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.

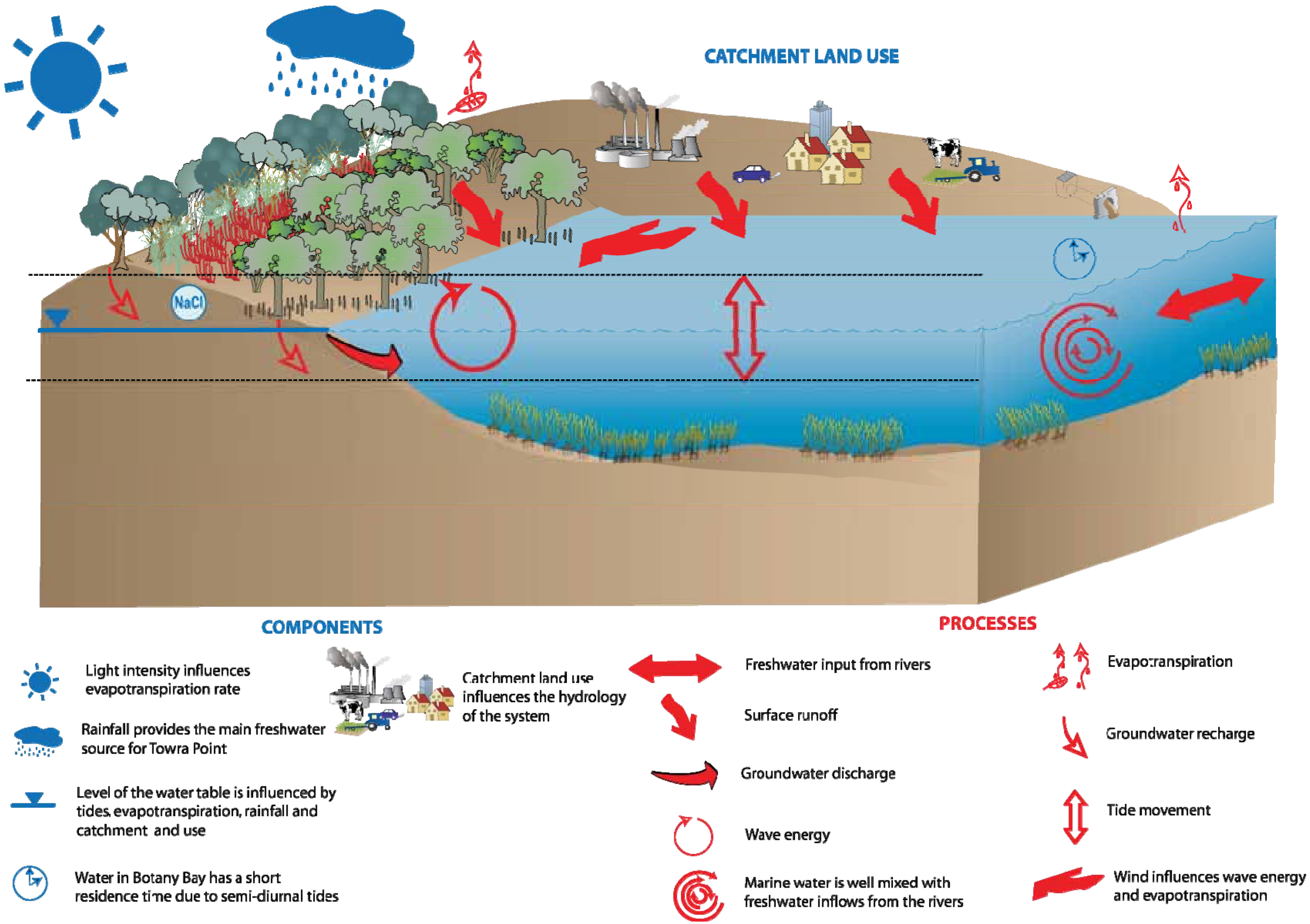
5.3.1 Tides

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.

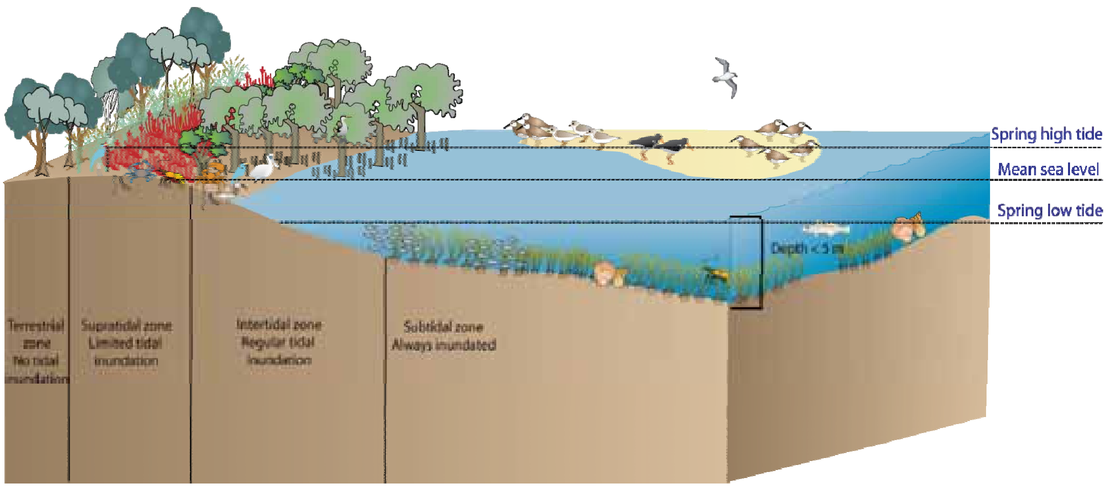


Figure 35: Tidal zones

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).

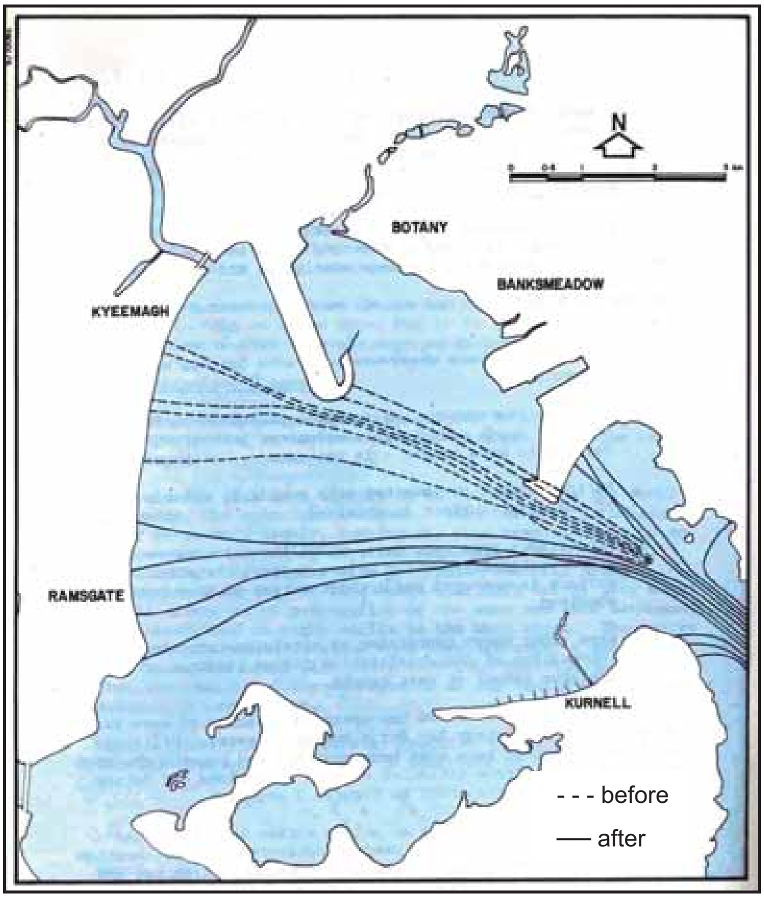
Changes in wave action since 1984

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

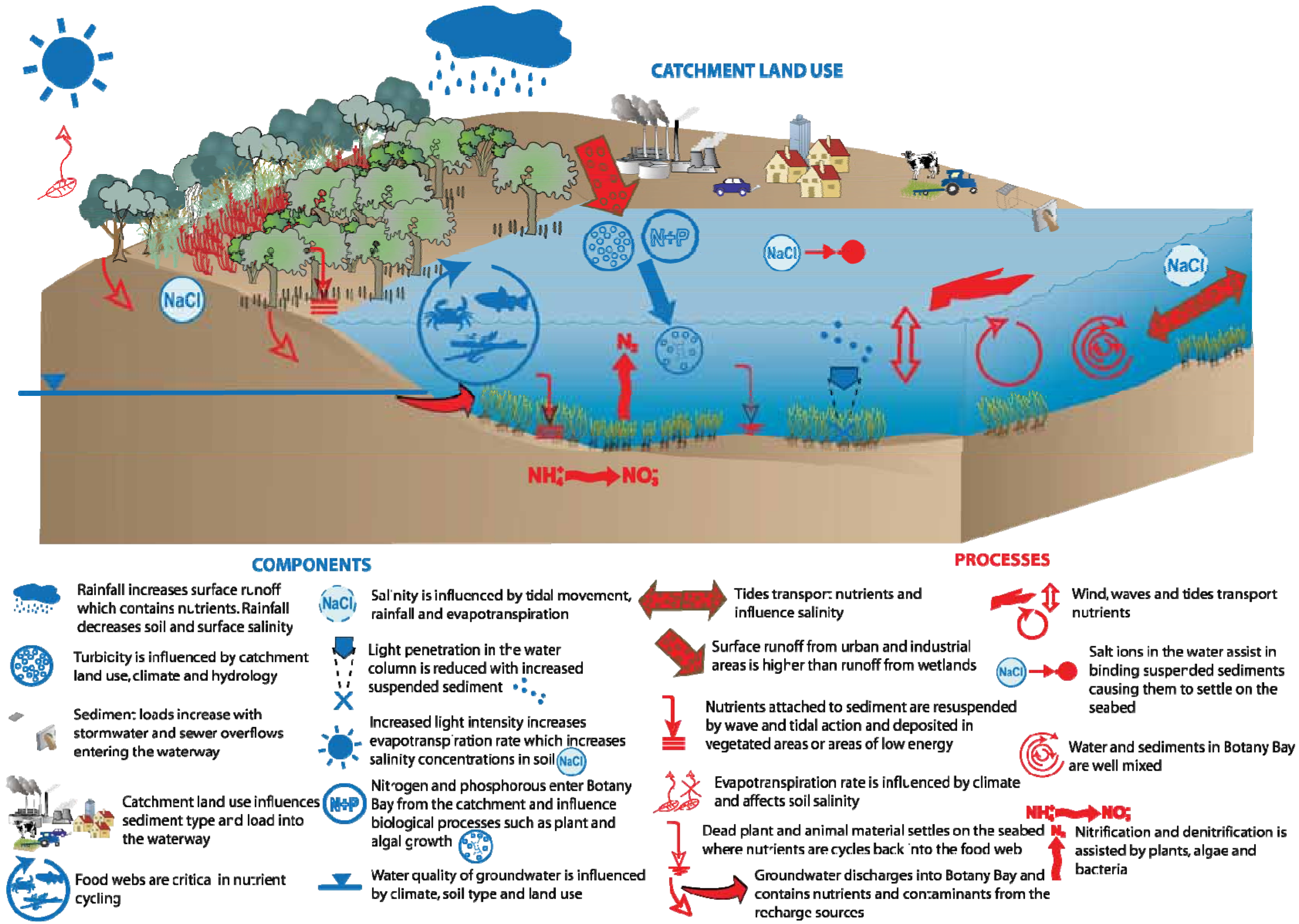
The location of Towra Point within a semi-diurnal marine embayment ensures that it is a well flushed and predominantly saline environment. The majority of fresh water is from rainfall with potentially some fluvial influence. Historically, freshwater flow from the Georges River to Botany Bay during dry 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.

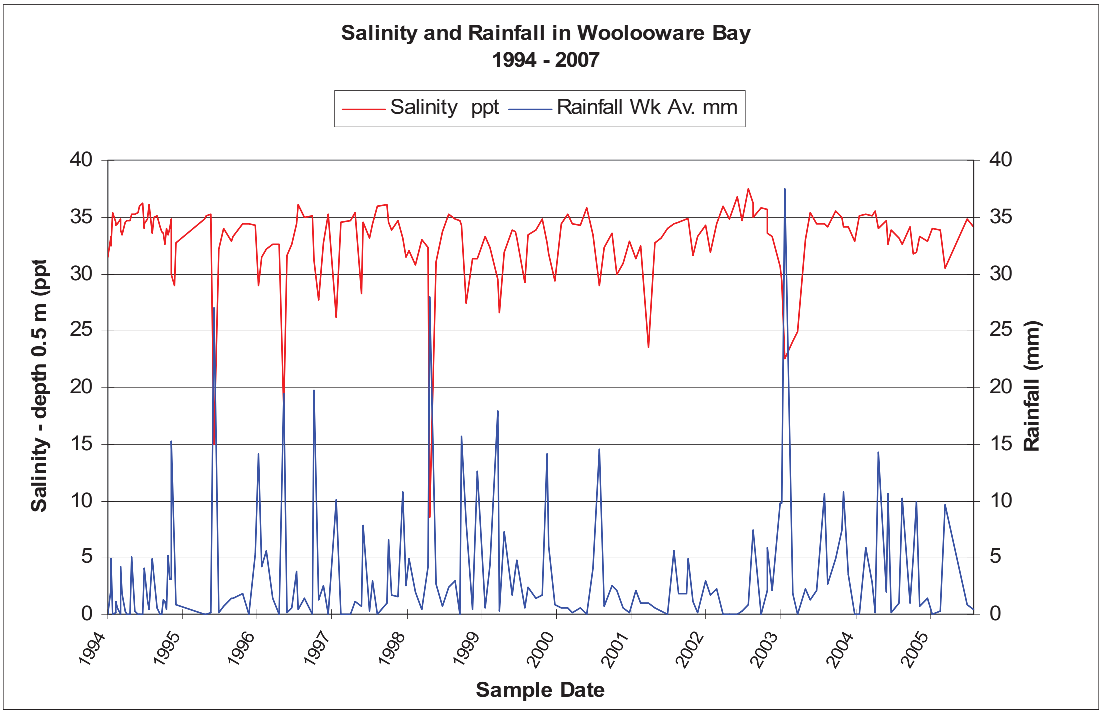
Clarke and Hannon (1970) conducted a study on the effects of salinity on plant growth and distribution. A summary of the results is below.

- 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

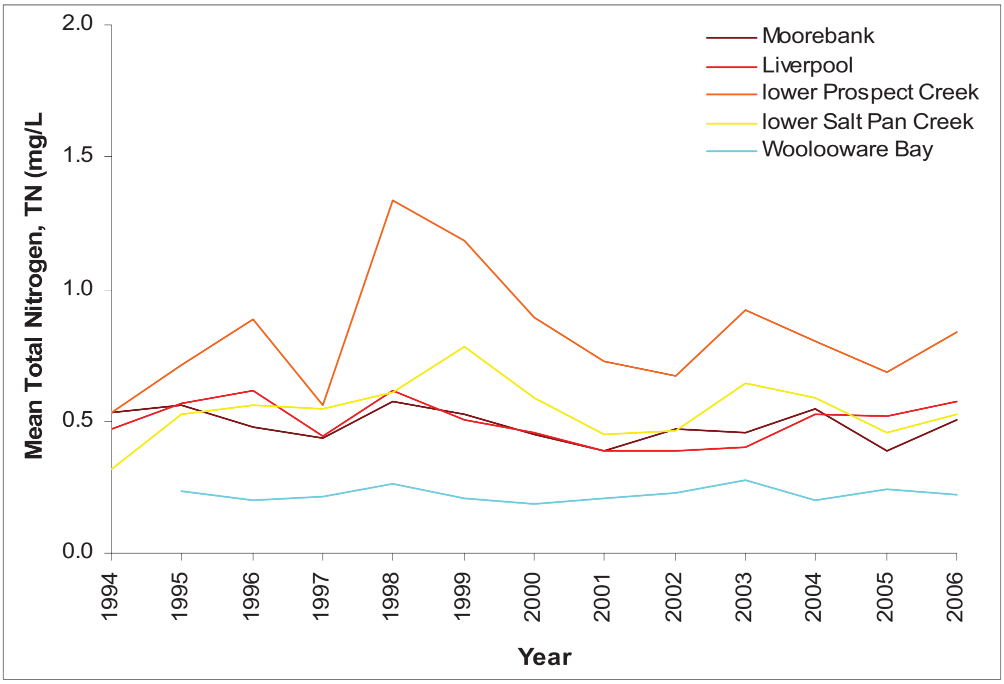
Nitrogen is present in Botany Bay in a number inorganic (nitrate, nitrite, ammonia and nitrogen gas) and organic (amino acids, proteins, urea and humic acids) forms (OzCoast and OzEstuaries 2005). Sources include runoff from rural land, stormwater and sewer overflows, runoff from urban and industrial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

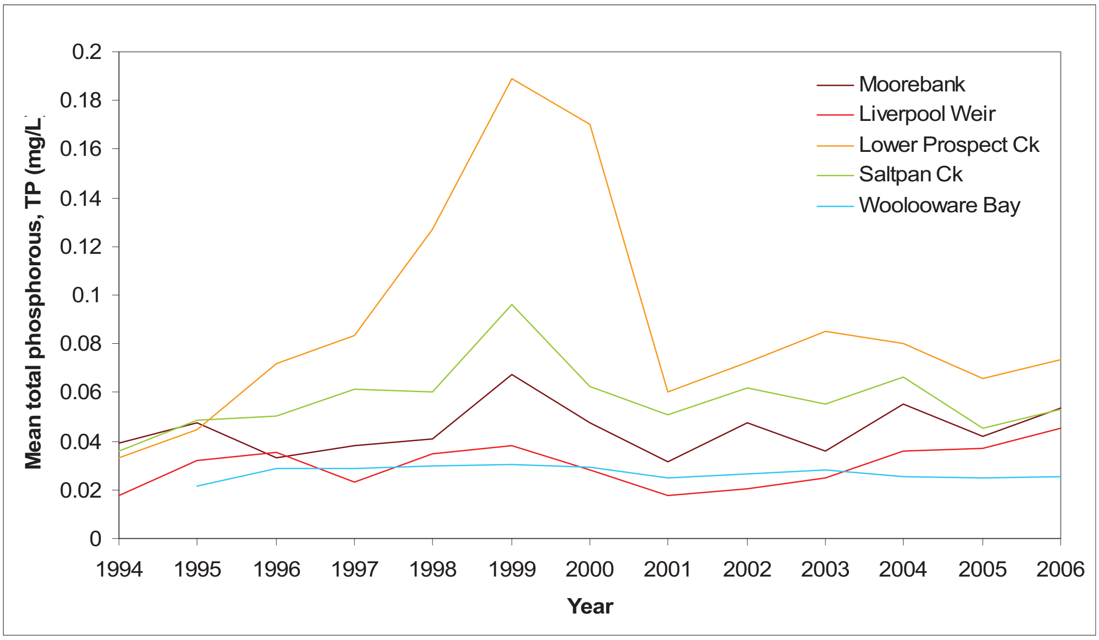
5.4.3 Heavy metals

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.

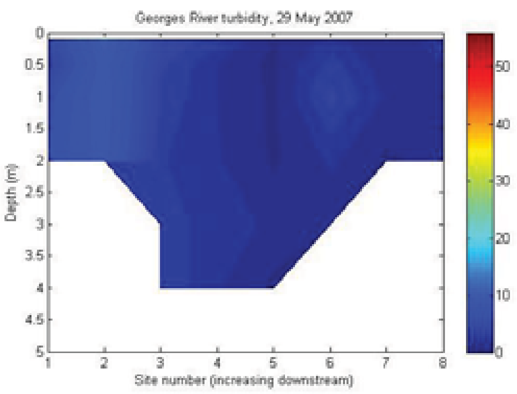
5.4.4 Turbidity

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).

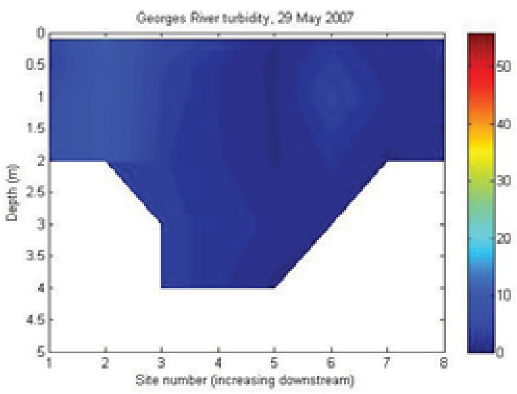
Turbidity is particularly relevant to Towra Point and surrounding seagrass meadows as it determines the conditions for seagrass growth. Increased turbidity reduces light available to seagrasses on the seabed or river bed. Seagrasses require high light intensity for survival and in Botany Bay are not 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

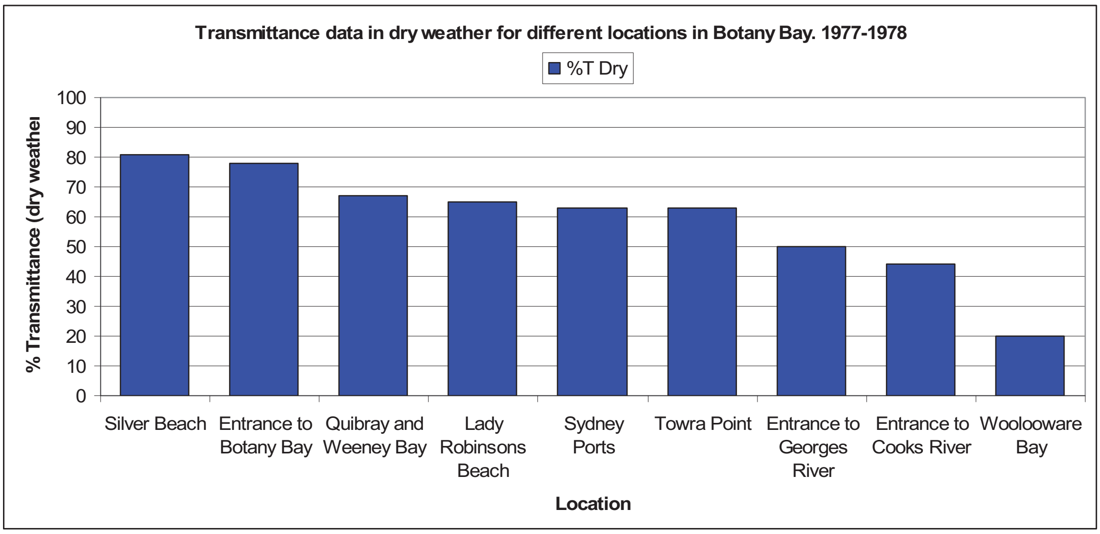
ecosystem. The settling of suspended sediments can damage gills of fish, affect crustaceans and smother benthic habitats (OzCoast and OzEstuaries 2005).

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

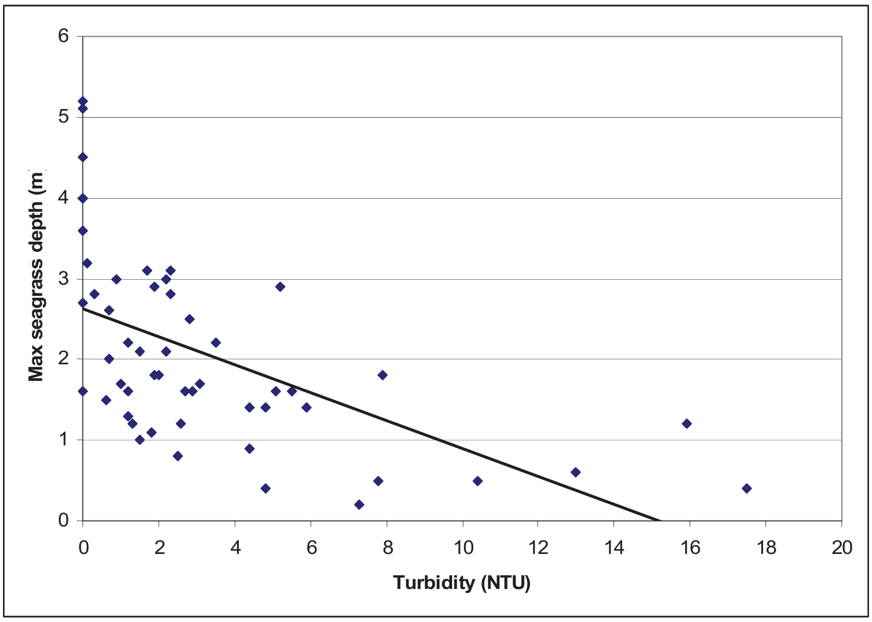
into the catchment, especially into the Georges River. Two major Sydney Water initiatives include improving the sewage system and reducing sewer overflows, and installing and maintaining stormwater quality improvement devices that help to remove litter and sediment from stormwater effluent (SWC 2007a).

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).

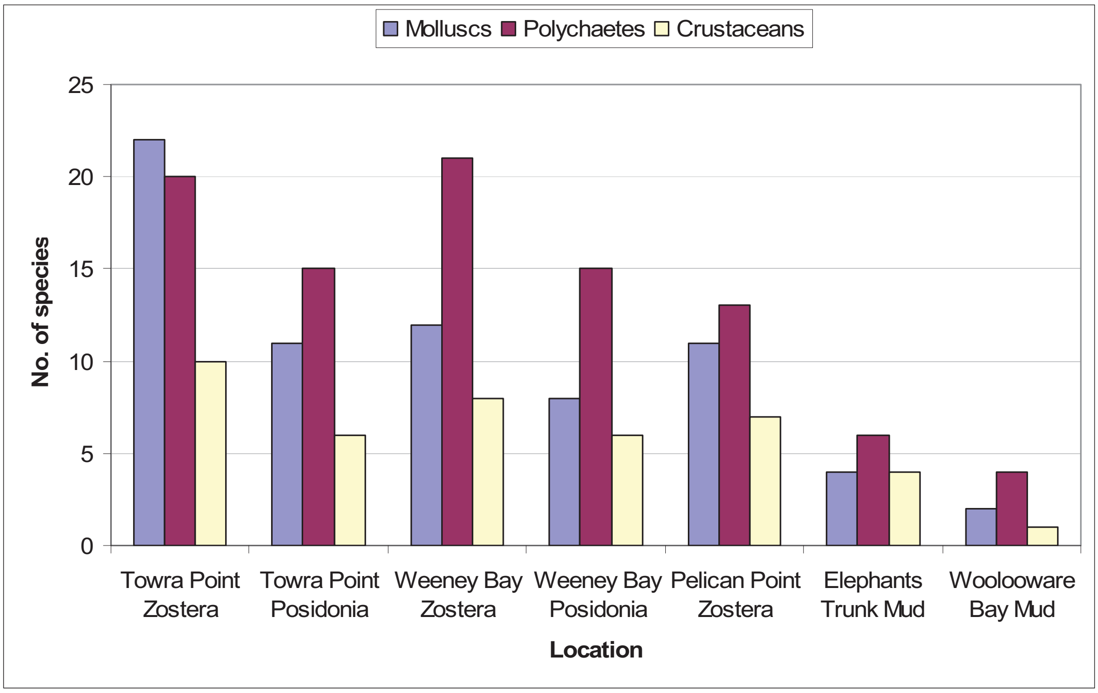
Macro-invertebrates are important components of the food web in the ecosystem at Towra Point. Mollusc, polychaete and crustacean species are part of the diet of fish and birds (Bell et al. 1984; Lane 1987). Seagrass meadows adjacent to the intertidal zone are critical as excess nutrients in the form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

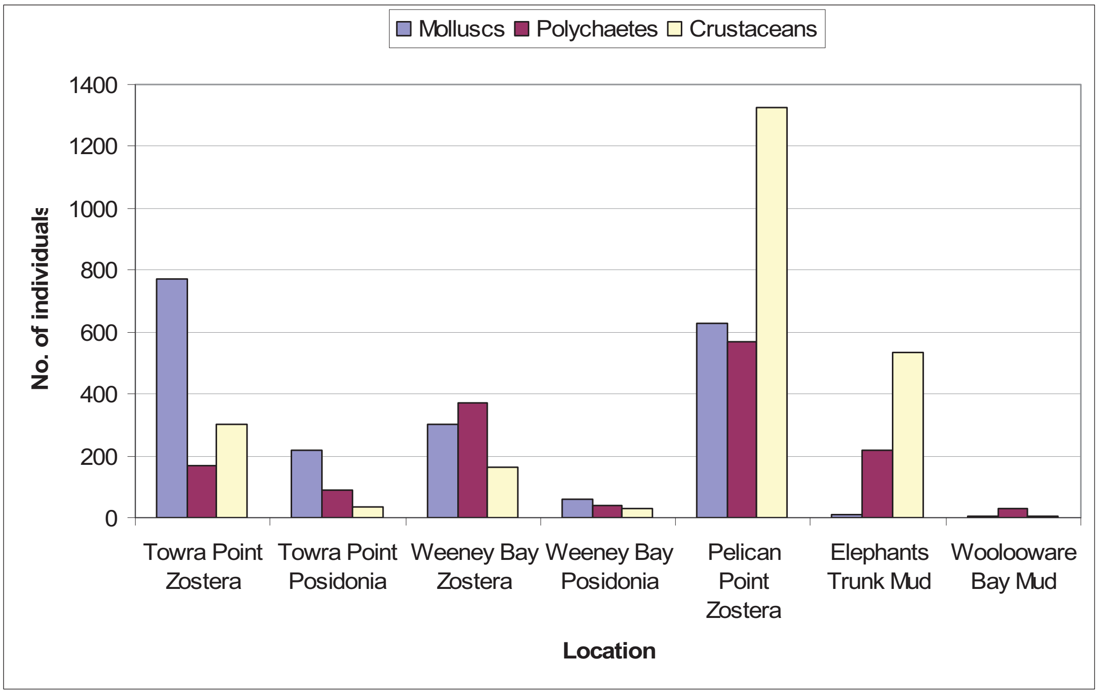
Changes in macro-invertebrates since 1984

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

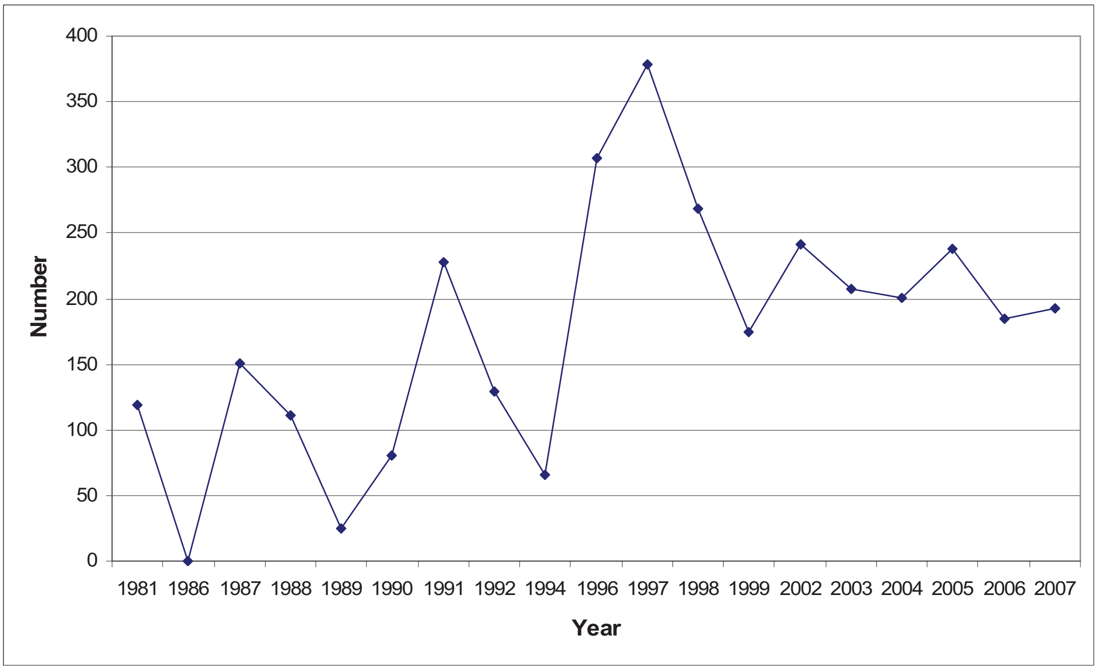
Changes in bird populations and habitats since 1984

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).



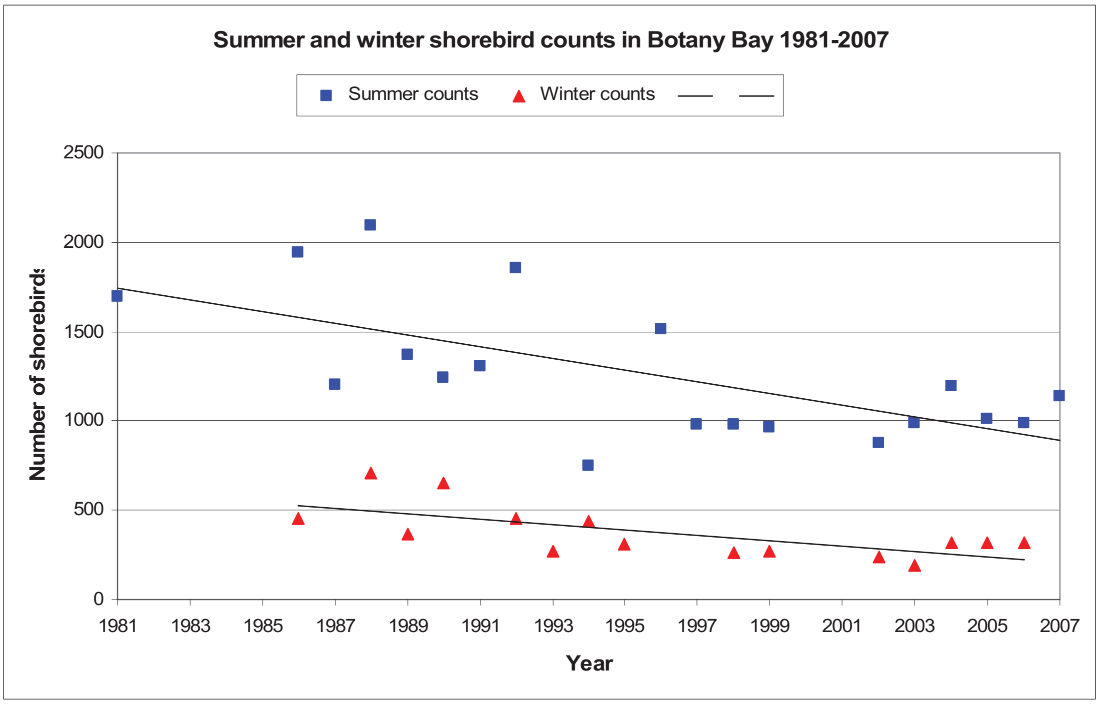
Adapted from WSG (2007) and AWSG (2008).

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.