-compete saltmarsh for light, which may explain the encroachment of mangroves into the saltmarsh zone.

The influence of soil subsidence could be detrimental to saltmarsh communities if it corresponds with sea-level rise or increased runoff from the catchment, diluting soil salinity and elevating nutrient concentrations, favouring the growth of mangroves. Therefore it is most likely that a contribution of all three factors has influenced the landward migration of mangroves at the expense of saltmarsh (Saintilan and Williams 1999).

Recommended actions for mangrove encroachment

In order to prevent loss of saltmarsh species, the causes of mangrove encroachment at Towra Point need to be established and managed. Further study is needed and monitoring of management is critical in order to allow for natural variability. Management actions should not include the removal of mangroves, as the causes of their encroachment will persist and they will regrow. Examples of management actions include (Harty 2004):

- water-sensitive urban design for new developments
- construction of wetlands or ecological buffer zones between areas prone to erosion or high runoff
- implementation of stormwater quality improvement devices and gross pollution traps
- minimisation of paved surfaces to allow groundwater recharge and filtration of sediments and nutrients.

6.8 Climate change

The effect of greenhouse gas emissions has most likely influenced the warming of the Earth and changes in other parameters of climate over the past 50 years. Observed changes in climate include sea-level rise, temperature change, altered rainfall patterns, changes in atmospheric carbon dioxide and methane levels and decreased snow and ice cover (Solomon et al. 2007).

Changed climatic conditions may alter species distribution and abundance and threaten their survival. A loss of species at Towra Point would have a large negative impact on the diversity of the Sydney bioregion. The key threats of climate change at Towra Point include sea-level rise, temperature change, changed rainfall patterns, intensity and frequency of storms and changes in the physicochemical environment.

Sea-level rise

The height of Australian coastal waters has risen by approximately 1.2 millimetres per year from 1920 to 2000 (CSIRO and BoM 2007) and this increase is expected to continue at this rate until the middle of the century (Solomon et al. 2007). This rise can partly be attributed due to global warming and is related to the melting of ice caps and snow. Sea-level rise on a local scale is dependent on regional climate, tides, geomorphology and the ENSO cycle (Solomon et al. 2007).

Sea-level rise is a key threat to the low-lying Towra Point as it will alter tidal levels, will likely change the distribution and abundance of species and may result in habitat and species loss. Hydrology is a key driver for the ecological character of Towra Point and past altered hydrological regimes have had long-term detrimental effects on the ecosystem. The major influence of tides on critical components and processes at Towra Point has been outlined in section 5.3.1.

Under current conditions the saltmarsh zone is inundated by seawater only during spring tides and grows optimally under highly saline conditions (Clarke and Hannon 1970). Sea-level rise would cause more frequent tidal inundation in the current saltmarsh zone, consequently diluting the soil salinity. This would create less favourable conditions for saltmarsh and, more significantly, provide more favourable conditions for mangroves, which out-compete saltmarsh species for light. Mangrove encroachment into saltmarsh areas at Towra Point has been documented since the 1950s and may be partly due to sea-level rise (Saintilan and Williams 1999; Wilton 2002; Saintilan et al. 2009).

Water depth will increase as a result of sea-level rise, which will cause a shift in the distribution of seagrasses (Short and Neckles 1999). An increase in water depth will increase the tidal prism of the water body, which will change the way water moves through the system and may alter wave action or tidal currents. Loss of a relatively small area of seagrass could cause cumulative loss due to increased exposure to waves and tides (Larkum 1976) and would have negative implications for the ecological character of Towra Point.

Temperature change

Average air temperatures in Australia have risen by approximately 0.9°C since 1950 (Figure 61). The temperature in Sydney is projected to increase by approximately 0.9°C by 2030 and by approximately 1.6–3.0°C (low–high greenhouse gas emissions) by 2070. A significant increase in the number of days over 35°C is also projected (CSIRO and BoM 2007). The average rate of global warming since 1950 is almost double the rate of warming since 1900 (Solomon et al. 2007).

Since 1955 global ocean temperature has increased and this has been at least part of the cause of sea-level rise. In the oceans surrounding Australia, sea surface temperature has risen since 1920 and is expected to rise by approximately 0.3-0.6°C off the east coast by 2030. Some of the increase in ocean temperature may be due to the more southerly flow of the warm waters of the east Australian current. Air and ocean temperatures differ on a regional scale and are also influenced by the ENSO cycle. There is no evidence to suggest that the ENSO cycle has been influenced by climate change, however, the effects of El Niño and La Niña on other components influenced by climate change may be significant. Therefore, in south-eastern Australia, it is estimated that El Niño events will become drier and La Niña events will become wetter (CSIRO and BoM 2007; Solomon et al. 2007).

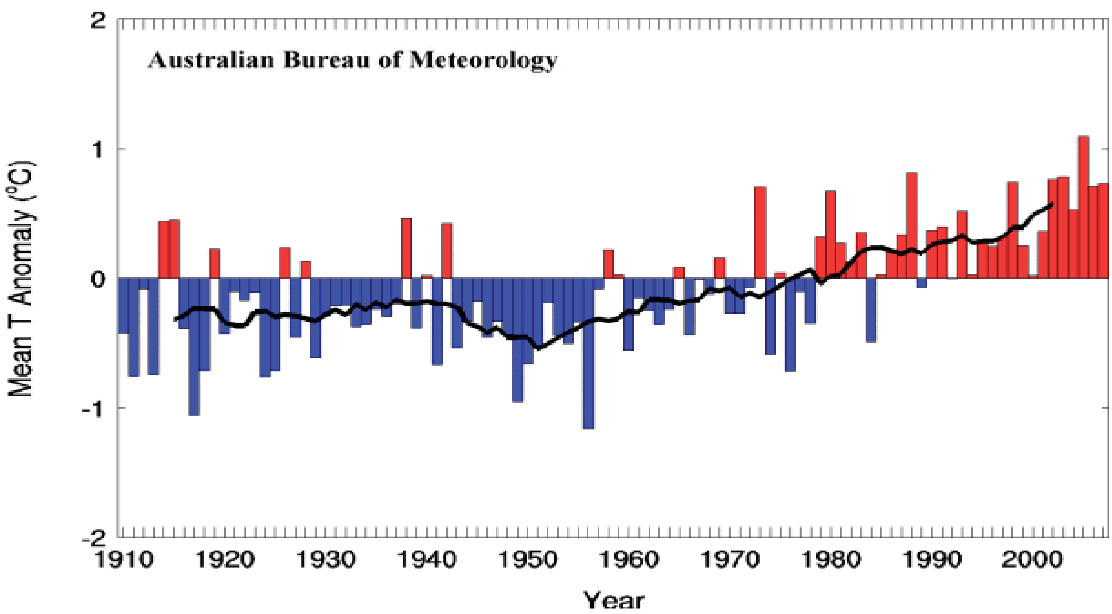
Mangrove distribution at Towra Point may increase with a rise in air temperature as mangroves favour tropical conditions (Clarke and Hannon 1967). The increase in distribution is likely to be supported by sea-level rise and will be at the expense of saltmarsh species (Saintilan et al. 2009). However, if annual average rainfall decreases over Towra Point and surface temperature increases, soil salinity will increase, which will limit the distribution of mangroves.

The east Australian current is critical in replenishing fish stocks and helping to improve water quality. It has strengthened since the late 1970s and the warmer waters are travelling further south (CSIRO and BoM 2007). Seagrass distribution is likely to shift south-wards and tropical species are likely to move into more temperate areas (Poloczanska 2006a). There is a risk that the distribution of caulerpa in Botany Bay may increase.

Warmer sea temperatures will cause a shift in distribution and abundance of marine species, from phytoplankton, zooplankton and macro-invertebrates to fish and species higher in the food chain. Phytoplankton are critical primary producers in an ecosystem and a shift in their distribution will influence the distribution and abundance of higher order species. Sea temperature influences fish distribution and abundance due to both the presence of prey and physiological processes of individual species (Bell et al. 1984; Kunz and Richardson 2006; Okey 2006; Okey and Hobday 2006; Richardson and Kunz 2006).

The solubility of oxygen decreases as water temperature increases, and warmer temperatures can promote epiphytic algae growth (Short and Neckles 1999; Okey 2006). In low energy areas such as Woolooware, Quibray and Weeney bays the combination of less dissolved oxygen and increased algal growth may increase the risk of a eutrophic system.

Species adaptation to new conditions will be necessary with a change in temperature, which will affect distribution and abundance of both flora and fauna (Short and Neckles 1999); the adaptability of different species will be determined by the rate at which temperature changes.



Source: BoM (2007b)

Figure 61: Annual mean temperatures for eastern Australia 1910–2007

Changed precipitation patterns

Hydrological components and processes are critical in an ecosystem and have a major influence on ecological character. In eastern Australia rainfall has declined since 1950 and is predicted to continue to decline, especially in winter. Rainfall in Sydney is expected to decline by three per cent by 2030 and by four to eight per cent by 2070 (CSIRO and BoM 2007).

A change in the hydrology in the Georges River and Botany Bay catchment will influence plant distribution and abundance. A decrease in annual average rainfall may disadvantage terrestrial and mangrove species and favour saltmarsh species due to an increase in soil salinity.

Although annual average rainfall is projected to decline in eastern Australia, the frequency and intensity of rain and storms is likely to increase (CSIRO and BoM 2007). This is likely to increase the rate of erosion, flooding and runoff entering the catchment, including sewer overflows and salt water which may inundate Towra Lagoon.

Increased carbon dioxide and ocean acidification

Oceans absorb atmospheric carbon dioxide which is used by seagrasses and mangroves for photosynthesis. As the amount of carbon dioxide in the atmosphere increases, so will the amount of carbon dioxide absorbed by the ocean increase, and this will make the surface water more acidic (Poloczanska 2006a; CSIRO and BoM 2007).

An increase in carbon dioxide in the air or dissolved in the oceans will favour the growth of terrestrial and marine plants. However, under acidic conditions, the production of calcium carbonate shells by some marine organisms such as molluscs will reduce. An increase in acidity will alter sediment composition and cause a shift in benthic organism distribution and abundance and will affect species higher in the food chain (Okey 2006; Poloczanska 2006a, 2006b; CSIRO and BoM 2007).

7 Knowledge gaps and recommendations for monitoring

A detailed understanding of a wetland is necessary in order to undertake sustainable holistic management. There are gaps in the knowledge base of some key components of Towra Point Nature Reserve, including some baseline data. Towra Point's proximity to a major city and a number of research institutions increases the possibility of obtaining the required data. Recommended actions are based on knowledge gaps and critical threats and are listed according to the key components and processes (Table 22). These recommendations will assist management authorities in decision-making for future funding and management plans.

A summary of recommended actions are:

- that the Ramsar site be expanded to match the nature reserve to provide extra protection for areas such as Towra Spit Island and saltmarsh communities
- that the Ramsar site be extended to include the Towra Point Aquatic Reserve due to the importance of the seagrass and intertidal areas to the Ramsar site.
- an integrated weed and pest management strategy be implemented which would involve participation of landowners on Kurnell Peninsula
- a comprehensive flora and fauna study is required to collect baseline or follow-up information and to determine limits of acceptable change
- information on the location and ecological condition of the freshwater and brackish lagoons is needed, including salinity and nutrient measurements, and groundwater status
- a study to understand the influence groundwater has on the wetland and to collect baseline water quality data to determine limits of acceptable change
- predictive modelling to estimate the influence of the changes to geomorphology and hydrology of Botany Bay on the ecological character of Towra Point
- monitoring of the sedimentation patterns surrounding Towra Point to ensure that Towra Beach and Towra Spit Island are maintained
- that protection of Towra Spit Island for little tern and other shorebird habitat should continue, including habitat improvement and boat patrols
- that protection of Aboriginal sites continues
- that areas of mangrove and saltmarsh are monitored to ensure the loss of saltmarsh habitats does not occur; limits of acceptable change need to be established
- an increase in education and signage on the importance of Towra Point Nature Reserve to emphasise the value of the area and to protect it from threatening processes such as inappropriate recreation.

Table 22: Knowledge gaps and recommendations for monitoring

Knowledge gaps	Recommendations for monitoring
Geomorphology	
Condition of Towra Lagoon, Weedy Pond, Mirrormere and other freshwater lagoons	Information on the ecological condition of freshwater and brackish lagoons is needed, including salinity and nutrient measurements, and groundwater status
Changes in surface elevation, accretion and erosion patterns	Surface Elevation Table and Marker Horizon technique
Effects of changes in sediment loads at Towra Point	Monitoring of the sedimentation patterns surrounding Towra Point Hydrodynamic modelling
Hydrology	
Groundwater data for areas draining into Towra Point sub-catchment	A study to understand the influence groundwater has on the wetland and to collect baseline water quality data to determine limits of acceptable change Continued monitoring and reporting of groundwater at Caltex oil refinery and Kurnell Landfill Company
Water quality	
Turbidity levels	Turbidity measurements and response to turbidity by seagrasses
Ecological effects of changes in nutrient loads on the values of Towra Point Ramsar site	Biogeochemical modelling to show the effects of changes in nutrient loads
Biota	
Limits of acceptable change for biodiversity	Comprehensive flora and fauna study is required to collect baseline or follow-up information
Extent of terrestrial vegetation	Map terrestrial vegetation and monitor its growth into saltmarsh areas
Macro-invertebrates	Survey macro-invertebrate species Establish benchmarks and limits of change
Fish	Survey fish species Establish benchmarks and limits of change
Birds	Survey shorebirds annually in Ramsar site Continue monitoring of shorebirds in Botany Bay (e.g. through regular counts by Australasian Waders Study Group) and extend to Ramsar site Maintain database for migratory shorebird species Establish benchmarks and limits of change

Knowledge gaps	Recommendations for monitoring
Reptiles	Survey reptile species Establish benchmarks and limits of change
Amphibians	Survey amphibian species Establish benchmarks and limits of change
Mammals	Survey mammal species Establish benchmarks and limits of change
Changes in the extent of seagrass area in Botany Bay	Aerial photography of Botany Bay and ground validation using a standard methodology that enables comparison over time
Changes in the extent of mangrove and saltmarsh areas within Towra Point Ramsar site	Areas of mangrove and saltmarsh are monitored to ensure the loss of saltmarsh habitats does not occur; limits of acceptable change need to be established Aerial photography of Towra Point and ground validation using a standard methodology that enables comparison over time

7.1 Important communication, education and public awareness messages

Towra Point Nature Reserve was listed as a Ramsar site due to the significant migratory bird habitat it supports. While it is still an important roosting, nesting and foraging site for both migratory and resident birds, there are other important reasons for its significance, including that:

- it is the last remaining wetland of its type in the Sydney area and the largest in the Sydney Basin bioregion
- it supports 60% of the remaining saltmarsh area and 40% of the remaining mangrove area in the Sydney region
- there are four nationally threatened species (EPBC Act) and 23 threatened species and five endangered ecological communities in NSW (TSC Act)
- various vegetation communities and habitats support a diverse range of fauna and biodiversity on a regional, national and international scale
- some of the habitats are the most extensive of anywhere in the Sydney area and may be the last remaining habitat for some fauna species, such as the white-fronted chat and little tern, in the biogeographic region
- it supports the last remaining nesting site for the endangered little tern (TSC Act) in the Sydney region and is the second most important little tern nesting site in NSW
- it is one of the four most important migratory shorebird habitats in NSW

- extensive seagrass meadows adjacent to the nature reserve provide an important fish nursery habitat and protect the shoreline from erosion
- approximately 25 species of fish found in the waters surrounding Towra Point are of economic or recreational importance and use Towra Point as a source of food and protection.

As Towra Point is located in the largest city in Australia and within the same catchment as a growing population, and is very close to Australia's largest airport, crude oil importing port, oil refinery and container port in NSW, threats to the ecological character of Towra Point include:

- catchment land use, which will affect sediment and nutrient loads in the waterway and hydrology
- changes to the morphology of the catchment, which influences hydrology
- weeds and pests which threaten native flora, fauna and habitats
- pollution
- climate change which may cause sea level rise, temperature change, change in precipitation patterns and increased atmospheric carbon dioxide
- inappropriate recreation such as use of four-wheel drive vehicles, motorbike riding and boating in and adjacent to the reserve, which can destroy habitats and disturb fauna.

Appendix A Ramsar criteria for identifying wetlands of international importance

Group A of the criteria: sites containing representative, rare or unique wetland types	
	Criterion 1: A wetland should be considered internationally important if it contains a representative, rare, or unique example of a natural or near-natural wetland type found within the appropriate biogeographic region.
Group B of the criteria: sites of international importance for conserving biological diversity	
Criteria based on species and ecological communities	**Criterion 2:** A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or threatened ecological communities. **Criterion 3:** 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:** 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.
Specific criteria based on waterbirds	**Criterion 5:** A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds. **Criterion 6:** 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.
Specific criteria based on fish	**Criterion 7:** 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:** 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.
Specific criteria based on other taxa	**Criterion 9:** 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.

Appendix B Macro-invertebrate species

Scientific name	Common name or type of species	Historical circa 1984	Present circa 2007
Octopus	Octopus	Y	
Acetes sibogae australis	swarming shrimp		Y
Alpheus edwardsi	pistol shrimp	Y	Y
Alvania sp.	sea snails	Y	
Ambuscintilla praemium	Bivalve	Y	
Anadara trapezia	ark cockle	Y	
Anomiidae	jingle shell	Y	
Aplysia parvula	sea slug	Y	
Assiminea relata	Gastropod	Y	
Australoplax tridentata	tuxedo crab	Y	
Austrocochlea constricta	ribbed top shell	Y	
Balanus amphitrite	striped barnacle	Y	
Bedeva paivae	Gastropod	Y	
Bembicum auratum	grazing snail	Y	
Cacozeliana lacertina	Caenogastropod	Y	
Callianassidae	ghost shrimp	Y	
Caridina type 1	Algae-eating shrimp		Y
Chiazacmea jacksoniensis		Y	
Cingulina spina	Gastropod	Y	
Diogenes sp.	hermit crabs	Y	
Eliminius modestus	Crustacean	Y	
Eumarcia fumigata	smoked venerid	Y	
Glauconomya plankta	Cockle	Y	
Halicarcinus ovatus	oval spider crab	Y	
Halicarcinus sp.	spider crab	Y	
Heloecius cordiformis	semaphore crab	Y	Y
Helograpsus haswellianus	grapsid crab	Y	Y
Hemigrapsus sp.	crab species	Y	
Hippolytidae	Shrimp		Y
Idiosepius notoides	southern pygmy squid	Y	Y
Ilyoplax paludicola	ocypodid shore crab	Y	
Laternula creccina	lantern clam	Y	
Latreutes pygmaeus	hump-backed shrimp	Y	Y
Latreutes sp.	Shrimp	Y	
Littorina scabra	scratched littoraria	Y	
Littorina sp.		Y	
Macrobrachium intermedium	grass shrimp	Y	Y
Macrophthalmus setosus	ghost or fiddler crab	Y	
Macrophthalmus sp. (juv.)		Y	
Matuta planipes	two-spined burrowing sand crab		Y
Melosidula zonata	Gastropod	Y	
Metapenaeus macleayi	school prawn	Y	Y
Mictyris longicarpus	soldier crab	Y	
Mytilus edulis	blue mussel	Y	
Nassarius burchardi	dog whelk	Y	
Nassarius jonasii	dog whelk	Y	
Nerita atramentosa	black nerite	Y	

Neritina oualaniensis	Nerite	Y	
Notospisula parva producta	Bivalve	Y	
Notospisula trigonella	clam	Y	
Okenia plana	gastropod	Y	
Onchidium damelli	air breathing sea slug	Y	
Ophicardelus ornatus	air breathing snail	Y	
Ophicardelus quoyi	air breathing snail	Y	
Ophicardelus sulcatus	air breathing snail	Y	
Ovalipes australiensis	sand crab; surf crab		Y
Palaemon debilis	estuarine shrimp		Y
Paragrapsus laevis	mottled shore crab	Y	Y
Penaeus esculentus	tiger prawn	Y	
Penaeus plebejus	king prawn	Y	Y
Petalifera sp.	sea slug	Y	
Pilumnopaeus serratifrons	mud crab	Y	
Polinices sordidus	sordid sand snail	Y	
Portunus pelagicus	blue swimmer crab	Y	Y
Prothalotia comtessei	Comtesse’s top shell	Y	
Pseudoliotia micans	gastropod	Y	
Pyramidellidae sp. A	pyramid shells, parasitic sea snails	Y	
Pyramidellidae sp. B	pyramid shells, parasitic sea snails	Y	
Pyrazus ebeninus	Hercules club whelk	Y	
Saccostrea cucullata	common milky oyster	Y	
Salinator fragilis	air breathing snail	Y	
Salinator solida	air breathing snail	Y	Y
Scylla serrata	mudcrab	Y	
Semelidae	bivalve	Y	
Sepiidae spp.	cuttlefish	Y	Y
Sepioloidea sp.	squid species	Y	Y
Sesarma erythrodactyla	red-fingered marsh crab	Y	Y
Sphaeroma quoyana	crustacean	Y	
Tatea rufilabris	hydrobiid snail	Y	
Tellina deltoidalis	sunset shell	Y	
Teredo sp.	burrowing bivalve	Y	
Thalamita sima	four-lobed swimmer crab	Y	Y
Trichomya hirsuta	hairy mussel	Y	
Velacumantis australis	Australian mud whelk	Y	
Wallucina assimilis	Cockle	Y	
Xenostrobus securis	Pygmy mussel	Y	

Source: ALS (1977); SPCC (1981a); Bell et al. (1984); Roach (2000); Williams (2000); Williams et al. (2004); Mazumder et al. (2005, 2006a, 2006b); Saintilan et al. (2007)

Appendix C Fish species

Scientific name #	Common name	Historical circa 1984	Present circa 2007
Acanthogobius flavimanus	yellowfin goby	Y	
Acanthopagrus australis#	yellowfin bream	Y	Y
Achlyopa nigra	black sole	Y	
Achoerodus gouldii	western blue groper	Y	
Afurcagobius tamarensis	Tamar River goby	Y	Y
Aldrichetta forsteri	yelloweye mullet	Y	
Ambassis jacksoniensis	glassfish	Y	Y
Ambassis marianus	estuary perchlet	Y	
Ammotretis rostratus#	longsnout (or large toothed) flounder	Y	Y
Anguilla australis	short-finned eel	Y	
Anguilla reinhardtii	long-finned eel	Y	Y
Antennarius striatus	striped anglerfish		Y
Arenigobius bifrenatus	bridled goby	Y	Y
Arenigobius frenatus	half-bridled goby	Y	Y
Argyrosomus japonicus	mulloway	Y	
Arripis trutta	eastern Australian salmon	Y	
Atherinomorus vaigiensis	Ogilby's hardyhead	Y	Y
Bathygobius krefftii	Krefft's goby	Y	Y
Batrachomoeus dubius	frogfish	Y	Y
Belone ferox	banded needlefish	Y	
Brachaluteres jacksonianus	pygmy leatherjacket		Y
Brachaluteres trossulus	pigmy leatherjacket	Y	
Centropogon australis	eastern fortescue	Y	Y
Chaetodon ephippium	saddle butterflyfish	Y	
Chelidonichthys kumu	red gurnard	Y	
Cnidoglanis macrocephalus	estuary catfish	Y	
Conger wilsoni	eastern (short-finned) conger eel	Y	
Cristatigobius cristatus	goby	Y	
Cristiceps australis	crested weedfish	Y	Y
Dendrochirus zebra	fire fish (zebra lionfish)	Y	
Dermatopsis macrodon	fleshfish	Y	
Dicotylichthys myersi	Myer's pufferfish	Y	
Dinolestes lewini	longfin pike	Y	
Engraulis australis	Australian anchovy	Y	
Enoplosus armatus#	old wife	Y	Y
Epinephelus daemelii	black cod	Y	
Euristhmus lepturus	longtailed catfish	Y	
Favonigobius exquisitus	exquisite sand goby	Y	Y
Favonigobius lateralis	long finned goby	Y	Y
Favonigobius sp.	goby	Y	
Filicampus tigris	tiger pipefish	Y	
Fistularia petimba	rough flutemouth	Y	
Gerres ovatus#	silver biddy	Y	
Gerres subfasciatus#	silver biddy	Y	Y
Girella tricuspidata#	luderick	Y	Y
Gobiomorphus australis	striped gudgeon	Y	Y

Gobiopterus semivestitus	glass goby	Y	Y
Herklotsichthys castelnaui	southern herring	Y	
Heteroclinus spp.	weedfish		Y
Hippocampus whitei	White's seahorse	Y	
Hyperlophus vittatus	sandy sprat	Y	
Hypnos monopterygium	electric ray (numbfish)	Y	
Hyporhamphus australis	eastern sea garfish	Y	
Leptatherina presbyteroides	silverfish	Y	
Liza argentea#	flat-tail mullet	Y	Y
Meuschenia freycineti#	six-spined leatherjacket	Y	Y
Meuschenia trachylepis#	variable (yellow tailed) leatherjacket	Y	Y
Microcanthus strigatus	stripey	Y	
Monacanthus chinensis#	leatherjacket	Y	Y
Monodactylus argenteus	silver batfish	Y	
Mugil cephalus#	sea mullet	Y	Y
Mugilidae	mullet	Y	
Mugilogobius paludis	mangrove goby		Y
Mugilogobius platynotus	flat-backed mangrove goby	Y	
Mugilogobius stigmaticus	checkered mangrove goby	Y	Y
Myliobatus australis	eagle ray	Y	
Myxus elongatus#	sand mullet	Y	Y
Neodax balteatus	little rock-whiting		Y
Nesogobius sp.nov.	goby	Y	
Omobranchus anolius	oyster blenny	Y	
Ophisurus serpens	serpent eel	Y	Y
Orectolobus maculatus	spotted wobbegong shark	Y	
Pagrus auratus	snapper	Y	
Pandaculus lidwilli		Y	
Paramonacanthus otisensis	dusky leatherjacket	Y	
Paraplagusia sp.	tongue sole sp		Y
Paraplagusia unicolor	lemon tongue sole	Y	Y
Pelates quadrilineatus#	trumpeter		Y
Pelates sexlineatus#	eastern striped trumpeter	Y	Y
Petroscirtes lupus	brown sabretooth blenny	Y	Y
Platycephalus arenarius#	flag-tail flathead		Y
Platycephalus fuscus#	dusky flathead	Y	Y
Platycephalus speculator#	yank flathead		Y
Pomatomus saltatrix#	tailor	Y	Y
Poutawa habenata	little conger eel	Y	
Pranesus ogilbyi	hardy head	Y	
Priopidichthys marinanus		Y	
Pseudocaranx dentex	white trevally	Y	
Pseudogobius olorum	blue spot goby	Y	Y
Pseudomugil signifer	southern blue-eye	Y	Y
Pseudorhombus arsius#	large toothed flounder	Y	Y
Pseudorhombus jenynsii#	small-toothed flounder	Y	Y
Pseudorhombus sp	sand flounder	Y	
Redigobius macrostoma	large-mouth goby	Y	Y
Rhabdosargus sarba#	tarwhine	Y	Y
Sardinops neopilchardus	pilchard	Y	

Scobinichthys granulatus#	rough leatherjacket	Y	
Selenotoca multifasciata	striped scat	Y	
Siganus nebulosus	happy moments		Y
Siganus spinus	little spinefoot	Y	
Sillago ciliata#	sand whiting	Y	Y
Sillago maculata#	trumpeter whiting	Y	Y
Siphamia cephalotes	little siphonfish	Y	Y
Siphamia roseigaster	silver siphonfish	Y	Y
Stigmatopora argus	spotted pipefish	Y	
Stigmatopora nigra	wide body pipefish	Y	Y
Syngnathidae juvenile	pipefish (juvenile)	Y	
Syngnathus sp.	pipefish	Y	
Taeniodes mordax	snake head goby		Y
Terapon jarbua	grunter	Y	
Tetractenos hamiltoni	common toadfish	Y	Y
Therapon jarbua	crescent perch	Y	
Torquigener pleurogramma	weeping toadfish	Y	Y
Torquigener squamicauda	brush-tail toadfish	Y	Y
Trachurus novaezelandiae	yellow-tail scad	Y	
Trygonoptera testacea	common stingaree	Y	
Trygonorrhina fasciata#	southern fiddler ray		Y
Upeneus tragula	bar-tail goatfish		Y
Urocampus carinirostris	hairy pipefish	Y	Y
Valamugil georgii	fantail mullet	Y	
Vanacampus margaritifer	pipefish	Y	
Velambassis jacksoniensis		Y	

Species of commercial or recreational importance

Source: SPCC (1981a); Bell et al. (1984); Williams (2000); Williams et al. (2004); Mazumder et al. (2005, 2006b); Saintilan et al. (2007)

Appendix D Bird species

Scientific name*	Common name	Historical circa 1984	Present circa 2007
Acanthiza chrysorrhoa	yellow-rumped thornbill		Y
Acanthiza nana	yellow thornbill	Y	Y
Acanthiza pusilla	brown thornbill	Y	
Acanthagenys rufogularis	spiny-cheeked honeyeater	Y	
Acanthorhynchus tenuirostris	eastern spinebill	Y	Y
Accipiter cirrhocephalus	collared sparrowhawk	Y	
Accipiter fasciatus	brown goshawk	Y	Y
Accipiter novaehollandiae	grey goshawk	Y	
*Acridotheres tristis**	common myna	Y	Y
Acrocephalus stentoreus	clamorous reed-warbler	Y	
Actitis hypoleucos	common sandpiper	Y	Y
*Alauda arvensis**	common skylark	Y	
Anas castanea	chestnut teal	Y	Y
Anas gracilis	grey teal	Y	Y
Anas rhynchotis	Australasian shoveler	Y	
Anas superciliosa	Pacific black duck	Y	Y
Anhinga melanogaster	darter	Y	Y
Anthochaera carunculata	red wattlebird	Y	Y
Anthochaera chrysoptera	little wattlebird	Y	Y
Anthus novaeseelandiae	Richard's pipit	Y	Y
Ardea alba	great egret	Y	Y
Ardea ibis	cattle egret	Y	Y
Ardea intermedia	intermediate egret	Y	
Ardea pacifica	white-necked heron	Y	
Arenaria interpres	ruddy turnstone	Y	Y
Aythya australis	hardhead	Y	
Biziura lobata	musk duck	Y	Y
Botaurus poiciloptilus	Australasian bittern		Y
Burhinus grallarius	bush stone-curlew	Y	
Butorides striatus	striated heron	Y	Y
Cacatua galerita	sulphur-crested cockatoo	Y	Y
Cacatua sanguinea	little corella	Y	
Cacomantis flabelliformis	fan-tailed cuckoo	Y	Y
Calidris acuminata	sharp-tailed sandpiper	Y	Y
Calidris alba	sanderling	Y	Y
Calidris canutus	red knot	Y	
Calidris ferruginea	curlew sandpiper	Y	Y
Calidris ruficollis	red-necked stint	Y	Y
Calidris tenuirostris	great knot	Y	
*Carduelis carduelis**	European goldfinch	Y	
*Carduelis chloris**	European greenfinch	Y	
Chalcites lucidus	shining bronze-cuckoo	Y	
Chalcophaps indica	emerald dove	Y	
Charadrius bicinctus	double-banded plover	Y	Y
Charadrius lenschenaultii	greater sand plover	Y	Y
Charadrius melanops	black-fronted plover	Y	Y
Charadrius mongolus	Mongolian plover	Y	Y

Charadrius ruficapillus	red-capped plover	Y	Y
Chenonetta jubata	Australian wood duck	Y	Y
Chlidonias hybrida	whiskered tern	Y	
Chlidonias leucopterus	white-winged black tern	Y	
Chrysococcyx basalis	rufous-tailed bronze-cuckoo	Y	
Chrysococcyx lucidus plagosus	golden bronze-cuckoo	Y	
Cincloramphus cruralis	brown songlark	Y	
Circus approximans	swamp harrier	Y	Y
Cisticola exilis	golden-headed cisticola	Y	Y
Colluricincla harmonica	grey shrike-thrush	Y	Y
Columbia livia	feral pigeon		Y
Columba leucomela	white-headed pigeon	Y	
Coracina novaehollandiae	black-faced cuckoo-shrike	Y	Y
Cormobates leucophaeus	white-throated treecreeper		Y
Corvus coronoides	Australian raven	Y	Y
Coturnix australis	brown quail	Y	
Coturnix pectoralis	stubble quail	Y	
Cracticus torquatus	grey butcherbird	Y	Y
Cuculus pallidus	pallid cuckoo	Y	
Cygnus atratus	black swan	Y	Y
Dacelo novaeguineae	laughing kookaburra	Y	Y
Dicaeum hirundinceum	mistletoebird	Y	Y
Dicrurus bracteatus	spangled drongo	Y	
Egretta garzetta	little egret	Y	Y
Egretta novaehollandiae	white-faced heron	Y	Y
Egretta sacra	eastern reef egret	Y	
Elanus axillaris	black-shouldered kite	Y	Y
Eolophus roseicapilla	galah	Y	Y
Eopsaltria australis	eastern yellow robin	Y	Y
Epthianura albifrons	white-fronted chat	Y	Y
Eudyptula minor	little penguin		Y
Eurystomus orientalis	dollarbird	Y	
Falco berigora	brown falcon	Y	
Falco cenchroides	nankeen kestrel	Y	Y
Falco longipennis	Australian hobby	Y	Y
Falco peregrinus	peregrine falcon	Y	Y
Fulica atra	coot	Y	
Gallinago hardwickii	Latham's (Japanese) snipe	Y	
Gallinula tenebrosa	dusky moorhen	Y	
Gallirallus philippensis	buff-banded rail		Y
Geopelia humeralis	bar-shouldered dove	Y	
Gerygone levigaster	mangrove gerygone		Y
Gerygone mouki	brown gerygone	Y	Y
Gerygone olivacea	white-throated gerygone	Y	
Grallina cyanoleuca	magpie-lark	Y	Y
Gymnorhina tibicen	Australian magpie	Y	Y
Haematopus fuliginosus	sooty oystercatcher	Y	Y
Haematopus longirostris	pied oystercatcher	Y	Y

Haliaeetus leucogaster	white-bellied sea-eagle	Y	Y
Haliastur sphenurus	whistling kite	Y	Y
Heteroscelus brevipes	grey-tailed tattler	Y	Y
Heteroscelus incanus	wandering tattler	Y	
Himantopous himantopus	black-winged stilt	Y	Y
Hirundapus caudacutus	white-throated needletail	Y	
Hirundo ariel	fairy martin	Y	Y
Hirundo neoxena	welcome swallow	Y	Y
Hirundo nigricans	tree martin	Y	
Hylacola pyrrhopygia	chestnut-rumped heathwren	Y	
Ixobrychus minutus	little bittern	Y	
Lalage sueurii	white-winged triller	Y	
Larus dominicanus	kelp gull	Y	Y
Larus novaehollandiae	silver gull	Y	Y
Larus pacificus	Pacific gull	Y	
Lichenostomus chrysops	yellow-faced honeyeater	Y	Y
Lichmera indistincta	brown honeyeater	Y	Y
Limicola falcinellus	broad-billed sandpiper	Y	
Limosa lapponica	bar-tailed godwit	Y	Y
Limosa limosa	black-tailed godwit	Y	
Malurus cyaneus	superb fairy-wren	Y	Y
Malurus lamberti	variegated fairy-wren	Y	Y
Megalurus gramineus	little grassbird	Y	
Megalurus timoriensis	tawny grassbird	Y	Y
Meliphaga lewinii	Lewin’s honeyeater		Y
Melithreptus lunatus	white-naped honeyeater		Y
Microeca fascinans	jacky winter	Y	
Morus serrator	Australasian gannet	Y	Y
Myiagra inquieta	restless flycatcher		Y
Myiagra rubecula	leaden flycatcher	Y	
Myzomela sanguinolenta	scarlet honeyeater		Y
Neochmia temporalis	red-browed finch	Y	Y
Neophema chrysostoma	blue-winged parrot	Y	
Ninox novaeseelandiae	southern boobook	Y	Y
Numenius madagascariensis	eastern curlew	Y	Y
Numenius minutus	little curlew	Y	
Numenius phaeopus	whimbrel	Y	Y
Nycticorax caledonicus	nankeen night heron	Y	Y
Ocyphaps lophotes	crested pigeon	Y	Y
Oriolus sagittatus	olive-backed oriole	Y	Y
Oxyura australis	blue-billed duck	Y	
Pachycephala pectoralis	golden whistler	Y	Y
Pachycephala rufiventris	rufous whistler	Y	Y
Pandion haliaetus	osprey	Y	
Pardalotus punctatus	spotted pardalote	Y	Y
*Passer domesticus**	house sparrow	Y	Y
Pelecanus conspicillatus	Australian pelican	Y	Y
Petroica multicolor	scarlet robin	Y	
Petroica rosea	rose robin		Y
Phalacrocorax carbo	great cormorant	Y	Y
Phalacrocorax melanoleucos	little pied cormorant		Y

Phalacrocorax sulcirostris	little black cormorant	Y	Y
Phalacrocorax varius	pied cormorant	Y	Y
Philemon corniculatus	noisy friarbird	Y	
Philomachus pugnax	ruff	Y	
Phylidonyris nigra	white-cheeked honeyeater	Y	
Phylidonyris novaehollandiae	New Holland honeyeater	Y	Y
Platalea flavipes	yellow-billed spoonbill	Y	
Platalea regia	royal spoonbill	Y	Y
Platycercus elegans	crimson rosella	Y	Y
Platycercus eximius	eastern rosella	Y	Y
Plegadis falcinellus	glossy ibis	Y	Y
Pluvialis dominica	lesser golden plover	Y	
Pluvialis fulva	Pacific golden plover	Y	Y
Pluvialis squatarola	grey plover	Y	
Podargus strigoides	tawny frogmouth		Y
Poliocephalus poliocephalus	hoary-headed grebe	Y	
Porphyrio porphyrio	purple swamphen	Y	Y
Porzana fluminea	spotted crake	Y	
Porzana pusilla	marsh crake	Y	
Porzana tabuensis	spotless crake	Y	
Psephotus haematonotus	red-rumped parrot	Y	
Psophodes olivaceus	eastern whipbird	Y	
*Pycnonotus jocosus**	red-whiskered bulbul	Y	Y
Rallus pectoralis	Lewin's rail	Y	Y
Rhipidura fuliginosa	grey fantail	Y	Y
Rhipidura leucophrys	willie wagtail	Y	Y
Rhipidura rufifrons	rufous fantail	Y	
Sericornis frontalis	white-browed scrubwren	Y	Y
Sterna albifrons	little tern	Y	Y
Sterna bergii	crested tern	Y	Y
Sterna caspia	caspian tern	Y	Y
Sterna hirundo	common tern	Y	Y
Sterna nereis	fairy tern	Y	
Sterna striata	white-fronted tern	Y	
Stipiturus malachurus	southern emu-wren	Y	Y
Strepera graculina	pied currawong	Y	Y
*Streptopelia chinensis**	spotted turtle-dove	Y	Y
Struthidea cinerea	apostlebird	Y	
*Sturnus vulgaris**	common starling	Y	Y
Tachybaptus novaehollandiae	little grebe	Y	
Tadorna tadornoides	Australian shelduck	Y	
Taeniopygia bichenovii	double-barred finch	Y	
Taeniopygia guttata	zebra finch	Y	
Threskiornis molucca	Australian white ibis	Y	Y
Threskiornis spinicollis	straw-necked ibis	Y	
Todiramphus sanctus	sacred kingfisher	Y	Y
Trichoglossus haematodus	rainbow lorikeet	Y	Y
Tringa glareola	wood sandpiper	Y	
Tringa nebularia	common greenshank	Y	Y
*Turdus merula**	common blackbird	Y	
Turnix varia	painted button-quail	Y	

Tyto novaehollandiae	masked owl		Y
Vanellus miles novaehollandiae	masked lapwing	Y	Y
Vanellus tricolor	banded lapwing	Y	
Xenus cinereus	terek sandpiper	Y	Y
Zosterops lateralis	silvereye	Y	Y

* Introduced species

Source: ALS (1977); Schulz (2006); WSG (2007); DECC (2009)

Appendix E Vascular plants

Scientific name[#] [*]	Common name	1977	2008
?Doodia sp.		Y	
Acacia ?implexa	hickory	Y	
Acacia irrorata ssp. *irrorata*	green wattle	Y	
Acacia longifolia var. *longifolia*	Sydney golden wattle	Y	
Acacia longifolia var. *sophorae*	coast wattle	Y	
Acacia maidenii	Maiden's wattle	Y	
Acacia suaveolens	sweet wattle	Y	Y
Acacia ulicifolia	prickly moses	Y	
*Acetosa sagittata**	rambling dock, turkey rhubarb	Y	
Acianthus sp.		Y	Y
Acmena smithii	lilly pilly	Y	Y
Aegiceras corniculatum	river mangrove	Y	Y
*Agapanthus praecox**	agapanthus		Y
Agrostis avenacea	blown grass	Y	
Alternanthera denticulata	lesser joyweed	Y	
Amyema congener	mistletoe	Y	
*Anagallis arvensis**	pimpernel	Y	
*Andropogon virginicus**	whisky grass, broomsedge	Y	
Aotus ericoides	golden pea, common aotus	Y	Y
Apium prostratum	sea celery	Y	
*Arctotheca calendula**	cape weed	Y	
*Asparagus densiflorus**	asparagus fern		Y
Asplenium sp.		Y	
*Aster subulatus**	bushy starwort	Y	
Atriplex ?cinerea	grey saltbush	Y	
*Atriplex hastata**		Y	
Atriplex australasica	green saltbush		Y
*Avena fatua**	wild oat	Y	
Avicennia marina	grey mangrove	Y	Y
*Axonopus affinis**	narrow-leafed carpet grass	Y	
Azolla ?pinnata	ferny azolla	Y	
Banksia integrifolia	coastal honeysuckle	Y	Y
Banksia serrata	old-man banksia	Y	
Baumea articulata	jointed twig-rush	Y	
Baumea juncea	bare twig-rush	Y	Y
Bidens pilosa	cobbler's pegs	Y	
Blechnum camfieldii[#]	swampwater fern	Y	
Blechnum indicum	bungwall fern	Y	
Bothriochloa macra	redleg	Y	
*Brassica tournefortii**	Mediterranean turnip	Y	
Breynia oblongifolia	coffee bush	Y	Y
Cakile edentula var. *edentula**	American sea rocket	Y	
Callitris rhomboidea	Port Jackson pine	Y	
Calystegia soldanella	sea bindweed	Y	
*Canna indica**	canna	Y	
*Cardiospermum grandiflorum**	balloon vine	Y	
Carex appressa	tall sedge	Y	

Carex breviculmis	short-stem sedge, common grass-sedge	Y	
*Carpobrotus aequilaterus**	angled pigface	Y	
Carpobrotus glaucescens	pigface	Y	
Cassytha paniculata	devil's twine	Y	
Cassytha pubescens	downy dodder laurel	Y	Y
Casuarina littoralis	black sheoak	Y	Y
Casuarina glauca	swap oak	Y	Y
Casuarina torulosa	forest oak	Y	
Cayratia clematidea	native grape	Y	
Centaurium sp.		Y	
Centella asiatica	Indian pennywort, gotu cola	Y	
Centipeda minima	spreading sneeze weed	Y	
*Ceratochloa unioloides**	prairie grass	Y	
Cheilanthes ?tenuifolia	rock fern	Y	
*Chenopodium ambrosioides**	Mexican tea	Y	
*Chenopodium murale **	nettle-leaf goosefoot	Y	
Chenopodiumtrigonon	fishweed	Y	
Christella dentata#	binung	Y	
*Chrysanthemoides moniliferum subsp. rotu**	bitou bush or boneseed	Y	Y
*Cinnamomum camphora**	camphor laurel	Y	
*Cirsium vulgare**	spear thistle	Y	
Cissus antarctica	kangaroo vine, water vine	Y	
Clematis aristata	old man's beard	Y	
Clematis glycinoides	headache vine	Y	Y
Clerodendrum tomentosum	hairy clerodendrum, downy chance tree	Y	
Commelina cyanea	scurvey weed	Y	Y
*Conyza albida**	tall fleabane	Y	Y
*Conyza parva**		Y	Y
*Coprosma repens**	taupata, New Zealand laurel	Y	
*Coreopsis lanceolata**	coreopsis	Y	
*Cortaderia selloana**	pampas grass	Y	
Corybas pruinosus	toothed helmet orchid	Y	
*Cotoneaster glaucophylla**	large-leaf cotoneaster	Y	
*Cotoneaster pannosa**	silver-leaf cotoneaster	Y	
Cotula australis	common cotula	Y	
Cotula coronopifolia	waterbuttons	Y	
Cotula longipes	creeping cotula	Y	
Crinum pedunculatum#	swamp lilly	Y	
Cupaniopsis anacardioides	tuckeroo	Y	Y
Cyclosorus gongylodes#	Willdenow's maiden fern	Y	
Cymbopogon refractus	barbwire grass	Y	
Cynodon dactylon	common couch	Y	Y
Cyperus brevifolius	Mullumbimby couch	Y	Y
Cyperus congestus	dense flat sedge	Y	
*Cyperus eragrostis**	umbrella sedge	Y	
Cyperus laevis		Y	
Cyperus polystachyos	bunchy sedge	Y	
Desmodium rhytidophyllum	rusty tick-trefoil	Y	
Desmodium varians	slender tick-trefoil	Y	Y
Deyeuxia quadriseta	reed bent grass	Y	

Dianella revoluta	blue flax lilly	Y	Y
Digitaria didactyla	Queensland blue couch	Y	
Digitaria parviflora	small-flowered finger grass	Y	
Dillwynia glaberrima	smooth parrot-pea	Y	
Dodonaea triquetra	hop bush	Y	
Drosera peltata	sundew	Y	
Echinopogon caespitosus	tufted hedgehog grass	Y	
Echinopogon ovatus	forest hedgehog grass	Y	
*Echium lycopsis**	Patterson's curse	Y	
*Ehrharta erecta**	panic veldt grass	Y	Y
*Eichhornia crassipes**	water hyacinth	Y	
Eleocharis gracilis	slender spike rush	Y	
Epaltes australis	spreading nut-heads	Y	
Eragrostis brownii	Brown's love grass	Y	
Eragrostis leptostachya	paddock lovegrass	Y	
Eragrostis philippica		Y	
*Erythrina lysistemon X sykesii**	coral tree	Y	
Eucalyptus botryoides	bangalay	Y	
Eucalyptus robusta	swamp mahogany		Y
*Eupatorium adenophorum**	crofton weed	Y	
*Euphorbia peplus**	petty spurge	Y	
*Euphorbia tirucalli**	naked lady	Y	
Eustrephus latifolius	wombat berry	Y	Y
Exocarpos cupressiformis	bush cherry	Y	Y
*Facelis retusa**		Y	
Ficus coronata	sand-paper fig	Y	
Ficus rubiginosa	Port Jackson fig	Y	
Ficus superba var. *henneana*#	deciduous fig	Y	
Fimbristylis ferruginea		Y	
*Foeniculum vulgare**	fennel	Y	
*Fumaria capreolata**	white-flowered fumitory	Y	
Gahnia clarkei	tall saw-sedge	Y	
Gahnia sieberana	red-fruit saw-sedge	Y	Y
Galium propinquum	Maori bedstraw	Y	Y
Geitonoplesium cymosum	scrambling lily	Y	Y
Geranium homeanum		Y	
Glochidion ferdinandi var. *ferdinandi*	cheese tree	Y	Y
Glochidion ferdinandi var. *pubens*	hairy cheese tree		Y
Glycine clandestina	twining glycine	Y	Y
Gnaphalium sp.		Y	
Gonocarpus micranthus	creeping raspwort	Y	
Gonocarpus teucrioides	raspwort	Y	Y
Halophila decipiens		Y	
Halophila ovalis	paddleweed	Y	
Hardenbergia violacea	purple coral pea	Y	
Helichrysum apiculatum	yellow buttons	Y	
Helichrysum diosmifolium	rice flower, white dogwood	Y	
Hemarthria uncinata	mat grass	Y	
Heterozostera tasmanica	eelgrass	Y	
Hibbertia linearis var. *obtusifolia*	narrow leaf hibbertia	Y	
Hibbertia scandens	climbing guinea flower	Y	Y

Hydrocotyle acutiloba		Y	
*Hydrocotyle bonariensis**	pennywort	Y	
Hydrocotyle laxiflora	stinking pennywort	Y	
Hypericum japonicum	matted St John's wort	Y	
*Hypochoeris radicata**	flat weed	Y	
Hypolepis muelleri	harsh ground fern	Y	
Imperata cylindrica var. *major*	blady grass	Y	Y
Indigofera australis	Australian indigo	Y	
*Ipomoea indica**	morning glory	Y	
Isolepis nodosa	knobby club-rush	Y	Y
*Juncus acutus**	spiny rush		Y
*Juncus capillaceus**		Y	
Juncus cognatus	rush	Y	
Juncus kraussii	sea rush	Y	Y
Juncus pallidus	pale rush	Y	
Juncus planifolius	broad-leaf rush	Y	
Juncus sp. *'D'*		Y	
Juncus sp. *unid.*		Y	
Juncus usitatus	common rush	Y	Y
Kennedia prostrata	running postman, scarlet coral pea	Y	
Kennedia rubicunda	dusky coral pea	Y	
Kunzea ambigua	tick bush	Y	Y
*Lantana camara**	lantana	Y	Y
Lemna minor	duckweed	Y	
*Lepidium bonariense**	peppercress	Y	
Lepidosperma sp.		Y	
Leptospermum attenuatum	paperbark tea-tree	Y	
Leptospermum juniperinum	prickly tea-tree	Y	
Leptospermum laevigatum	coast tea-tree	Y	Y
Lepyrodia scariosa	chaffy scale rush	Y	
Leucopogon parviflorus	coastal beard-heath, native currant	Y	
*Ligustrum sinense**	small-leafed or chinese privet	Y	
Lobelia alata	angled lobelia	Y	
Lomandra longifolia	mat rush	Y	
*Lonicera japonica**	Japanese honeysuckle	Y	
Ludwigia sp.		Y	
*Lycium ferocissimum**	African box-thorn	Y	
Maclura cochinchinensis	cockspur thorn	Y	
Malva sp. *	mallow	Y	
Marsdenia rostrata	milk vine	Y	Y
*Medicago arabica**	spotted medic	Y	
Medicago polymorpha var. *vulgaris**	burr medic	Y	
Melaleuca ericifolia	swamp paperbark	Y	Y
Melaleuca quinquenervia	paperbark or broadleaved tea-tree	Y	
*Melilotus indica**	hexham scent or island melilot	Y	
Microlaena stipoides	weeping grass	Y	Y
*Modiola caroliniana**	red flower mallow	Y	
Monotoca elliptica	tree broom-heath	Y	Y
Muellerina celastroides	coast mistletoe	Y	

Narcissus sp. *	jonquil	Y	
Notelaea longifolia	mock olive	Y	Y
*Oenothera ?indecora**		Y	
*Oenothera drummondii**	beach primrose	Y	
*Oenothera stricta**	scented primrose	Y	
*Olea africana**	wild olive	Y	Y
Olea europaea subsp. *cuspidata**	African olive		Y
Omalanthus ?populifolius	bleeding heart, native poplar	Y	
Opercularia aspera	thin stink weed	Y	Y
Opercularia varia	stink weed	Y	
Oplismenus aemulus	basket grass	Y	Y
Oplismenus imbecillis			Y
*Opuntia stricta**	prickly pear	Y	
Ottochloa gracillima	ottochloa	Y	
Oxalis corniculata	yellow wood sorrel	Y	
Pandorea pandorana	wonga wonga vine	Y	
*Parapholis incurva**	coast barb grass	Y	
Parsonsia straminea	common silkpod	Y	Y
*Paspalum dilatatum**	paspalum	Y	
Paspalum paspaloides	water couch	Y	
*Paspalum urvillei**	vasey grass	Y	
Paspalum vaginatum	salt water couch	Y	
*Pelargonium capitatum**	rose pelargonium	Y	
Pellaea falcata	sickle fern	Y	
Pellaea viridis	green cliff brake	Y	
*Pennisetum clandestinum**	kikuyu	Y	
Phragmites australis	common reed	Y	
*Phytolacca octandra**	ink weed	Y	
Pimelea linifolia	slender rice flower or granny's bonnet	Y	Y
*Pinus radiata**	Monterey pine	Y	
Pittosporum revolutum	rough fruit pittosporum	Y	Y
Pittosporum undulatum	mock orange or sweet pittosporum	Y	Y
Plantago coronopus ssp. *Coronopus**	bucks-horn plantain	Y	
*Plantago lanceolata**	ribwort or rib-grass	Y	
Platycerium bifurcatum	elk horn	Y	
Plectranthus parviflorus	cock spur	Y	
Poa affinis		Y	Y
Polycarpon tetraphyllum	four-leaf or all-seed	Y	
*Polygala myrtifolia**	myrtleleaf milkwort	Y	
Polygonum decipiens	slender knott weed	Y	
Polygonum lapathifolium	pale knotweed	Y	
Pomax umbellata	pomax	Y	
Poranthera microphylla	small poranthera	Y	
Posidonia australis	strapweed, tapeweed	Y	
Pratia purpurascens	white root	Y	
Pteridium esculentum	bracken	Y	Y
Pterostylis sp.		Y	Y
Pyrrosia rupestris	rock felt-fern	Y	
*Ranunculus ?muricatus**	sharp buttercup or rough-seeded buttercup	Y	

*Ranunculus ?repens**	creeping buttercup	Y	
Rapanea variabilis	muttonwood	Y	Y
Ricinocarpos pinifolius	wedding bush	Y	
*Ricinus communis**	castor oil plant	Y	
*Rubus vulgaris**	blackberry or bramble	Y	
Rumex brownii	swamp dock	Y	
*Rumex crispus**	curled dock	Y	
Rumex sp.		Y	
Salsola kali var. *kali*	saltwort	Y	
Samolus repens	creeping brookweed	Y	Y
Sarcocornia quinqueflora	samphire or glasswort	Y	Y
Sarcopetalum harveyanum	pearl vine	Y	
Scaevola calendulacea	scented fan-flower	Y	
Scirpus cernuus		Y	
Scirpus litoralis#		Y	
Scirpus validus	river club-rush	Y	
Selliera radicans	swamp weed	Y	
Senecio bipinnatisectus		Y	
Senecio hispidulus var. *hispidulus*	hill fireweed	Y	
Senecio lautres	fire weed	Y	
Senecio lautus	variable groundsel	Y	
Senecio linearifolius	common fireweed	Y	
*Senecio mikanioides**	cape ivy	Y	
Senecio quadridentatus	cotton fireweed	Y	
Sida rhombifolia	Paddy's lucerne	Y	
Smilax glyciphylla	sarsaparilla	Y	Y
Solanum ?gracilius		Y	
*Solanum mauritianum**	wild tobacco tree	Y	
*Solanum nigrum**	blackberry nightshade	Y	
Solanum nodiflorum ssp. *nutans*		Y	
*Solanum sodomaeum**	apple of sodom	Y	
*Sonchus asper**	rough sowthistle	Y	
*Sonchus oleraceus**	common sowthistle	Y	Y
*Spergula arvensis**	corn spurrey	Y	
Spinifex hirsutus	hairy spinifex	Y	
Spirodela pusilla	duckweed	Y	
*Sporobolus africanus**	Parramatta grass	Y	
Sporobolus virginicus	sand couch	Y	
*Stellaria media**	chick weed	Y	
*Stenotaphrum secundatum**	buffalo grass	Y	Y
Stephania japonica var. *discolor*	tape vine	Y	Y
Streblus brunonianus#	whalebone tree	Y	
Suaeda australis	seablite	Y	
Syzygium coolminianum	brush cherry	Y	
*Taraxacum officinale**	dandelion	Y	
Tetragonia tetragonioides	New Zealand spinach	Y	
Themeda australis	kangaroo grass	Y	
*Tradescantia albiflora**	wandering jew	Y	
Triglochin striata	streaked arrowgrass	Y	
*Tropaeolum majus**	nasturtium	Y	
Typha orientalis	bull-rush	Y	
*Verbascum virgatum**	twiggy mullein	Y	

*Verbena bonariensis**	purple top	Y	
*Verbena litoralis**		Y	
Veronica plebeia	trailing speedwell, creeping speedwell	Y	
Vicia sativa ssp. *angustifolia**	narrow-leaf vetch	Y	
Viola hederacea	native violet, ivy-leaved violet	Y	
*Watsonia angusta**	watsonia	Y	
*Xanthium chinese**	noogoora burr	Y	
*Zantedeschia aethiopica**	arum lilly	Y	
Zostera capricorni	eelgrass	Y	Y

* Introduced species

\# Native plants uncommon in the Sydney region

\+ The 2008 survey was not as comprehensive as the ALS (1977) survey.

Source: ALS (1977); SMCMA (in press)

Glossary

Accretion	An increase in size as a result of accumulation of material.
Aeolian (or eolian)	Carried or produced by the wind.
Adverse conditions	Ecological conditions unusually hostile to the survival of plant or animal species, such as occur during severe weather like prolonged drought, flooding, or cold.
Alluvial	Relating to material deposited by running water (NLWRAAC 2002).
Anthropogenic	Relating to or resulting from the influence that humans have on the natural world.
Assessment	The identification of the status of, and threats to, wetlands as a basis for the collection of more specific information through monitoring activities (Ramsar Convention 2002, Resolution VIII.6).
Baseline	Condition at a starting point. For Ramsar wetlands it will usually be the time of listing of a Ramsar site (Lambert and Elix 2006).
Bathymetry	The measurement of the depths of oceans, seas, lakes or other large water bodies and the data derived from such measurements.
Benchmark	A standard or point of reference (ANZECC and ARMCANZ 2000). A pre-determined state (based on the values which are sought to be protected) to be achieved or maintained (Lambert and 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.
Biogeographic region	A scientifically rigorous determination of regions as established using biological and physical parameters such as climate, soil type, and vegetation cover. (Ramsar Convention 2005).
Biodiversity	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 and among species and diversity within and among ecosystems (Millennium Ecosystem Assessment 2003).
Biota	Refers to all plant and animal life in an area (NLWRAAC 2002).
Catchment	The total area draining into a river, reservoir, or other body of water (ANZECC and ARMCANZ 2000a).
Change in ecological character	The human-induced adverse alteration of any ecosystem component, process, and/or ecosystem benefit/service (Ramsar Convention 2005, Resolution IX.1 Annex A).
Community	An assemblage of organisms characterised by a distinctive combination of species occupying a common environment and interacting with one another (ANZECC and ARMCANZ 2000).

Conceptual model	Wetland conceptual models express ideas about components and processes deemed important for wetland ecosystems (Gross 2003).
Contracting Parties	Countries that are Member States to the Ramsar Convention on Wetlands; there were 159 as of 20 March 2009. Membership in the Convention is open to all states that are members of the United Nations, one of its specialised agencies, or the International Atomic Energy Agency, or is a Party to the Statute of the International Court of Justice (www.ramsar.org/key_cp_e.htm).
Critical stage	Stage of the life cycle of wetland-dependent species. Critical stages being those activities (such as breeding, migration stopovers, moulting) which if interrupted or prevented from occurring may threaten long-term conservation of the species (Ramsar Convention 2005).
Detritus	Organic material such as leaves and twigs (NLWRAAC 2002).
East Asian–Australasian Flyway	A corridor used by migratory waterbirds to fly from breeding and non-breeding areas. The flyway extends from within the Arctic Circle, through East and South-east Asia, to Australia and New Zealand. Stretching across 22 countries, it is one of eight major waterbird flyways recognised around the globe.
Ecological character	The combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point in time. Within this context, ecosystem benefits are defined in accordance with the variety of benefits to people (Ecosystem Services). The Millennium Ecosystem Assessment (2003) defines ecosystem services as 'the benefits that people receive from ecosystems' (Ramsar Convention 2005, Resolution IX.1 Annex A). 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 ones may contain smaller ones (Ramsar Convention 2005).
Ecosystems	Described within the Millennium Ecosystem Assessment (2003) as the complex of living communities (including human communities) and non-living environment (Ecosystem Components) interacting (through Ecological Processes) as a functional unit which provides inter alia a variety of benefits to people (Ecosystem Services) (Ramsar Convention 2005, Resolution IX.1 Annex A).

Ecosystem components	Include the physical, chemical and biological parts of a wetland (from large scale to very small scale, for example habitat, species and genes) (Ramsar Convention 2005, Resolution IX.1 Annex A).
Ecosystem processes	The dynamic forces within an ecosystem. They include all those processes that occur between organisms and within and between populations and communities, including interactions with the non-living environment that result in existing ecosystems and bring about changes in ecosystems over time. They may be physical, chemical or biological.
Ecosystem services	The benefits that people receive or obtain from an ecosystem. The components of ecosystem services are provisioning (for example food and water), regulating (flood control), cultural (spiritual, recreational), and supporting (nutrient cycling, ecological value) (Millennium Ecosystem Assessment 2003). See also Benefit.
El Niño and La Nina–Southern Oscillation (ENSO)	ENSO is a global climatic phenomenon marked by fluctuating shifts in air pressure between the Indo–Australian and eastern regions of the tropical Pacific Ocean. El Niño and La Niña refer to extreme phases in the 2–7 year cycle. During the warm 'El Niño' phase, the Australian seaboard cools, south-east trade winds slacken and extended periods of drought are experienced in Australia. In the cool 'La Niña' phase, the seas around Australia warm, the south-east trade winds intensify, and widespread rain and flooding occur in Australia. The strength and phase of ENSO is measure by the Southern Oscillation Index (OzCoast and OzEstuaries 2005).
Endemic	Refers to a species that is unique or confined to a specific locality (NLWRAAC 2002).
Erosion	The group of natural processes, including weathering, dissolution, abrasion, corrosion and transportation, by which material is worn away from the Earth’s surface.
Estuary	Broadly described as a semi-enclosed coastal water body where salt from the open sea mixes with fresh water draining from the land, or where marine and fluvial sediments occur together (NLWRAAC 2002).
Eutrophication	The process by which a body of water becomes rich in dissolved nutrients from a source of organic matter, thereby encouraging the growth and decomposition of oxygen-depleting plant life and resulting in harm to other organisms.
Flood tide	A rising tide – the phase of the tide between low water and the next high tide (OzCoast and OzEstuaries 2005).
Fluvial	Relating to or occurring in a river (NLWRAAC 2002).
Geomorphology	The study of the nature and history of landforms and the processes which create them (OzCoast and OzEstuaries 2005).

Groundwater	Water below the ground surface.
Habitat	Area occupied by and supporting living organisms. Also used to mean the environmental attributes required by a particular species or its ecological niche (Millennium Ecosystem Assessment 2003).
Holocene	Most recent geologic epoch of the Quaternary period of geologic time, extending from about 10,000 years ago to the present. The Holocene is the latest epoch of the Quaternary period (OzCoast and OzEstuaries 2005).
Hydrology	The study of the movement, distribution and quality of the water that moves through a particular system.
Intertidal	The zone of shore between the high water mark and low water mark (NLWRAAC 2002).
Introduced (non-native) species	A species that does not originate or occur naturally in a particular country.
Limits of acceptable change	The variation that is considered acceptable in a particular component or process of the ecological character of the wetland without indicating change in ecological character which may lead to a reduction or loss of the criteria for which the site was Ramsar listed (modified from the definition adopted by Phillips 2006).
List of Wetlands of International Importance (‘the Ramsar list’)	The list of wetlands which have been designated by the Ramsar Contracting Party in which they reside as internationally important, according to one or more of the criteria that have been adopted by the Conference of the Parties (www.ramsar.org/about/about_glossary.htm).
Monitoring	The collection of specific information for management purposes in response to hypotheses derived from assessment activities, and the use of these monitoring results for implementing management.
Native species	A species that originates and occurs naturally in a particular country.
Neap tide	Tide smaller than the mean tidal range. Occurs about every two weeks, during half-moons (OzCoast and OzEstuaries 2005).
Pleistocene	Epoch of geologic time, about 1.6 million to 10,000 years ago, characterised by the disappearance of continental ice sheets and the appearance of humans.
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 (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 (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 (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 (www.ramsar.org/about/about_glossary.htm).
Semi-diurnal tide	Twice daily phases of high tide and low tide.
Spring tide	Tide greater than the mean tidal range. Occurs about every two weeks, when the Moon is full or new (OzCoast and OzEstuaries 2005).
Tidal prism	Volume of water moving into and out of an estuary or coastal waterway during the tidal cycle (OzCoast and OzEstuaries 2005).
Wetlands	Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres (Ramsar Convention 1987).
Wetland types	As defined by the Ramsar Convention's wetland classification system (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, within the context of sustainable development.

Abbreviations

ANZECC	Australian and New Zealand Environment Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
CAMBA	China–Australia Migratory Bird Agreement
DECC	Department of Environment and Climate Change NSW
DECCW	Department of Environment, Climate Change and Water NSW
DEWHA	Department of the Environment, Water, Heritage and the Arts (Commonwealth)
DSE	Department of Sustainability and Environment (Victoria)
ENSO	El Niño–Southern Oscillation
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth)
FM Act	*Fisheries Management Act 1994* (NSW)
I&I NSW	Industry and Investment NSW
IPCC	Intergovernmental Panel on Climate Change
JAMBA	Japan–Australia Migratory Bird Agreement
NPWS	National Parks and Wildlife Service NSW
RIS	Ramsar Information Sheet
ROKAMBA	Republic of Korea–Australia Migratory Bird Agreement
SMCMA	Sydney Metropolitan Catchment Management Authority
TSC Act	*Threatened Species Conservation Act 1995* (NSW)

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