Careel Bay Wetlands Plan of Management

June 1998

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1.0 INTRODUCTION

1.1 The Plan of Management

Careel Bay Wetlands Plan of Management has been prepared for the conservation of the estuarine wetland within the context of the entire catchment. The plan of management describes the estuary and the laws, treaties, policies and strategies that apply. The important biophysical characteristics of the wetland are described and current environmental impacts, management issues, objectives and actions are outlined. Actions achieved are to be reported annually in the State of the Environment Report.

1.2 Scope of the Plan

The primary focus of this Plan of Management is on the estuarine wetland complex in the context of the surrounding catchment.

The estuarine complex includes the seagrass beds, intertidal mudflats, Mangrove forest, Saltmarsh and Swamp-Oak Woodland and the surrounding catchment includes Careel Creek, Avalon Commercial Centre and Residential Zones dominated by plant communities relating to sandstone and Narrabeen Group Slopes.

2.0 SIGNIFICANCE AND GOALS

2.1 Statement of Significance

"Given the small total area of intertidal wetlands in NSW (5,500 ha of saltmarsh, 10,000 ha of Mangroves) even small areas are significant (in the case of saltmarsh, the variability between sites is also important).

"Careel Bay is of high value because of the range of communities - holding a substantial area of mudflat (a fairly rare habitat in NSW, and one essential for waders).

"Amongst the seagrasses, the presence of Posidonia is of high significance given the susceptibility of Posidonia to disturbance, and the fact that the site is approaching the northern limit of the species.

"The saltmarsh, although small, does have features of interest- such as Bacopa monnieri, approaching its southern limit.

"Swamp Oak Woodland Casuarina glauca is poorly conserved in the Sydney region

"As a complex, I would regard Careel Bay highly at any scale including state"
(Paul Adam, 1997).

"The avifauna of Careel Bay has a number of features of special conservation significance at regional level (Sydney region, County of Cumberland) or local level (Pittwater Local Government Area). Most importantly, it is a regionally significant site for the Bush Stone-curlew. This species is listed on the *Threatened Species Conservation Act 1995* as endangered in New South Wales". This is the only site in the Sydney Region where the species regularly occurs and may be an important site for dispersing young from Rileys Island.

"Mangrove gerygone is a species of regional significance, which has a resident population of at least two pairs in the Careel Bay mangroves; the species has only recently colonised the Sydney region and is currently known from only three localities in the region, Botany Bay in 1982, Brooklyn in 1990 and Careel Bay in 1991.

" two other species listed in the Threatened Species Conservation Act 1995 have been recorded at Careel Bay or its catchment, the Glossy Black-Cockatoo and the Pied Oystercatcher. The Glossy Black-Cockatoo is an occasional visitor to McKay Reserve, where there are large numbers of two of its major food trees, *Allocasuarina littoralis* and *A. torulosa* (Smith and Smith 1992a). The birds probably come from the population in Ku-ring-gai Chase National Park. The Pied Oystercatcher is a very rare visitor to Careel Bay, only recorded by Steege (1988), and the site has little significance for this species."
(Smith and Smith, 1997)

Of local conservation significance are the Striated Heron, Whistling Kite and Azure Kingfisher, which appear to be resident in Careel Bay. At least one breeding pair of Striated Heron is at Careel Bay; it is an uncommon species around Sydney that is restricted to sites with extensive mangrove stands. A resident pair of Whistling Kite ranges widely in search of food around the shores of Pittwater, from West Head to Church Point, and formerly nested regularly in the Careel Bay catchment in tall *Eucalyptus maculata* trees on Stokes Point peninsula (Martin 1992 & 1997); it is uncommon around Sydney and its numbers have noticeably declined over the years (Hoskin et al. 1991).

A resident breeding pair of Azure Kingfisher has occurred along Careel Creek since at least 1972 (Hutchings and Recher 1974, Steege 1988, Smith and Smith 1997) and is another species which, although not especially rare, has declined in the Sydney region (Hoskin et al. 1991).

> *"Careel Bay provides habitat of high local conservation significance for a variety of waterbirds. These include migratory waders from the Northern Hemisphere such as the Eastern Curlew, Whimbrel and Bar-tailed Godwit. Australia has an international obligation to protect these species and their habitat under several international agreements, the Japan-Australia and China-Australia Migratory Birds Agreements and the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention). The apparent decline since 1972 in the numbers and variety of migratory waders using Careel Bay must be viewed with some concern.*
>
> *"The most significant of the migratory waders recorded at Careel Bay is the Eastern Curlew. The majority of the world population comes to Australia. It is not rare but it is generally considered a species of special concern, with declining numbers being recorded at several sites in Australia (Smith 1991, Watkins 1993, Garnett 1993)."*
>
> *Smith and Smith 1997*

Careel Bay also has local significance as a temporary stopover for waterbirds and bushbirds during migration with a surprising variety of migratory bushbirds recorded during April, 1997, especially in the casuarina forest (Rose Robin, Golden Whistler, Rufous Whistler, Black-faced Monarch, Leaden Flycatcher, Grey Fantail and Rufous Fantail). None of these species was seen at the site during the counts in February and March.

The estuary plays a major role as a nursery ground for aquatic organisms. The preservation of the ecosystems and our sustainable use of them requires recognition of the diverse and complex interactions between estuarine biota and their habitats.

2.2 Goals for Wetlands Management

Council is seeking to restore and manage the estuarine wetland to conserve its natural heritage values and to facilitate sympathetic public use of the area to achieve the following broad goals for Careel Bay:

- To conserve, maintain and restore the native wetland vegetation, its assemblages of fauna and thus sustain ecological processes within the diverse complex;
- To maintain the filtering function of the wetland;
- To restore habitat and mitigate threatening processes operating on the wetland and on threatened species, significant and migratory species; and
- To provide appropriate and compatible opportunities for environmental education and passive recreation for the local and wider community.

3.0 DESCRIPTION

3.1 Location of Careel Bay

Careel Bay (33° 37' S; 151° 20' E) is located on the eastern shore of Pittwater, 40 km north of Sydney. It is part of the Broken Bay estuary, and is derived from a tributary of the drowned river valley of the lower Hawkesbury River. The bay is about 2.5 km long and covers an area of 1.5 km^2. Careel Bay is shallow (<5 m in depth) with intertidal flats. To the north of the entrance is Sand Point, and to the south is Stokes Point. Careel Bay opens to Pittwater Estuary, which in turn opens to the Broken Bay. The depth of Broken Bay extends to 20 m. Pittwater Estuary adjacent to Careel Bay is relatively shallow with depths ranging from 4 to 5m. Ku-Ring-Gai Chase National Park is the western border of Pittwater Estuary (AWT, 1997).

Careel Creek is the main source of fresh water to Careel Bay. The bay also receives freshwater from rain and stormwater drains. The creek traverses Barrenjoey Road and extends to Avalon.

3.2 Land Tenure

The intertidal land is crown land owned by the Department of Land and Water Conservation mangrove forest, saltmarsh and some casuarina forest have been zoned 7(a) Environment Protection "A", while the seagrass beds and mudflats have been zoned 7(a1) Environment Protection – Waterways.

Pittwater Council is responsible for the care, control and management of part of Careel Bay owned by the Department of Land and Water Conservation. Part of the wtland is owned by Pittwater Council.

Two sports/playing fields are located on the northeastern side of Careel Creek, previously land fill/ tip zones. Both are zoned 6 (a) Public Open Space extending over crown lands and council owned land (Hitchcock Reserve) and (Careel Bay Playing fields).

3.3 Catchment Uses

The catchment of Careel Bay includes the sub-catchments of Careel Creek, Stokes Point Catchment, and parts of Whale Beach and Palm Beach catchments (Figure 2). The land use patterns of these catchments include residential, recreation open space and commercial including marina and boat sheds.

The major land use patterns in different sub-catchments of Careel Bay are given in Table 1.

The catchment drains to Careel Bay through the stormwater system and Careel Creek. Appendix 1 shows the sewer overflow locations in the entire peninsula. Some overflow sites are located close to the mangroves and saltmarshes while the others are close to Careel Creek.

Sub-catchment	Catchment area (km^2)	Land use
Careel Creek	3.73	Residential, Commercial, School, Golf Course, Open space
Stokes Point	0.89	Residential, Open space
Whale Beach	2.03	Residential l, Open Space, Commercial
Palm Beach*	3.53	Residential, Open Space, Commercial, Boatsheds

Table 1. Land use pattern in Careel Bay Catchment.
*(*Main part of the catchment drains to the ocean*

3.4 History

Pittwater became a port for early settlers in 1790 and shipbuilding and limeburning commenced in the 1800s. There were two shipyards, one south of Careel Bay near Stokes Point, the other at Clareville in 1855 (Anderson, 1920). The earliest settlement of Careel Bay occurred in 1818 and the area developed as farmlands (RAHS,1920). From 1840 to 1880 extensive farms were established, in the area south of Avalon Road, east of Careel Creek and east of Barrenjoey Road.

By 1906 the waterway was a popular yacht racing area with such events as the Pittwater Regatta. Fred's Boatshed was established in the early 1900's and run by Fred Shearer. The same site is now occupied by a public wharf and Careel Bay Boatshed and slipway, owned by the Royal Sydney Yacht Squadron.

Elements of farms were still evident in the 1946 photos on the eastern side of Barrenjoey Road. It is likely that the intertidal wetlands and adjoining land had been used for stock grazing over this period and that mangroves and casuarinas may have been felled to promote pasture growth. The extensive areas of young mangrove regeneration in the photos may suggest regeneration following the cessation of grazing and associated clearing practices. Dense casuarina forest was restricted to only a few tiny stands in 1946, but rapid regeneration followed and by 1961 it covered a large area around the saltmarsh.

A council tip was operated on the east side of Careel Creek in the 1960s which was filled and converted to playing fields when the and early 1970s. An Equestrian area also occupied an area on this side of the creek. A number of tracks were established through the saltmarsh and mangroves. In the middle of the marsh a 2 m high and 2 m wide mound was made to install an electricity pole (Wilton, 1996).

During this time the area has changed from a sparsely populated district of mainly weekend and holiday homes and small farms, and extensive bushland, to densely populated suburbs (McDonald McPhee and Burton 1989).

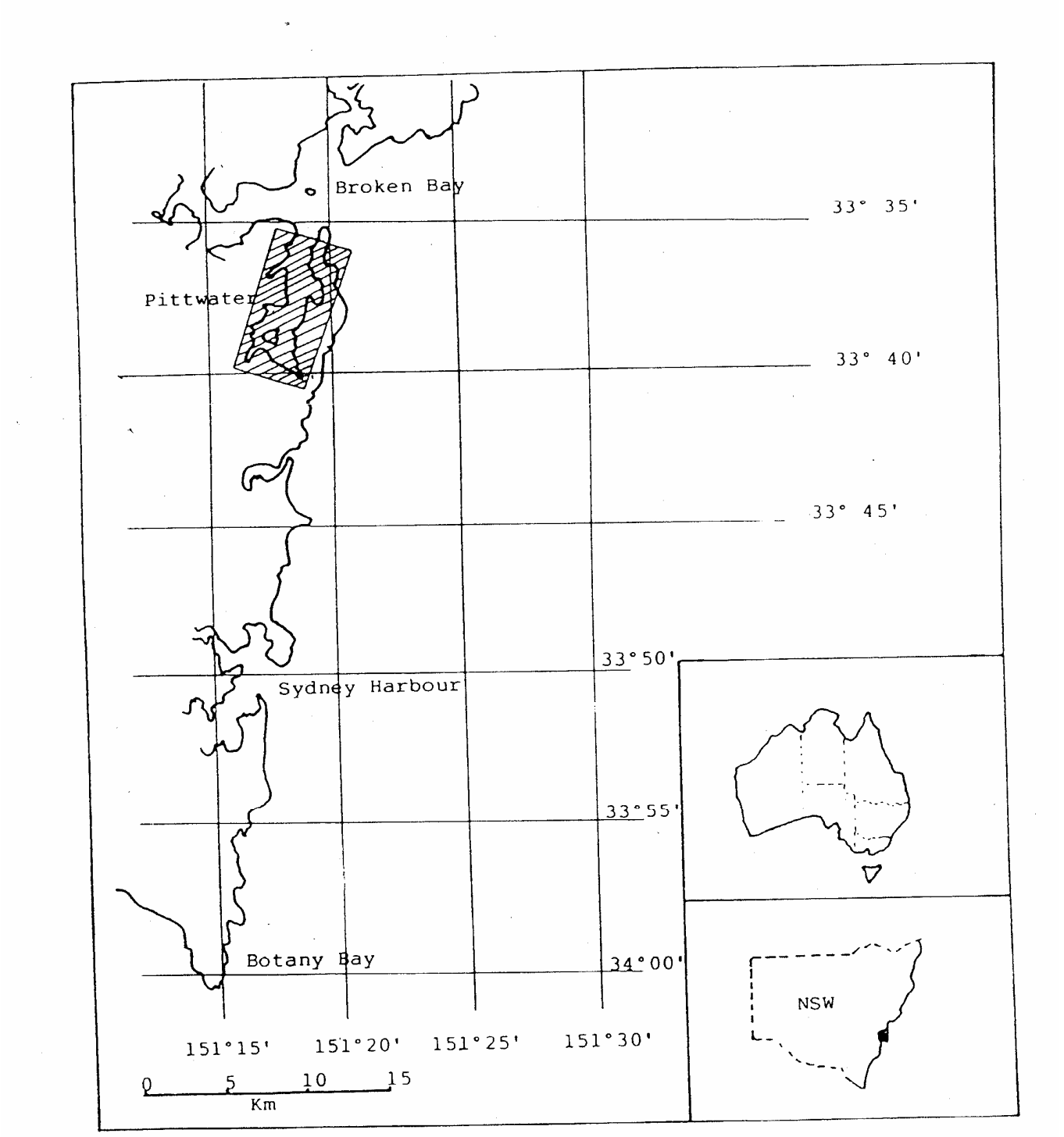


Figure 1 Locality Map

4.0 PLANNING CONTEXT

Several Acts of Parliament, state and local government policies, plans and strategies and International Treaties affect the management of Careel Bay. The conservation process and the plan of management follow the *Australian Natural Heritage Charter for the Conservation of Places of Natural Heritage Significance* (Cairns, 1996).

It should be noted that any Pittwater Council documents which contradict any information or actions in the *Careel Bay Wetlands Plan of Management* should be reviewed to ensure consistency with this plan. All current and future landowners and developers in the catchment have a responsibility for environmental conservation and management in consultation with Pittwater Council.

4.1 Crown Land Management Act, 1989

Careel Bay wetlands are largely comprised of Crown land and is under the jurisdiction of the Crown Land Management Act 1989 (CLMA). The CLMA states that a plan of management may be prepared for Crown land and Section 11 of the CLMA lists the principles of Crown land management:

- Environmental protection principles be observed in relation to the management and administration of Crown land.
- The natural resources of Crown land (including water, soil, flora, fauna and scenic quality) be conserved wherever possible.
- Public use and enjoyment of appropriate Crown land be encouraged.
- Where appropriate, multiple use of Crown land be encouraged.
- Where appropriate, Crown land should be used and managed in such a way that both the land and its resources are sustained in perpetuity.
- Crown land may be occupied, used, sold, leased or otherwise dealt with in the best interests of the State consistent with the above principles.

4.2 Local Government Act 1993

For consistency of Council's management of its natural areas, the Local Government Act 1993 may also be applied. The owner of the majority of the land is the Department of Land and Water Conservation and Pittwater Council has care, control and management of part of the crown land. Council is also the owner of part of the land.

Under this act, the category of the land is a natural area which is further categorised as wetland, watercourse and bushland.

4.3 Fisheries Management Act

The Fisheries Management Act (1994) is enforced by the NSW Fisheries with the purpose of managing the fisheries resources. It makes provision for habitat protection plans, protection for mangroves and certain other marine vegetation, declaration of aquatic reserves and declaration of Intertidal Protected Area's(IPA's). A conflict has been identified in the Careel Bay Estuarine Wetlands where there are currently commercial hauling grounds over the nursery areas of seagrasses.

4.4 Environmental Planning and Assessment Act, 1979

The Environmental Planning and Assessment Act 1979 ensures that effects on the natural environment are taken into account by Council in granting consent to development or approval to undertake activities. The Act is also the enabling legislation for several State Environmental Planning Policies, including SEPP 19 and SEPP 44 which relate to Careel Bay and the Pittwater Local Environment Plan, 1993.

4.4.1 State Environmental Planning Policies

State Environmental Planning Policy No. 19 (SEPP 19) – Bushland in Urban Areas was made to project remnant bushland in urban areas within New South Wales. Careel Bay meets the definition of bushland under SEPP 19. Under the Policy, Councils may prepare management plans for bushland.

Circular No. B13 of the Department of Urban Affairs and Planning states that a management plan should:

- Describe the bushland in light of the aims and objectives of the Policy;
- Include measures to enable the recreational use of bushland, where appropriate;
- Specify the intended methods of bush fire reduction, measures to prevent bushland degradation and restore degraded areas.

The Department of Urban Affairs and Planning has also published management guidelines for urban bushland. The guidelines identify the need to prepare a resource inventory of the bushland area, to identify

management objectives and strategies, and to derive an action plan for the bushland.

SEPP 19 requires that Council take into account the effect of future development and building works on urban bushland and, in particular, on soil erosion, the siltation of streams and waterways and the spread of weeks and exotic plants.

State Environmental Protection Policy 44 – Koala Habitat Protection applies to Pittwater. In 1995, Pittwater Council resolved to prepare a Koala habitat plan of management for the local government area in order to identify and conserve known and potential habitat areas.

4.4.2 Pittwater Local Environment Plan

The Pittwater Local Environment Plan (Pittwater Council 1993) as amended, zones the mangrove forest, saltmarsh and Casuarina forest as 7(a) (Environment Protection 'A') while the seagrass beds and mud flats are zoned 7(a1), (Environment Protection – Waterways). Under this LEP no developments can proceed without development consent. Consent is only permitted for drainage, landscaping, passive public recreation and utility installations.

The Pittwater LEP is complemented by the Pittwater Waterways Plan of Management and Development Control Plan 14 (Pittwater 1994). These plans provide more detailed provisions than the LEP in regard to development standards. The controls relate to works or activities carried out within the waterway (ie below Mean High Water Mark).

4.5 Threatened Species Conservation Act

The Threatened Species Conservation Act 1995 protects species, populations and communities listed as Endangered or Vulnerable. Several threatened species occur at Careel Bay, namely, the endangered species Bush Stone-curlew, Pied Oystercatcher and Glossy Black-cockatoo. Records exist for other threatened species from the surrounding catchment including the Koala and Squirrel Glider.

4.6 The NSW Wetlands Management Policy

The NSW Wetlands Management Policy (DLWC, 1993) is a component policy of the NSW State Rivers and Estuaries Policy (Water Resources Council, 1993). This policy established the framework for the management of rivers and estuaries and related systems based on the Total Catchment Management (TCM) philosophy and ecologically sustainable development principles. The Policy provides guidance on the wise use and rehabilitation of wetlands and associated best management practices.

4.7 NSW Draft Estuary Management Manual

The Estuary Management Policy is a component of the State Rivers and Estuary Policy (1993). The Estuary Management Policy was developed by the NSW Government to address resource planning and management on a catchment basis. The Policy focuses on tidal waterways and coastal lakes. The Estuary Management Manual was produced in draft form to assist the community with the implementation of the Estuary Management Policy in accordance with existing legislation.

The Estuary Management Manual outlines guidelines for the development and implementation of Estuary Management Plans. This document is intended to be a Plan of Management under the Estuary Management Manual.

4.8 NSW Floodplain Development Manual

The primary objective of the Government's Flood Policy is to reduce the impact of flooding and flood liability on individual owners and occupiers, and to reduce private and public losses resulting from flooding. The Floodplain Development Manual was developed to assist consent authorities to deal with flood liable land. The Manual covers the floodplain management system, administration and guidelines for development.

A Flood Study is being prepared for Careel Creek.

4.9 Sydney Northern Beaches Catchment Management Committee Strategic Plan

The Sydney Northern Beaches Catchment Management Committee (SNBCMC) was established in 1992 to coordinate and facilitate catchment management between Manly and Pittwater. The functions of the Committee are set out under the Catchment Management Act 1989.

The mission of the SNBCMC (1997, p.4) is:

"To ensure that management in the catchments is biologically and socially in keeping with their protection and enhancement, based on the best information available."

The major components of the of the CMC's Strategy are land, water and habitat. The Strategy recognises the importance of economic and social features which have major impacts on catchments. Progressive implementation is emphasised and action plans are identified for each component.

4.10 Other Planning Instruments

A range of land use zones occur in the catchment.

For all adjoining residential zones various locality plans apply and these are:

- Careel Bay
- Avalon Central
- Draft Avalon Valley (new plan)
- Bilgola Plateau and Ridge
- Sand Point
- Pittwater Escarpment
- Pittwater Waterfront
- Palm Beach Ridgeline

Other Council Policies that may affect the use of adjoining land include:

- On-site stormwater detention
- Floodplains "Pittwater Estuary Wave Action & Tidal Inundation"

4.11 Urban Bushland Plan of Management

The Pittwater Urban Bushland Plan of Management (UBPM) (Pittwater Council, 1996) is a generic management plan for the Pittwater local government area prepared under the requirements of the NSW Local Government Act 1993. The UBPM provides management policies for all bushland areas. The objectives aim to fulfil management and statutory responsibilities and assist with the management of bushland for biodiversity, natural heritage, aesthetic, recreational, educational and scientific values.

4.12 Habitat and Wildlife Corridors Conservation Strategy

The Pittwater Habitat and Wildlife Corridors Conservation Strategy (1996) identifies habitats and corridors in Pittwater highlighting areas of priority for future action. Careel Bay is identified as an area of high priority in terms of bushland management.

Protection and enhancement of habitat and corridors are stressed with guidelines included for identifying and improving priority areas. Under the Local Government Act 1993 annual State of the Environment Reports must identify important wildlife and habitat corridors.

4.13 MIGRATORY BIRD AGREEMENTS – JAMBA, CAMBA and Bonn Convention

International Treaties have been signed for the protection of the habitats of migratory wading birds between the governments of Japan and Australia (JAMBA), China and Australia (CAMBA) and the Convention on the Conservation of Migratory Species and Wild Animals, signed at Bonn. A number of the bird species that occur at Careel Bay wetlands are protected under these treaties, including the Eastern Curlew, the Whimbrel and the Bar-tailed Godwit.

4.14 AGENDA 21

Agenda 21 was signed as part of the Rio Biodiversity Treaty representing international consensus on actions necessary to move the world towards the goal of ecologically sustainable development. As part of the agreement, each OSD country is required to produce a four yearly State of The Environment (SOE) Report and is required to produce a Local Agenda 21 plan integrating environmental, social and economic sustainability goals.

4.15 RAMSAR TREATY

The Ramsar Convention (1975) is also known as the 'Convention on Wetlands of International Importance especially as Waterfowl Habitat' and the 'Convention on Wetlands'. It is a worldwide intergovernmental treaty on 'conservation and wise use of natural resources' and is to 'provide a framework for international cooperation for the conservation and wise use of wetland habitats and resources'. The guidelines for management planning for RAMSAR and other wetlands include 4 components:

1) Description of the site and its processes,

2) Recognition of past modifications and future threats,

3) Evaluation and Objectives, and

4) Action Plan which includes: habitat management, species management, usage, access, education, interpretation, communication and research.

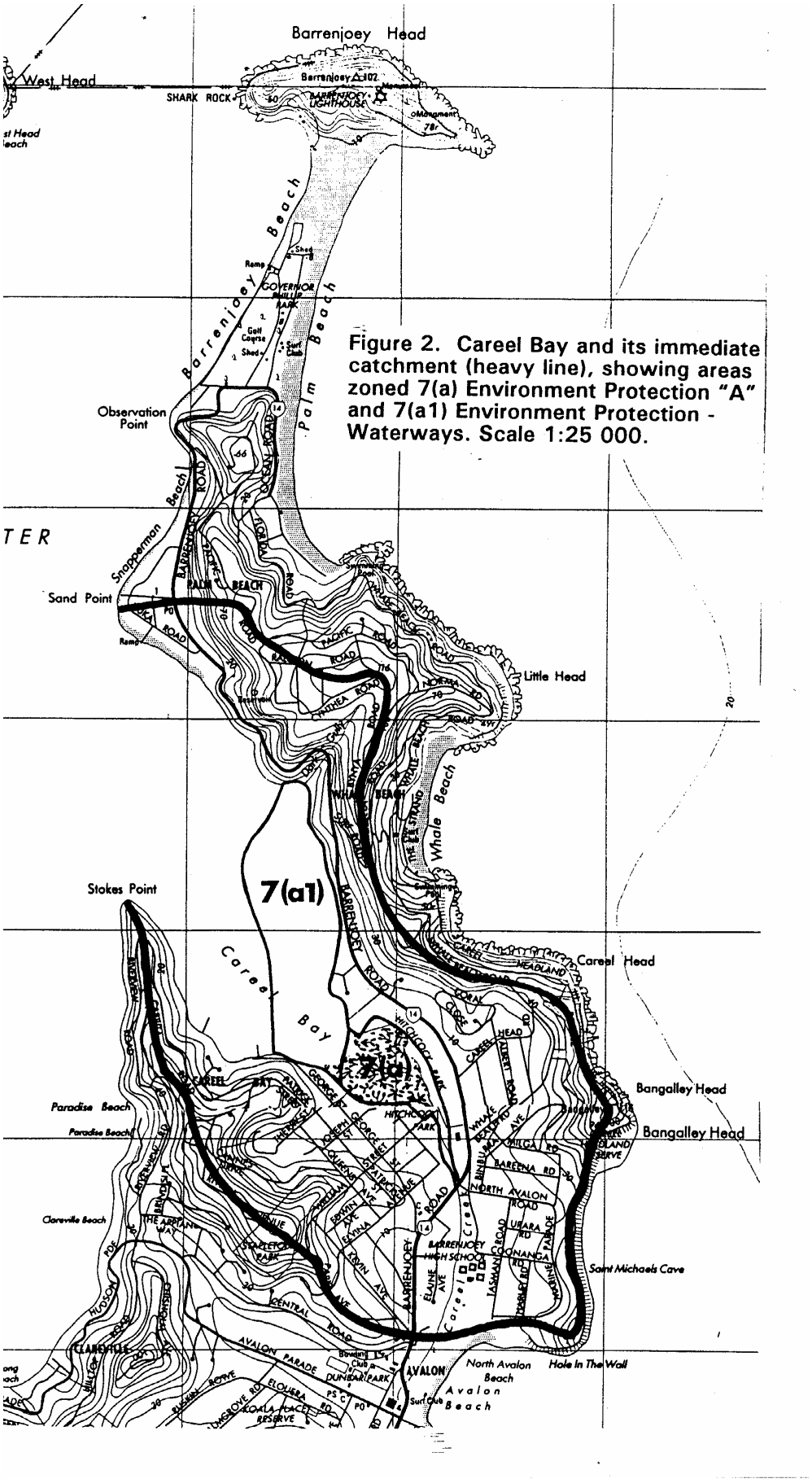


Figure 2 Immediate Catchment of Careel Bay

5.0 PHYSICAL GEOGRAPHY

Goals:

- To conserve the estuarine wetland and natural processes within the constraints of the catchment and estuary
- To manage water and sediment quality

5.1 Hydrodynamic processes

The movement of water in the estuary is mainly due to tide and fresh water inflow, while local eddy currents also contribute to vertical and horizontal movement of water.

5.1.1 Tide

The mean spring tide range at Sydney is 1.3 m. The tidal pattern within Pittwater resemble that of Sydney (AWACS 1991), but a tidal time lag exists in the estuary.

Shallow sections of the estuary where the flood tide is significantly higher than the ebb tide have resulted in causing upstream movement of water and sediment.

5.1.2 Freshwater flow

Freshwater input to Careel Bay is via Careel Creek, stormwater drains, runoff from residential houses and from direct rainfall. Freshwater inflows to the estuary fluctuate randomly in response to surface runoff from subcatchments. During large floods, freshwater flows are much greater than tidal flows. During rainfall events, sewage overflows may occur, and effluent can enter the stormwater bringing suspended solids, litter, hydrocarbons and other pollutants.

Flooding has been a problem in some areas of Pittwater and by the 1980s flooding was common in Catalina Crescent/Coonanga Road, Avalon; and Tasman Road/North Avalon Road/Marine Parade. Flooding was attributed to surcharges from undersized pipes and hydraulically deficient pipe junctions. During the October 1987 storms. The height of floodwater reached RL3.05 (Sinclair Knight & Partners, 1988). A Flood Study for Careel Creek is being undertaken to determine flood flows within the Catchment (Sept 1997). A Floodplain Management Study and Plan will follow providing strategies and actions.

5.1.3 Sea level

About 20,000 years ago the sea level was about 120 m below the present and estuaries extended into the sea. About 6000 years ago the sea level had stabilised but during the past 2000 years it has increased slightly. With the rise of sea level, sediments have been deposited and estuaries have migrated landwards.

According to Bryant, (1990) the sea level rise for Sydney Harbour is currently 0.4 to 1.4 mm/yr.

The future expected sea level rise will cause changes to the distribution of ecological communities in Careel Bay and its environs. Increasing flooding, tidal inundation, the flow of sediments to the bay, increased storms, increased wind action, expansion of the mangrove zone and continued landward migration and possible loss of the saltmarsh are expected.

Management Issues

Increased freshwater inflows, inundation, sediment movement and the impact on the biota that depend on sediments and tide, are the major issues associated with hydrodynamic processes.

Tide and water currents are partly responsible for the dispersion of sediments, erosion and accretion of various parts of the bay. These processes also play an important role in the development and maintenance of mudflats, and sedimentation rates upstream and downstream in the bay.

1. An observed increase in inundation and flooding in the upper estuary is due to a range of factors including: the increased freshwater input from domestic sources; decreased surface retention due to increased impermeable surfaces; interference with tidal flushing due to obstructions; reclamation of saltmarsh; sedimentation; estuarine tidal characteristics such as elevation of half-tide levels, time lag in the flow, low water velocities in the ebb tide and the sea level rise.

2. The fauna and flora within the bay are dependent on the maintenance of tidal variation. Mudflats which are the feeding habitats of migratory birds are exposed during the low tide. Filter feeders such as oysters and mussels feed during the high tide while deposit feeders such as gastropod molluscs and mudflat crabs feed during low tide.

3. Saltmarsh is inundated only by High Spring Tide and Equinoctial Tide, while mangrove are inundated by low tides. Further changes in tidal regime such as that from sea level rise or from increased urban development could affect the distribution of estuarine vegetation in the bay.

4. Changed floodplain/fill sites have caused the flow dynamics to change.

5. Urban runoff from hard surfaces may be affecting the salinity of the estuary, particularly the saltmarsh. Wilton has observed the impermeable nature of the saltmarsh to water

6. With most development adjacent the Bay being on fill, this may prevent percolation of surface water into the ground.

Management Objectives

- To promote research to assess the impact of water levels on the fauna and flora communities

- To maintain estuarine processes to maintain a natural water movement as far as possible within the estuary and catchment:

Performance Targets

- To continue the policy of On Site Detention for developments within the catchment.

- Monitor hydrological processes

- Monitor the impacts of hydrology on flora and fauna

Future Management Options

- Investigate retro fitting of detention basins in developed areas, following completion of flood studies.

5.2 Sedimentary processes

The current sedimentary processes in Careel Bay are influenced by the geological history of the land mass, recent weather patterns, tide and human activities.

5.2.1 Geology and historical sedimentary processes

Careel Bay is situated within the former tributary of the extensively drowned river valley of the lower Hawkesbury River. The river system was scoured to bedrock and then partially filled with sediment during the last post glacial sea level rise which finished 6000 years ago, drowning the river valley and bringing sea level to its present level. With the inundation of the Hawkesbury Valley by the sea, sand from the ocean side of Pittwater has progressively built up in a broad bar across the entrance until it reached Sand Point. The sandy beach north of Etival Street is a result of these sedimentary processes (AWT, 1997).

Avalon and Careel Bay are characterised by recent Quaternary Alluvium sands and muds through deposition of marine and estuarine sediments in the

lower catchment, and erosion of the upper catchment relating to the Mangrove Creek Soil Landscape.

The geology and soil landscapes within the catchment of Careel Bay include Hawkesbury Sandstone on the plateau, ridges and crests, Narrabeen sediments on the steep sideslopes and Quaternary Alluvium in the freshwater swamps of the Avalon Valley. The soil landscapes derived from these parent geologies are characterised by extreme, severe and very high soil erosion hazard (Chapman and Murphy, 1989).

Fossilised tubes of polychaete worms are present in the shale beds on Barrenjoey Head, considered to extend southwards to Newport, forming part of the lithology. This links the past historical geological processes to present day polychaete worms and other benthic organisms which are currently inhabiting the estuarine zone of Careel Bay, highlighting the need for preservation of the geodiversity and conservation of the processes.

5.2.2 Recent sedimentary processes

Natural Processes

Tidal motion in Careel Bay is insufficient to move sediments out of the bay, though it moves sediments within the bay. If tidal eddies around Sand Point or Stokes Point exist in sufficient strength, they could only contribute to the containment of sediment in Careel Bay and not to its removal.

The containment of sediment within the bay is attributed to two principal causes. Firstly, the action of waves brought on by winds from the westerly direction which produce active inward drift of beach sand, and secondly the growth of sea grasses, mangroves and saltmarshes which trap sediments in the intertidal and subtidal zones (AWT, 1997).

Accelerated Processes Due to Development

The landuse pattern in the catchment has affected the flow rates of suspended solids into the bay. As a result of the early rural settlement it is considered that the rates of erosion and siltation have accelerated and large quantities of organic matter have entered the water from clearing, burning, farm fertiliser and animal excreta (McLoughlin, 1987). The urban growth was most intense from 1950 to 1970 resulting in a heavy load of sediments to the bay being released (Blacker, 1977) with scant regard for erosional problems arising from development.

While development activities progressed in the general catchment, in the immediate surroundings of Careel Bay some activities occurred, which would have contributed more sediments to the bay. These events include:

- the construction of a landfill site in the south-east corner of Careel Bay adjacent to Careel Creek after 1965;
- the extension of the waste site/landfill along the eastern and northern perimeters of Careel Bay in 1972;
- the conversion of the landfill to the sports fields of Hitchcock Park; and
- continued urbanisation of the land surrounding Careel Bay.
- Introduction of sand in 1990-91 by Sydney Water backfilling sewer trenches appears to be linked to accumulated hard sand at the end of Etival Street.

In the bay there are two distinct forms of sediments, 'sand' and 'mud', the latter being the predominant form. The movement of suspended solids and bedload sediments have resulted in the upstream sections of Careel Bay accumulating muddy sediments. The litter from mangroves, saltmarshes and the hinterland vegetation also contributes organic matter to the sediments.

5.2.3 Trace metals in sediments

Trace metals occurring in coastal waters originate from diverse sources. In higher concentrations metals are toxic to estuarine organisms. Even when present in sub-lethal concentrations, heavy metals can have a number of debilitating effects that reduce health and survival of aquatic organisms. The toxic and sub-lethal effects of heavy metals are affected by factors such as pH, salinity, temperature, DO and carbon dioxide concentration. The metal content in the sediments is the result of human inputs as well as the physico-chemical processes in the sediments.

Since 1980, the concentration of chromium and nickel in Pittwater Estuary sediments has not increased significantly, but the concentration of copper, lead and zinc has increased, and shows variation across the area (Judge, 1992). The concentration of trace metals in the eastern estuary is higher than that in the western estuary

The main source of copper, zinc and some lead to the estuary is probably the boating activities. Antifouling paints used to contain small amounts of tin and copper which may have been deposited in the sediments. Zinc is used in modern boat motors for sacrificial anodes. Copper and zinc may also have originated from light industry and domestic activities. Light industries and roadways may have contributed lead to the estuary.

In Pittwater Estuary there is a tendency for manganese and copper to bind with sediments rather than iron and chromium.

Petroleum products enter estuarine waters as runoff from road surfaces, by wind and tidal action, oil leaks or discharges from motors of commercial and leisure boats. Currently, no information is available on the hydrocarbons in Careel Bay water.

Management Issues

The recent sediments in the bay are predominantly of terrestrial origin, movement of marine is considered insignificant. The causes of sediment movement are, development activities in the catchment, structures interfering with tidal flushing and reclamation of saltmarsh and housing development fringing the saltmarsh. ·

Landfill to the east of Careel Creek at Hitchcock Park, the playing fields and urban development are most likely to have contributed sediments to areas upstream of the bay and adjacent to the creek.

Impacts of sedimentation and bed load transport has direct reference to land elevation and to the natural vegetation that colonises the niche. Land elevation is one of the factors that contribute to plant succession in coastal communities. Sedimentation will also cause depth reduction, geomorphological alterations and can contribute to localised flooding, smother seagrasses.

Pollutants to the bay are in particulate or soluble form and originate from activities in the catchment and the surrounding bay. Some pollutants are associated with clay particles and can be transported to the bay or remain buried in clay sediments. In storm weather such pollutants are released to the water column.

It is important to assess the state of suspended solids entering the bay, particularly from Careel Creek and drain. The understanding of pollutant loads, rates of sedimentation, and the sensitivity of areas to erosion/accretion is desirable to assess impacts on the natural processes within the bay. Not only may sedimentation contribute to localised flooding but also vegetation communities will change as the relative soil level changes.

Management Objectives

- To conserve geodiversity and natural systems within the Bay within urban constraints
- To minimise the risk of pollution within the Bay

Performance Targets

- Continue removing sediment from Careel Creek GPT.

- Investigate installation of sediment traps in stormwater channels and wet filters or stormwater trenches for drainage works .

- To make it a condition of development consent and building approval, that erosion control measures and on-site treatment of stormwater be required, reduce increased sediment movement, through Council's planning process.

- Ongoing monitoring of the soil conservation during works involving soil disturbance from site construction phase through to the landscaping phase.

Future Management Options

- To examine the sediment loads and their chemical composition of sediments transported to the bay from the catchment for their impacts on the habitats and the benthic community.

- To examine changing trends of copper, tin and lead concentrations in sediments to evaluate the impacts through a limited number of sediment samples analysed for these metals annually.

5.3 Water quality and physico-chemical processes

The water quality of the estuary is determined by the interaction of the following processes:

- imports and exports of materials in particulate, dissolved and gaseous forms, via freshwater inflows, coastal flows and the atmosphere;

- physical transport by tidal, flows, currents and mixing;

- energy inputs in the form of light and heat;

- chemical transformations; and

- biological processes.

Although the physical and chemical processes are well understood, their interactions are complex and less known. The major factors that contribute to the estuarine water quality are from point sources such as sewage and industrial effluent discharges and diffuse sources such as Careel Bay catchment (roads, residences, shops and Golf courses).

5.3.1 Suspended solids

Suspended solids in Careel Bay are diverse in form and origin. They may originate as clay from catchment erosion, litter from mangroves, seagrasses, saltmarshes and associated vegetation, plankton, sewerage and industrial wastes. Suspended solids reduce light penetration and limit photosynthesis. They affect the benthic fauna as well as the fish and crustaceans. Initial sampling '97 and '95 results indicate high levels of suspended solids.

5.3.2 pH

Acidity or pH affects fish, which can tolerate pH of 5.0 to 9.0. The tolerance of fish to toxic substances can vary with the pH. The pH in natural waters range from about 4.5 for acidic, peaty upland freshwaters to around 10 for waters supporting intense photosynthetic activity; most estuaries have a pH ranging from 7.5 to 8.8 (Day et al, 1989); Careel Bay and Careel Creek are within these ranges

Table 2: Dry and wet weather water quality results

Dry weather

SAMPLE NO	SITE	DATE	TIME	WATER TEMP	pH	Salinity	EC	TP	FTP	NH_3-N	TN	SS	FC
				C°		ppt	mS/cm	µg/L	µg/L	mg/L	mg/L	mg/L	CFU/100mL
97018846	Control α	7/4/97	10:09	20.7	8.1	34.6	52.3	6	4	0.01	0.13	89	100
97018847	Man-groves β	7/4/97	11:00	19.6	7.3	33.2	51.0	29	11	0.07	0.53	61	5700
97018844	Salt-marsh δ	7/4/97	12:00	20.9	8.5	43.7	65.5	101	38	0.05	1.39	111	55
97018845	Wharf ε	7/4/97	02:00	20.1	8.0	35.5	53.7	19	12	0.01	0.29	78	110

Wet weather$^{\phi}$

SAMPLE NO	SITE	DATE	TIME	WATER TEMP	pH	Salinity	EC	TP	FTP	NH_3-N	TN	SS	FC
				C°		ppt	mS/cm	µg/L	µg/L	mg/L	mg/L	mg/L	CFU/100 mL
97024735	Control α	9/5/97	10:10	18.4	8.2	35.4	46.8	19	16	0.01	0.08	3	7
97024736	Man-groves β	9/5/97	11:45	15.4	7.6	31.5	39.4	53	45	0.06	0.28	6	1600
97024737	Salt-marsh δ	9/5/97	12:15	19.2	8.2	47.8	62.0	55	33	0.02	0.93	20	520
97024738	Wharf ε	9/5/97	11:00	18.7	8.1	35.3	47.2	19	13	0.01	0.10	4	39

α Towlers Bay on Ku-ring-gai Chase National Park

β Careel Creek near tip site

δ Biking area in the saltmarsh

ε Careel Bay at the wha rf

ϕIntermediate wet weather

Table 3. Water quality in some selected sites in Careel Bay (ANZECC guideline for TP is 15 µg/L; for TN 0.1 mg/L and for FC <150 CFU/100mL in marine water)

5.3.3 Salinity

Salinity influences the physico-chemical process of the estuary as well as the distribution of plant and animal species within the estuary. Saline water is denser than freshwater, and is partly responsible for the stratification of the estuary , contributing to localised eddy currents.

In a previous investigation, freshwater algae were observed between the saltmarsh and the residential houses which led to the conclusion that saltmarsh receives freshwater from domestic sources (Hattersley *et al.* 1973). Some marine species are *stenohaline* and occur at salinities ≥30 ppt. The other marine species are *euryhaline* and can tolerate salinities from 15 ppt to 30ppt. Brackish water or the estuarine species live in salinities ranging from 5 ppt to 30 ppt. Freshwater species are few and cannot tolerate salinities above 5 ppt.

5.3.4 Dissolved Oxygen

Dissolved oxygen (DO) is the source of oxygen for respiration for aquatic organisms. The amount of oxygen or lack of oxygen determines whether the water is aerobic or anaerobic and this influences different chemical processes. Dissolved oxygen enters estuaries by direct diffusion from the air, turbulence, tide, flows and photosynthesis, and is removed by respiration, tide and flows. Increased temperatures and salinity decreases the solubility of DO, resulting in diurnal and seasonal fluctuations. The DO of estuaries is between 6.5 mg/L and 9.0 mg/L.

Council data indicates that DO values are generally high. Samples upstream of the creek near the playing field were below the ANZECC (1992) guidelines, possibly due to the high biological oxygen demand from litter decomposition and sewage overflows through the stormwater channels.

5.3.5 Phosphorus

Phosphorus and nitrogen are necessary for the growth of phytoplankton, algae, macrophytes, mangroves, seagrasses and saltmarsh. Phosphorus flows into the estuary in soluble or particulate form from the catchment. Phosphorus is exported from estuaries by being flushed into coastal waters or in the bodies of migratory birds. Some phosphorus remains in the estuary, is trapped in the sediments in the form of insoluble calcium compounds, and is released during low pH and low oxygen concentrations (Emsley, 1980).

High phosphorus values in the saltmarsh are possibly due to litter decomposition or from the catchment. During wet weather Filterable Total Phosphorus (FTP) and TP were high in Careel Creek indicating a contribution from the catchment.

It is necessary to maintain and improve catchment management activities to reduce phosphorus inflow to the bay

5.3.6 Nitrogen

Nitrogen though essential for growth, is present in the bay in significant quantities. It enters the bay from the catchment from animal excreta, litter decomposition, sewage overflows, tidal transport and diffusion from the atmosphere. Nitrogen is present in water in different forms, the most frequent being nitrites, nitrates, ammonia and total nitrogen. Turnover of nitrogen in the estuary is rapid as it is the case with phosphorus. Ammonia is produced from the excreta of animals and humans as well as by the death and decay of organisms. Ammonia is highly soluble in water and at high levels is toxic to fish and other organisms.

The Ammoniacal Nitrogen (NH3-N) was high on two occasions during wet and dry weather in Careel Creek. Total Nitrogen (TN) concentration in the saltmarsh and Careel Creek was high. It is probably due to sewer overflows, excreta from birds and dogs and litter decomposition, fertiliser or wastewater.

5.3.7 Bacteriological pollutants

The bacteriological pollutants to Careel Bay originate from the catchment, sewage overflows and the excreta of birds, cats and dogs. A number of microorganisms are associated with sewage and they include bacteria, viruses, protozoans and helminthic pathogens (Helmer *et al.* 1992). Such organisms can cause a range of illnesses and diseases.

Both in the current study and Council's study the density of faecal coliforms (FC) in Careel Creek exceeded the ANZECC (1992) guideline (<150 CFU/100 ml) for recreational waters. Careel drain exceeded ANZECC guidelines on four out of five occasions. In the current study, FC in the saltmarsh exceeded the guideline only in wet weather indicating that FC are washed into the saltmarsh from the drains transporting excreta of pets and/or the sewerage system adjacent to the saltmarsh.

Management Issues

The quality of water draining from catchments collects atmospheric and surface pollutants consisting of materials such as sediments and nutrients influenced by the land uses and associated activities taking place. To protect the wetlands, one strategy is to identify discharge points to enable removal of sediments and nutrients prior to entry into the Creek and/or Bay.

Coastal areas in NSW often have sediments consisting of minerals rich in sulphate. The exposure of these sediments to the air, results in oxidation of the sulphur minerals to form sulphuric acid. This type of soil is known as acid sulphate soil. Acid sulphate soils and acid sulphate affected ground water may have a detrimental effect on the flora and fauna such as 'burning' of the plants. This area has been mapped by the Department of Land and Water Conservation as having a severe potential of acid sulphate soils. Should any action proceed that seeks to disturb the soils causing oxidation, the potential for acid sulphates must be identified.

Diffuse source water pollution can be better managed in the catchment through education campaigns about minimum use of fertilisers and household detergents, in addition to on-site stormwater treatment. Water quality monitoring should occur to indicate whether pollution is improving or declining and to assist in identifying levels of concern for ecosystem and human health.

Point sources contributing faecal coliforms and nutrients need to be identified and remedial strategies put in place using best management practices (septic, broken sewer, sewer overflow, pumping station) and if the stormwater system is linked.

After heavy rains, salinity reductions in Careel Creek are significant. The input of freshwater into the saltmarsh appears to affect it adversely and this requires further investigation to determine whether this inflow should be addressed.

Management Objectives

- to manage water and sediment quality to minimise pollution
- to promote research into the impacts of freshwater on the saltmarsh
- to minimise the potential for the release of acid sulphate soils.

Performance Targets

- identify point and non-point sources of pollution to the bay to better target reduction programs and management activities.
- assess acid sulphate soil potential according to EPA guidelines for acid sulphate soils prior to carrying out works that disturb potential acid sulphate soils.
- commence a water quality sampling and monitoring program and set goals and objectives.
- regular maintenance of trash rack with follow-up after storm events.
- investigate installation of stormwater treatment devices incorporating wet filters at inflow points.

Future Management Options

- Stormwater runoff is to be managed through appropriate stormwater controls on private land through the use of vegetation management practices such as the use of vegetated filter strips adjacent to drainage lines and watercourses and on-site detention.
- further planting can be undertaken and maintenance of vegetation surrounding the Bay on public land to filter overland water flows.

5.4 Leachate

From 1965 to 1972 parts of the saltmarsh in the southeastern section of Careel Bay was used as a tip site now known as Hitchcock Park and Careel Bay Playing Field.

The source of the heavy metal contamination detected at the site is unclear.

Management issues

Two samples were taken to test for impacts of potential leachate on the wetlands. Concentrations of the majority of trace and heavy metals were below ANZECC guidelines. The exception to this was copper which exceeded the ANZECC guideline, but was below the intervention level.

Management Objectives

- To minimise the release of pollutants from soil into water.

Performance Targets

- To regularly remove sediments and litter from GPT
- To protect the estuarine soil around Careel Creek from dredging or excavation.

Future Management Options

- To assess the potential impacts of pollutants on human activities such as swimming and collection of oysters, it is necessary to determine the levels of pollutants in water, sediments and the biota or undertake a risk assessment study.

Pamphlets in letterboxes, articles in local newspapers, definition of council boundaries (fences/massed plantings) and signage on site are some methods of increasing public appreciation of wetlands.

5.5 Gross pollutants

Gross pollutants to Careel Bay include organic and inorganic litter and sediments are from direct and indirect human activities. They are:

- direct – garbage dumping, especially in the saltmarsh; and
- indirect - from the catchment through Careel Creek, stormwater drains and from Pittwater.

While the bulk of the litter is concentrated close to the landward boundary of the saltmarsh, scattered litter in the saltmarshes and mangroves was observed.

5.5.1 Gross pollutant trap

Careel Creek is a potential path for gross pollutants to enter Careel Bay Wetlands and to arrest the flow of gross pollutants into the bay, a trash rack was constructed on the main drain upstream of Careel Creek near Barrenjoey High School (Appendix 2). This drain receives wastewater from most commercial and recreational parts of the catchment affecting the water movement, light penetration, the biota and the aesthetic value of estuary.

The analysis of the trash trapped in the rack indicated a relatively high percentage of leaves and papers originating from the catchment. Rubble, plastics and metals were also trapped in small quantities. Though designed to trap litter, sediments are also deposited upstream of the trash rack. Annually about 40 m^2 of sediments are deposited in the Main Drain and are removed from the drain.

Management Objectives

- Reduction in the litter in the reserves and estuary.
- An effective strategy to protect against oil spills.

Performance Targets

- To regularly remove gross pollutants from GPT.
- To regularly cleanup the accumulated inorganic litter in the saltmarsh and mangrove habitats.
- Appropriate measures should be taken to prevent dumping rubbish into the saltmarsh and mangrove habitats. These measures include public awareness, education, and enforcement.
- Appropriate measures should be taken to prevent dumping rubbish into Pittwater by users of the waterway.
- To have in place oil spill equipment to protect Careel Bay.

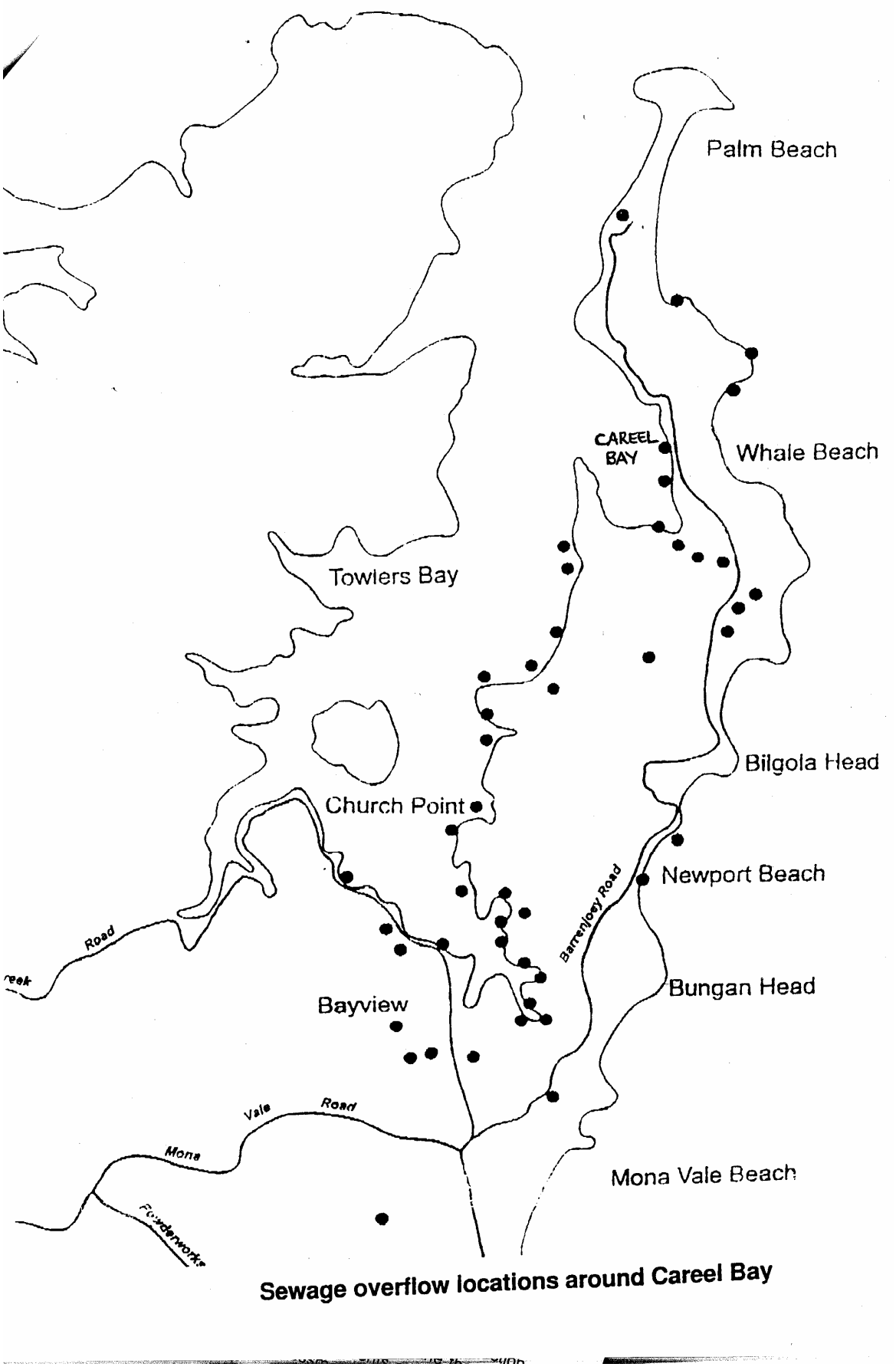


Figure 3. Sewage Overflow Locations

6.0 VEGETATION MANAGEMENT

Goal: To conserve the native vegetation

6.1 Description and Significance

Careel Bay forms an estuarine complex of wetland vegetation communities, namely swamp oak woodland, saltmarsh, mangroves and seagrass beds. There are other habitats with less visible vegetation, such as sandy beaches and mudflats with their microfloral communities. There are also transitional zones with sedges and grasses at vegetational boundaries and exotics bordering the residential houses. Many of the plant species present in the estuary are at their northern or southern limit.

Some of the significant features of the vegetation habitats include:

- the complex comprises seagrass beds, intertidal mudflats, Mangrove, saltmarsh, swamp oak Woodland and Swamp Mahogany Forest remnants.
- the mangrove community contains Grey Mangrove and River Mangrove
- the Swamp She-Oak (*Casuarina glauca)* is also important in that although this species is poorly conserved in the Sydney Region and a food source to the sedentary threatened species Glossy Black-Cockatoo
- extensive intertidal mudflats are present, crucial to migratory waders as a food resource
- seagrass bed includes *Posidonia australis* at its northern limit a plant highly susceptible to disturbance and habitat essential for fisheries productivity
- remnants of an extensive saltmarsh community which is habitat for the threatened Bush Stone-curlew and plant species *Bacopa monnereri* approaching its southern limit
- the estuarine communities form an important green link with the adjoining Narrabeen Slope Forests of Whale Beach and Avalon

6.2 Background

"Dramatic habitat changes have occurred around Careel Bay over the last 50 years. …. Clearing for residential development reduced the area of forested land on Barrenjoey Peninsula from 705 ha (47% of the peninsula) in 1946 to 125 ha (8%) in 1989 (Smith and Smith 1990).

"The area of saltmarsh at Careel Bay has been greatly reduced since 1946…. Saltmarsh areas on the eastern side of Careel Creek were used as a council tip in the 1960s and early 1970s, then filled and converted to playing fields. On the western side of the creek, the saltmarsh has been steadily invaded by mangroves. In 1946 the areas mapped as mangroves consisted mainly of low, regenerating, rather sparse mangroves. True mangrove forest only occurred in a narrow strip along Careel Creek, and very few mangroves were evident in the areas mapped as saltmarsh. In 1997, however, the mangrove forest is taller, denser and more uniform, and the remnant saltmarsh areas have many low mangroves … . In addition to invasion of the saltmarsh on their landward side, the mangroves have also gradually invaded the intertidal mudflats on their seaward side, although to a much lesser extent than the invasion of the saltmarsh … .

"Seaward expansion of mangroves has been widely reported around Sydney and has been linked to land clearing and urbanisation leading to increased sedimentation on the fringes of the mangrove stands, providing new habitat for the mangroves to colonise (Thorogood 1985, McLoughlin 1987, Mitchell and Adam 1989)."

"Farms were established at Careel Bay in the early 1800s (McDonald McPhee and Burton 1989) and were still evident in the 1946 photos on the eastern side of Barrenjoey Road. It is likely that the intertidal wetlands and adjoining land had been used for stock grazing over this period and that mangroves and casuarinas may have been felled to promote pasture growth. The open, partially cleared appearance of the casuarinas in the 1946 photos indicates that this was the case … . The extensive areas of young mangrove regeneration in the photos are suggest their regeneration following the cessation of grazing and associated clearing practices.

"Dense casuarina forest was restricted to only a few tiny stands in 1946, but rapid regeneration followed and by 1961 it covered a large area around the saltmarsh … . Subsequent decades have seen an ebb and flow in the distribution of the casuarina forest as some stands have been cleared, while others have regenerated or been replanted. Good stands of casuarina trees are still present, but the understorey vegetation has been grossly disturbed and has proved less resilient than the casuarinas themselves, although a variety of native species can still be found, especially in the stand south of the tennis courts (Appendix 2).

"The areas of eucalypt forest and coastal scrub that were evident in the 1946 photos between Careel Creek and George Street were steadily cleared for residential development during the following decades. By 1977 all that remained was one tiny stand of Angophora costata trees that barely warrants description as remnant bushland.

"Changes in the distribution of seagrasses at Careel Bay have been less pronounced. The most obvious change has been the reduction of the area of Posidonia seagrasses in the southwestern corner of the beds … . The loss corresponded to the increasing numbers of boats moored in this area."

(Smith and Smith, 1997)

6.3 Subtidal and Intertidal Vegetation

6.3.1 Seagrasses

Seagrasses are the most productive areas of the marine ecosystem and they provide habitat for a range of animals.

"There are extensive seagrass beds in the bay, mainly in the south-eastern section … . These are of two types. Permanently submerged beds of Broad-bladed Strap-grass Posidonia australis occur in deeper water, while beds of Eelgrass Zostera capricorni occur in shallow water and extend into the intertidal zone. Seagrasses play a crucial ecological role in estuaries, providing food and shelter for many aquatic animals and contributing large amounts of organic matter to the estuarine food chain (Hutchings and Recher 1974)."

(Smith and Smith, 1997)

Diverse assemblages of grazing animals feed on epiphytes on seagrasses and these assemblages have very complex dynamics and interactions with other animals in estuaries, eg. Many are prey of small fish (reviewed by Jernakoff et al.,1996). Therefore, changes to abundances or types of organisms in other assemblages in an estuary, eg the assemblages of fishes, have the potential to indirectly affect epiphytic growth on seagrasses. This effect may be frequently underestimated in attempts to understand causes of declines of seagrasses (K. Heck, pers. comm., in Chapman and Underwood, 1997). Power boat motors have been known to damage sea grasses.

6.3.2 Mangroves

Mangroves are saline woody plants that occur in intertidal and supra-tidal regions, subject to frequent tidal inundation. They provide: organic matter to the estuary and coastal waters; macro and micro-habitats to fish, crustaceans, molluscs, polychaetes, birds, insects and worms; food to juvenile crustaceans and fish; protect and stabilise the shoreline and maintain water quality by filtering land-based runoff. Mangroves are highly productive and nutrients are recycled mainly through grazing food chains (Camilleri, 1992).

"At the head of Careel Bay, around Careel Creek, is a dense mangrove forest covering about 10 ha … . The dominant tree species is Grey Mangrove Avicennia marina. River Mangrove Aegiceras corniculatum, a shrub species, is also common, especially on the landward fringes. Other vascular plant species are generally absent except for occasional plants on the edges (Appendix 2). …. The ground is thick with pneumatophores. A large proportion of the mangrove forest is inundated at each high tide, although the outermost sections generally remain above the water level except during the highest tides."

(Smith and Smith, 1997)

During the last 50 years, the mangrove area of Careel Bay has nearly trebled. Aerial photographs from 1946 to present provide evidence of the changing vegetation pattern in Careel Bay. In 1946 there were few residents, farmers and vacationers at Careel Bay and development was limited. Then mangroves occurred on the banks of Careel Creek and formed a barrier between the sea and the inner saltmarsh.

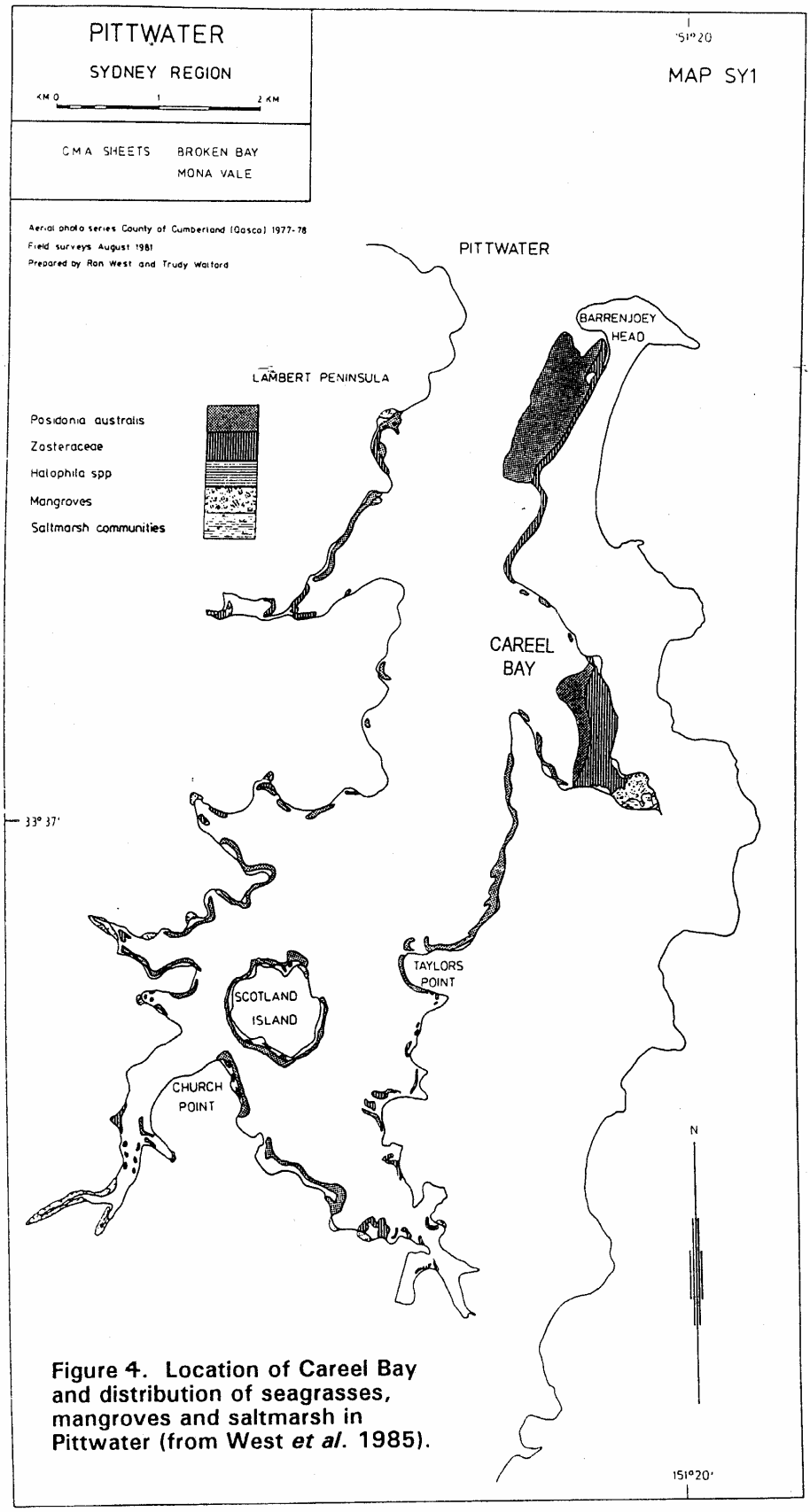


Figure 4. Location of Careel Bay and distribution of seagrasses, mangroves and saltmarsh in Pittwater (from West *et al*. 1985).

Figure 4. Estuarine Vegetation (West et al.1985)

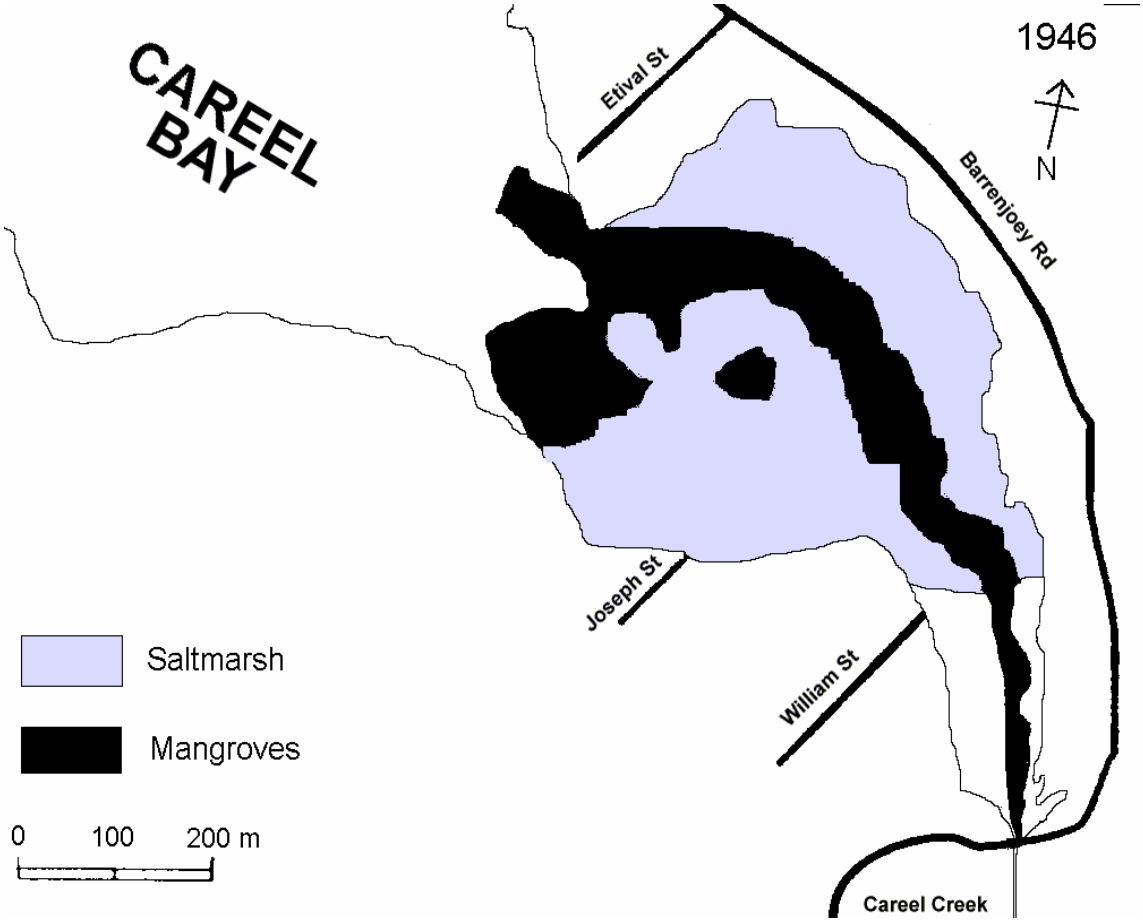


Fig 5. Saltmarshes and mangroves of Careel Bay in 1946 (Wilton 1997)

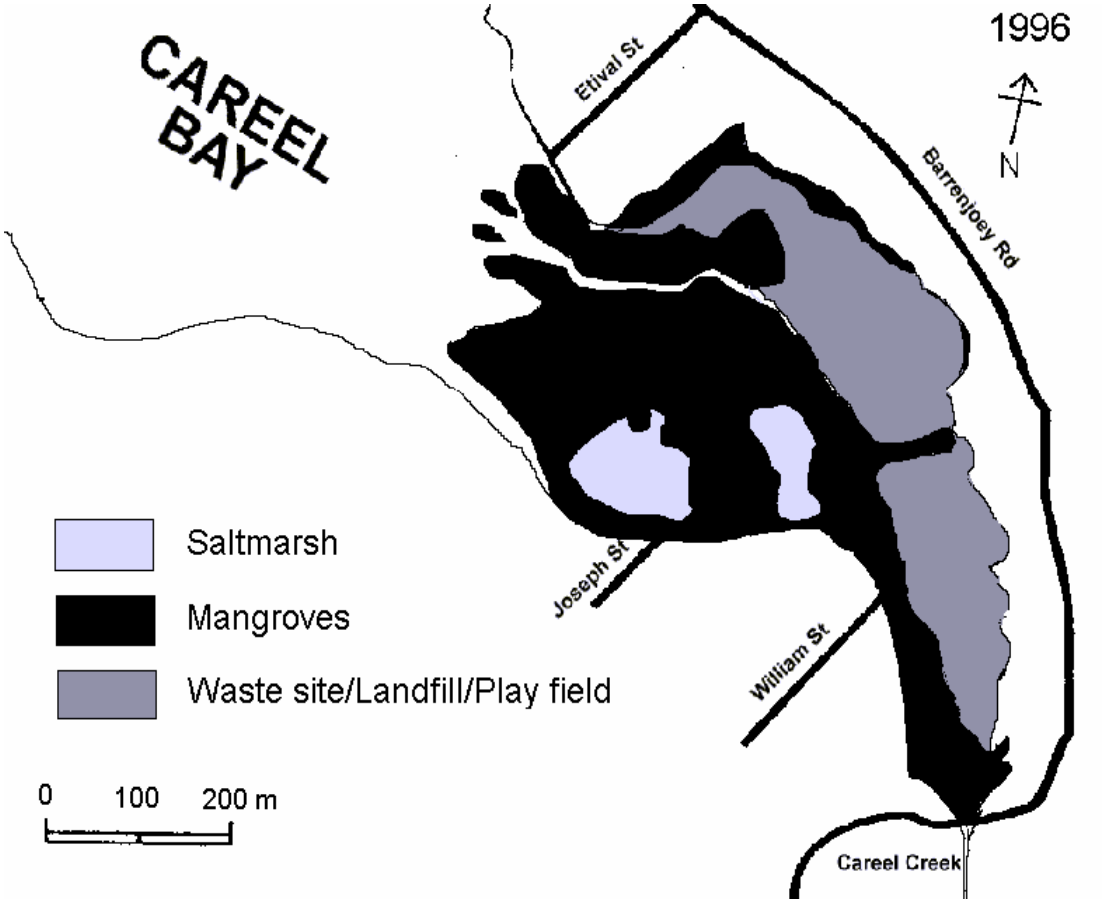


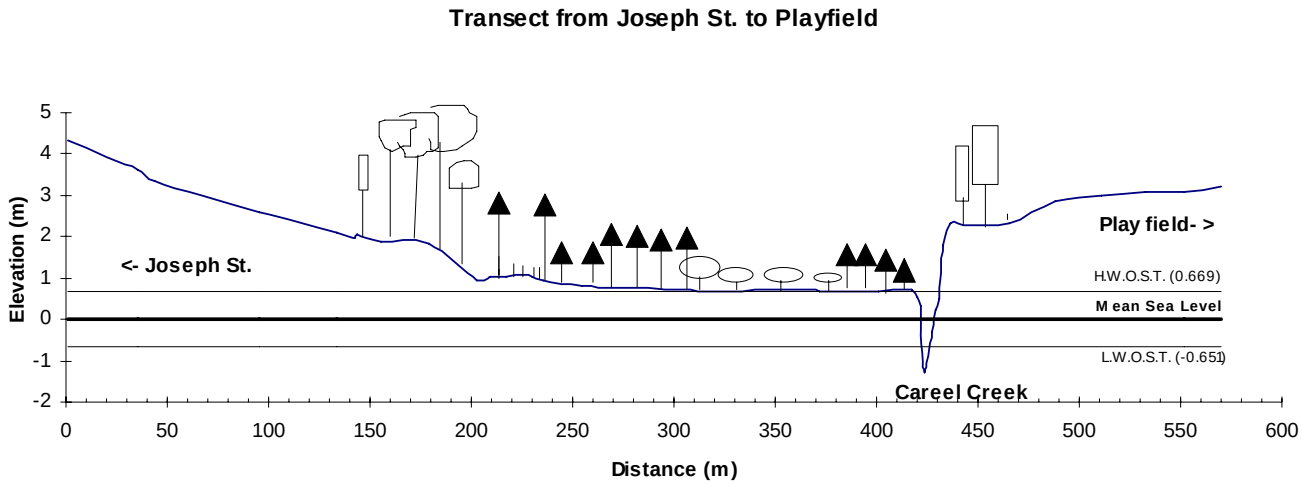
Fig 6. Saltmarshes and mangroves of Careel Bay in 1996 (Wilton 1997)

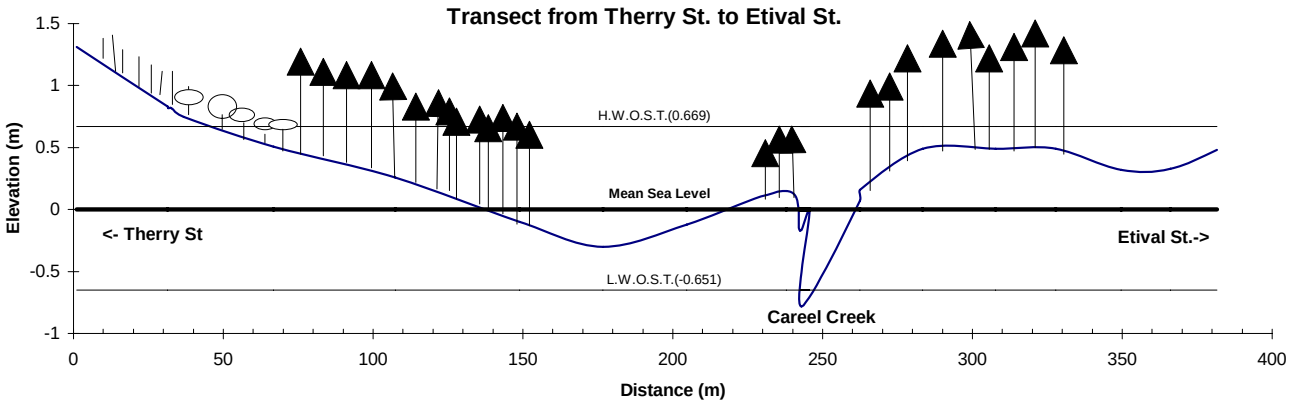
6.3.3 Saltmarsh

Saltmarshes are communities of emergent vegetation rooted in soils that are alternatively inundated and drained by tidal action. They usually occur on the landward side of mangroves, where tidal inundation is regular but infrequent. Saltmarshes prefer higher salinities and temperatures than mangroves and thrive in saline conditions. The distribution of saltmarsh is determined by tidal inundation, soil salinity and temperature.

The aerial photographs of 1972 show extensive human impacts on the saltmarsh of Careel Bay. North east of the creek, where an extensive saltmarsh occurred, was completely covered by the landfill. A number of tracks were established through the saltmarsh and mangroves. In the middle of the marsh a 2 m high and 2 m wide mound was made to install an electricity pole (Wilton, 1996). Decrease in the spatial distribution of the saltmarsh was characterised by the complete absence of the northern saltmarsh; the reduction of the southern saltmarsh; and incision of the southern saltmarsh into a left and right zone.

> *"There are two main patches of saltmarsh at Careel Bay, each about 1.5 ha in area, and a much smaller patch less than 0.2 ha in area … . The latter is a dense stand of Common Reed Phragmites australis with some Sea Rush Juncus kraussii and Broad-leaved Cumbungi Typha orientalis. The vegetation in the main saltmarsh patches, however, consists of a sparse layer of low Avicennia marina mangroves, 1-4 m tall, averaging about 1.5 m, over a sparse layer of young or stunted Avicennia marina and Aegiceras corniculatum mangroves about 0.5 m tall, and a moderately dense layer of Samphire Sarcocornia quinqueflora about 0.15 m tall … . Other plant species in the main patches of saltmarsh include Marine Couch Sporobolus virginicus, Creeping Brookweed Samolus repens and Sea Rush Juncus kraussii (Appendix 2). At the southern end of the eastern patch is an area of about 0.25 ha that is bare of vegetation. Soil conditions in the saltmarsh are moist and there are many tiny pools of water, but total inundation only occurs during the highest tides."*
>
> (Smith and Smith, 1997).





Legend Mangroves, Saltmarsh, *Casuarina*, Ornamentals, *Juncus*

Fig 7. Distribution of vegetation along 2 transects of Careel Bay from a survey completed in May 1997 (AWT, 1997).

Human impacts on the Careel Bay saltmarsh are diverse. They include:

- the use of saltmarsh as a tip site, its reclamation for other uses;
- construction of walking tracks through the saltmarsh;
- disposal of litter, cars, metals and garden refuse;
- the use of bikes and trail bikes on the bare patch area;
- walking in the saltmarsh;
- use of saltmarsh for dog walking and by unleashed animals;
- the spread of ornamental plants and grass from backyards of residential houses into the saltmarsh;
- mowing saltmarsh vegetation;
- nutrient inputs from the catchment;
- sediment input from the catchment;
- increased freshwater input from storm water system; and
- sewer overflows.

The impacts caused by natural processes are attributed to:

- sedimentation and accretion of the bay;
- expansion of the habitat that is more suitable for the mangrove competitor, and
- the rise of sea level.

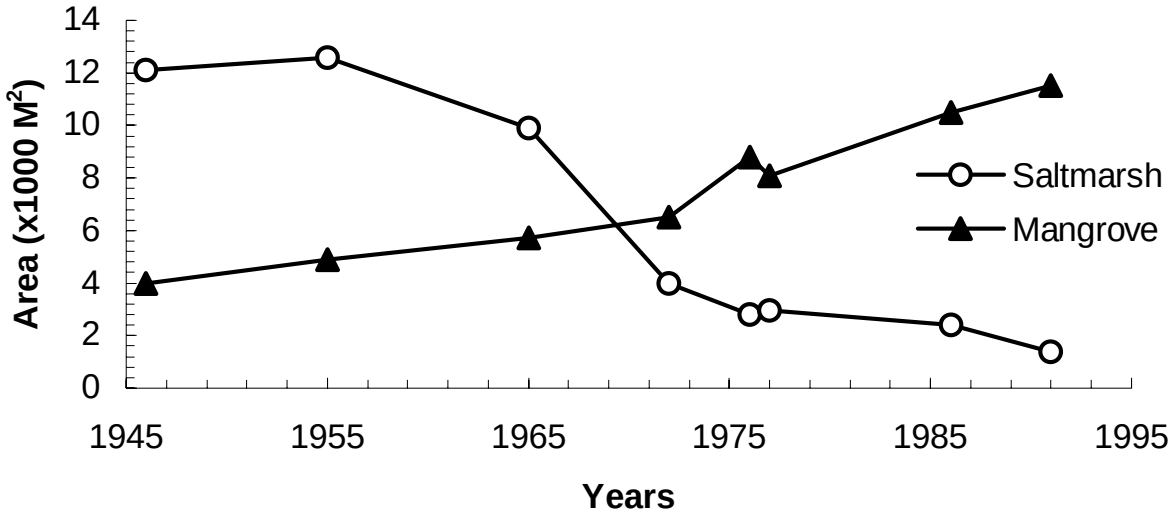


Fig 8. Change in the areas of saltmarshes and mangroves in Careel Bay (Sewell *et al.*)

During the last few decades, the saltmarsh community in Careel Bay has declined. Figure 4 shows the decline of the saltmarsh in Careel Bay, and the increased area of mangroves during the last 50 years.

6.4 Terrestrial Vegetation

6.4.1 Casuarina Forest

> *"Forest vegetation dominated by Swamp Oak Casuarina glauca occupies a total area of about 4 ha around the head of Careel Bay, above the intertidal zone … the vegetation consisted of a moderately dense layer of Casuarina glauca trees to about 15 m tall, a sparse layer of saplings and shrubs 1.5-6 m tall, chiefly Casuarina glauca and introduced Cassia Senna pendula, and a dense ground layer about 0.6 m tall dominated by the introduced Asparagus Fern Protasparagus aethiopicus … . A more diverse native understorey occurs in the casuarina forest at the southern end of Hitchcock Park, including native species such as Tall Saw-sedge Gahnia clarkei, Harsh Ground Fern Hypolepis muelleri, Common Reed Phragmites australis, Bleeding Heart Omalanthus populifolius, Ivy-leaved Violet Viola hederacea, Scurvy Weed Commelina cyanea, Bordered Panic Entolasia marginata, Seablite Suaeda australis and Basket Grass Oplismenus aemulus. The tree layer here includes some Swamp Mahogany Eucalyptus robusta trees mixed with the Casuarina glauca. A total of 59 plant species were recorded in the casuarina forest at Careel Bay, of which two-thirds were native and one third introduced (Appendix 2)."*
>
> (Smith and Smith, 1997)

6.4.2 Open Parkland

> *"Hitchcock Park, with its playing fields and dog exercise area, provides extensive open grassy areas that are favoured feeding sites for bird species such as the Australian Magpie, Magpie-lark, Crested Pigeon and Galah. The patches and strips of native and introduced trees and shrubs around the open areas are used for feeding, roosting and nesting by various species."*
>
> (Smith and Smith, 1997)

A small freshwater swamp occurs near the corner of Etival Street and Barrenjoey Road and should be conserved in the future.

6.5 Vegetation in the Surrounding Catchment

6.5.1 Eucalypt Forests

> *"Eucalypt forest occurs in the catchment of Careel Bay at McKay Reserve, Stapleton Park and Careel Headland Reserve. Six different eucalypt communities occur in these reserves: Eucalyptus maculata open-forest, Angophora costata-E. maculata open-forest, E. botryoides –E. maculata woodland with a rainforest understorey, E. gummifera-A. costata open-forest/woodland, E. gummifera-E. haemastoma woodland and E. gummifera-A. floribunda low open-forest (Smith and Smith 1990, 1992). Three further types formerly occurred elsewhere in the catchment, but are now represented mainly by remnant trees: E. robusta open-forest, E. botryoides open-forest and A. floribunda-E. haemastoma low open-forest (Smith and Smith 1990)."*
>
> (Smith and Smith, 1997)

6.5.2 Residential areas

The gardens, lawns and remnant and planted trees of the residential areas provide feeding, roosting and nesting habitat for a variety of bird species. The residential areas surrounding Careel Bay have a high density of trees, with an average of about 100 *Eucalyptus* and *Angophora* trees per hectare recorded by Smith and Smith in 1990 (unpublished data, excluding counts from major reserves).

6.6 Unvegetated Sediments

6.6.1 Intertidal mudflats

Extensive intertidal mudflats occur in the southeastern corner of the bay, from Dark Gully around to the Careel Bay Boatshed. Around the fringe of the mudflats is a narrow strip of sandy beach, most of which is submerged at high tide, except for the sandspit north of Etival Street. Most of the area of mudflats is bare of vegetation, but adjacent to the mangrove forest at the head of the bay is a zone with many mangrove seedlings and pneumatophores (aerial respiratory roots). Also, the outer mudflats have extensive *Zostera capricorni* seagrass beds exposed at low tide. The different sections of the mudflats support different invertebrate faunas and differ in their importance as feeding zones for birds (Hutchings and Recher 1974).

6.7 Management Issues

6.7.1 Invasion of Saltmarsh by Mangroves

Invasion of saltmarsh by mangroves has also been recorded elsewhere around Sydney, notably at Botany Bay (Mitchell and Adam 1989) and Homebush Bay (Clarke and Benson 1988). The reasons for this

landward expansion of the mangroves are not well understood and may reflect site-specific disturbance factors rather than general factors.

Wilton (1997) has suggested a variety of factors that may be involved in the mangrove and saltmarsh changes at Careel Bay, including natural factors (sea level rise, microtopography and changes to the tidal prism) and human-related factors (water quality, pollution, land use change, landfill, residential encroachment and species competition).

Incursion of mangroves into the remaining saltmarsh areas should be closely monitored in future years. If the process continues and further saltmarsh is threatened with conversion to dense mangrove forest, then appropriate steps should be taken to restore saltmarsh conditions, such as clearing or thinning of the invading mangroves. The present layer of low mangroves in the saltmarsh provides excellent shelter and cover for the Bush Stone-curlews and should not be removed at this stage (Chapman and Underwood, 1997).

Revegetation of the large bare patch at the base of the eastern saltmarsh may be desirable, however its saltpan appearance could be due to hypersalinity rather than bike riding. There may be a similar high level of salinity in the smaller bare area at the base of the western saltmarsh. Saltmarsh revegetation on the bare areas could interfere with the use of the saltmarsh by the Bush stone-curlews. Proposals to extend the saltmarsh through clearing in adjoining areas of mangrove forest are unwarranted (Chapman and Underwood, 1997). Revegetation of saltmarsh landwards of the bare areas is however desirable to create a buffer between the private properties and the wetland.

Management Objectives

- to maintain the full range of structural and floristic diversity of habitats of the Careel Bay estuarine wetlands;
- to conserve the swamp oak woodland, saltmarsh, mangrove forests, mudflats and seagrass beds;
- to adequately manage the wetland in relation to weed invasion, encroachments, pollution, human uses and estuarine processes;
- to restore, regenerate and revegetate degraded areas using best practice techniques;
- to control and manage weed species;
- to continue to support the volunteer bush regeneration group;
- to create buffer zones between playing fields / developed areas and natural areas; and
- to use ‘soft ‘engineering practices to resolve future works in and adjacent to the estuarine wetland.

Performance Targets

- encourage research into the causes of saltmarsh decline and strategies for conservation.
- plant buffer zone of saltmarsh and other appropriate locally indigenous species between existing houses and southern saltmarsh areas in consultation with residents.
- implement a walking track to act as a buffer zone between playing fields and the wetland.
- undertake a program of assisted bush regeneration in the Casuarina forest areas.
- undertake a program of saltmarsh restoration near the playing fields in a staged manner to allow for fauna habitats to be reinstated.
- undertake a program of revegetating the banks of Careel Creek.
- undertake an awareness program for residents adjoining the wetland about the damage caused by dumping of garden refuse to minimise regrowth and spread of weeds.
- maximise the use of local seeds/cuttings/propagules for the propagation of native plants for restoration of natural areas.
- ensure development applications adjacent to the estuarine zone include a vegetation and stormwater management plan to ensure the conservation of the wetland and native vegetation.

Future Management Options

- monitor vegetation changes through the use of low level colour aerial photography on a regular basis;
- monitor and examine growth and densities of saltmarsh and mangroves, particularly incursion of mangroves over saltmarsh;
- encourage possible future controlled experiments on saltmarsh/mangrove ecotone;
- integrate bush regeneration works with any construction of paths etc;
- implement appropriate strategies for saltmarsh conservation

- investigate the suitability of rehabilitating the large bare patch at the base of the eastern saltmarsh and a similar but smaller bare area at the base of the western saltmarsh, whilst avoiding large scale habitat disturbance;

- all surrounding foreshore areas, drainage swales and creek banks should be gradually rehabilitated and stabilised using appropriate local indigenous species;

- install additional interpretive signage indicating the value of the saltmarsh and the importance of protection of the wetlands;

- monitor seagrasses for eutrophication;

- discharge of freshwater into the saltmarsh from residential houses should be prohibited and alternate stormwater disposal strategies such as absorption trenches utilised.

7.0 FAUNA AND HABITAT MANAGEMENT

7.1 Background

Faunal surveys have been carried out by Hutchings and Recher, 1973, indicating that Careel Bay is rich in species diversity and provides habitat for rare species. Among the invertebrates, 39 species of insects, 23 species of molluscs, 16 species of spiders, 6 species of polychaetes and 5 species of crabs have been reported in the mangrove and saltmarsh areas. Insect larvae associated only with mangrove species such as the plume moth larvae (*Cenoloba obliteratis*) and the mangrove fruit fly (*Euphranta* sp.) occur in Careel Bay. Two interesting tropical genera of flies, *Merodonta* and *Pemphigonotus* have been reported in the Bay. Five uncommon species of Lauxaniid flies have also been recorded from the bay. The commercial Sydney Rock Oyster *Saccostrea commercialis* occurs at the base of mangroves and small sesarmid crabs that play a major role in the ecology of the mangrove ecosystem, in food chains and soil upturn were present (Hattersley *et al.* 1973). The abundant fish species of the bay includes Bream, Flathead, Garfish, Trevally, Blackfish, Leatherjacket and Tarwhine.

A number of migratory bird species occur; Careel Bay plays an important role as a feeding ground for these species as the fat build up from February to April is critical for migratory species who feed day and night for the journey north to Asia.

7.2 Benthic Assemblages

Four wetland habitats - mangrove forests, saltmarshes, mudflats and seagrass beds - were sampled in 1996 and 1997 by the Institute of Marine Ecology to investigate the current assemblages of species in the wetland benthic fauna and habitats.

Data were collected on the densities of macrofauna in mangroves and mudflats, estimates of the condition of mangrove forests and seagrass beds and the extent of saltmarsh vegetation under the canopy of mangroves. Data from Careel Bay were compared to similar data from wetlands at Woolaware Bay (qualitatively for molluscs and crabs in mangrove forests and saltmarsh), Bundeena and Patonga (quantitatively for benthic fauna in mudflats), and Woody Point and Palm Beach (for epibiota on seagrasses).

7.2.1 Benthic Molluscs and Crabs in Mangrove Forests and Saltmarsh Habitats

Molluscs and crabs are important components of the benthic macrofauna of mangrove forests and saltmarsh, and have been described for Careel Bay by Hutchings and Recher, 1974. Concerns exist about potential impacts of landward influences on saltmarshes and mangroves, including changed drainage, pollutants such as nutrients and sediment, and dog exercising on mudflats and in mangroves on the north side of the creek.

The recent study by Chapman and Underwood used rapid assessment of large-scale measures of damage in urban mangrove forest, which correlates reasonably well with abundances of molluscs in sediments and shows decrease in abundance and species richness of molluscs with increasing damage. Two sites were sampled, separated by tens of metres, at each of six locations in the Careel Bay mangroves and saltmarshes. The results indicated that there was some damage in most transects, although it appears more widespread and severe on the southwestern side of the creek. Most damage was household garbage, such as milled timber, plastics, shoes, bottles, etc. scattered in large patches throughout the forest. The damage found in this study was less than the estimate of damage in mangrove forests throughout the Sydney Region.

Cover of the saltmarsh plant species *Sarcocornia quinqueflora* was very extensive, persisting for tens and sometimes hundreds of metres below the canopy of the mangrove *Avicennia marina* measured along transects. *Samolus repens* was, however, very patchy, less extensive and seldom found under the canopy of *A. marina*. Any recent expansion of the mangrove forest has not, at this stage, killed the saltmarsh vegetation.

The cover of leaf litter was very patchy; leaf litter tended to be more abundant on the northeastern side of Careel Creek. Generally there was more leaf litter at Woolaware Bay than Careel Bay. Leaf litter was not correlated with distance from the water's edge indicating that tidal flushing may not be important in removing litter. Cover of algae was very sparse, generally less than 1%, which is similar to Woolaware Bay, except at two locations at Careel Bay.

Numbers of mangrove saplings were extremely variable, with generally fewer saplings than at Woolaware West but similar densities to those at Woolaware East. Similarly, the numbers of pneumatophores varied; there were fewer pneumatophores in the mangroves than in the saltmarshes. Numbers of pneumatophores in mangrove forests at Careel Bay were similar to Woolaware Bay. There were more crab-holes at two

locations out of seven, but these were not correlated to any environmental variables.

Fifteen species of molluscs were found in the mangrove forests of Careel Bay (compared to twenty-two species at Woolaware Bay) Table 3. Between 1.6 and 5.1 species were found in each site at each time of sampling. There were significant differences in these assemblages among the five locations in the mangrove forest and saltmarsh at each time of sampling, which is probably a natural phenomenon.

Table 3. List of species of benthic molluscs found in quadrats at Careel Bay in May and July, 1996 and additional species found in Woolaware Bay in August, 1994 (Chapman and Underwood, 1997).

Shore	Class	Family	Species
Careel Bay	Gastropoda	Littorinidae	*Bembicium auratum*
			Littoraria luteola
		Assimineidae	*Assiminea buccinoides*
			Assiminea sp.
		Hydrobiidae	*Tatea huonensis*
			Tatea rufilabris
		Muricidae	*Bedeva hanleyi*
		Amphibolidae	*Salinator solida*
			S. fragilis
		Ellobiidae	*Ophicardelus quoyi*
			Melosidula zonata
		Acmaeidae	*Patelloida mimula*
	Bivalvia	Laternulidae	*Laternula tasmanica*
		Leptonidae	*Arthritica helmsi*
		Ostreidae	*Saccostrea commercialis*
Woolaware Bay	Gastropoda	Batillariidae	*Batillaria australis*
		Vitrinellidae	*Pseudoliotia micans*
		Hydrobiidae	*Ascorhis victoriae*
	Bivalvia	Mytilidae	*Xenostrobus securis*
		Psammobiidae	*Sanguinolaria donacioides*
		Mactridae	*Notospisula trigonella*
		Laternulidae	*Laternula* sp.

Six abundant and widespread species were important in characterising different locations in Careel Bay.

Table 4. The percentage that the most important species contributed to measures of similarity within locations at Careel Bay (averaged over both times of sampling) (Chapman and Underwood, 1997).

Species	Location 1	Location 2	Location 3	Location 4	Location 5
B. auratum	4.9	10.6	8.8	0	0
A. buccinoides	25.1	34.2	0	13.7	16.3
T. rufilabris	34.2	5.2	0	0	42.5
S. solida	17.6	27.7	39.2	41.9	30.6
O. quoyi	1.2	8.7	0	0	5.2
A. helmsi	15.9	12.3	50.2	42.2	5.3

Four species of crabs, *Paragrapsus laevis, Sesarma erythrodactyla, Heloecius cordiformis* and *Helograpsus haswelliensis* were collected in the mangrove and saltmarsh locations in May and July 1996 at Careel Bay and in August 1994 at Woolaware Bay. . The numbers and diversity of crabs were within natural variability. Only *P. laevis* was abundant enough for further analysis; this species was found to be smaller on average in Careel Bay with a larger proportion of small crabs and fewer large crabs than at Woolaware Bay. This may be due to natural variability, reduced rates of growth or mortality of larger animals.

There was no evidence that the mangrove forests are in poor condition, with respect to broad-scale measures of damage, features of the mangrove trees themselves or molluscan or crab macro-fauna.

7.2.2 Benthic Fauna in Mudflats

The intertidal mudflats in Careel bay are very large and extend from the mangrove forests each side of Careel Creek down to low water, extending on the northeastern side of the bay towards the mouth of Pittwater. Visible disturbances include exercising dogs, human trampling and yabby pumping, which can cause adverse effects on organisms in soft sediment habitats (Foster, *et al.*, 1990 and Inglis, 1995, described in Chapman and Underwood, 1997).

Macro-benthic organisms were sampled in the mudflats in four areas in the sandy (highshore level), sandy/muddy (upper midshore level), muddy unvegetated (lower midshore level) and muddy vegetated (lowshore level with sparse to medium cover of *Zostera capricornii*) and compared to Patonga and Bundeena. Dog exercise occurs more frequently towards the mid and high shore, and yabby pumping more common at mid to low shore levels. Two sites were near the dog exercise area and two further away. Sediment cores were sampled in July and September,

sieved and sorted under binocular microscope and grain sizes of sediments compared.

Significant differences occurred in assemblages among habitats, with assemblages being very diverse probably due to sediment size and height on the shore.

Most habitats on the mudflats at Careel Bay contained slightly different assemblages than were found in similar habitats at Bundeena and Patonga. Soft sediment infauna is, however, very variable naturally from place to place and time to time. This study suggested that the infauna in sediment cores at Careel Bay is within the natural range of variability for these habitats.

Small molluscs, crabs and polychaetes on the surface of the mud were counted in quadrats along with cover of seagrass, algae, detritus, bare sediment and standing water, crab holes and tubes of chaetopterid polychaetes. Large snails and crabs on the surface of the mud were counted in transects. Small and large epifauna were very sparse and patchy and found on different types of habitat in Careel Bay, Bundeena and Patonga. Although there was considerable variability between July and September and from location to location in the abundances and types of organisms found, there is no indication that Careel Bay is depauperate, or has an abundance of species not found on other mudflats, suggesting Careel Bay has a natural suite of epifauna living on the surface of the intertidal mudflats.

Densities of soldier crabs were estimated at different locations and sites in July and September. Results indicated the patchy and dynamic patterns of occurrence.

In summary, whilst there is considerable small-scale variability in the numbers and types of fauna, there is no evidence that variability was significantly different from Bundeena or Patonga and there appears to be no persistent measurable disturbance from dog or human trampling or bait collection on these mudflats.

7.2.3 Epibiota on Seagrasses

Careel Bay has large intertidal beds of eelgrass, *Zostera capricorni* and subtidal beds of strapweed, *Posidonia australis,* which are important in productivity and provide habitat, with their epibiota, for numerous small grazing animals, which are prey for small fish. Widespread concern exists about loss of seagrasses in urban areas due to eutrophication of waterways and growth of epibiota on the leaves such as excessive filamentous algae or large macroalgae.

Amounts of epibiota, algal debris and density of shoots of seagrasses were studied in Careel Bay and two external reference locations (Palm Beach and Woody Point) by Chapman and Underwood in November, 1996 and January, 1997.

Seagrasses were significantly longer at Woody Point than at Careel Bay or Palm Beach. On the tips of seagrasses, there was significantly more cover of epibiota at Palm Beach and significantly less cover at Woody Point than at Careel Bay.

The composition of organisms was different; at Palm Beach most were animals (encrusting and branching bryozoans, spirorbid polychaetes, hydroids and encrusting sponges), at Woody Point most were plants (green and red filamentous forms and encrusting algae). Careel Bay had more plants than animals, with this difference pronounced at one site. There was greater biomass of epibiota on seagrass blades at Palm Beach than at Careel Bay or Woody Point.

Plant debris in the seagrass beds was primarily *Posidonia australis* and to a lesser extent the large alga, *Microdyctyon* sp. There was significantly more debris at Woody Point and significantly less debris at Palm Beach than Careel Bay. Depth of dead *P. australis* was thicker at Woody Point than at Palm Beach and Careel Bay. Percentage cover of seagrasses and density of shoots at Careel Bay were within the range of variability found at the locations in Pittwater (Chapman & Underwood, 1997). Increased brown filamentous algae, as well as red tides have been observed (Martin, pers.comm).

7.2.4 Bioaccumulation

Due to the prevalence of termites in the Avalon Area, pesticides are frequently used to control them. In wet weather unbound pesticides may be transported in the runoff to Careel Creek and subsequently to Careel Bay. Likewise, Copper present in sediments may be an issue for oysters. The levels of pesticides and trace metals in the biota of Careel Bay or in its sediments are currently not known.

7.3 Avifauna

7.3.1 Overview and Significance

Careel Bay is the most significant area of estuarine wetlands in the Pittwater Local Government Area. The bird habitats of Careel Bay and its immediate catchment may be divided into eight categories: subtidal waters of the bay (including an extensive area with submerged *Posidonia australis* seagrass beds); intertidal mudflats (including *Zostera capricorni* seagrass beds that are exposed at low tide); mangrove forest (10 ha, dominated by Grey Mangrove *Avicennia marina*); saltmarsh (3 ha, consisting of low, sparse mangroves over a ground layer of Samphire *Sarcocornia quinqueflora*); casuarina forest (4 ha,

dominated by Swamp Oak *Casuarina glauca*, with a weedy understorey); eucalypt forest (McKay Reserve, Stapleton Park and Careel Headland Reserve); open parkland (Careel Bay Playing Fields and Hitchcock Park); and residential areas (notable for their high tree density).

A total of 122 bird species (114 native) have been recorded from the area, of which 72 species (65 native) were recorded during the 1997 survey.

It is a regionally significant site for an endangered species in NSW, the Bush Stone-curlew *Burhinus grallarius*. Careel Bay, which has a single resident pair, is the only site in the County of Cumberland where this species is still regularly recorded. Careel Bay is likely to be a dispersal site for young birds from Rileys Island in Brisbane Water, the nearest known population. Other NSW threatened species that occur at Careel Bay from time to time include the Glossy Black-cockatoo and Pied Oystercatcher.

Also regionally significant is the Mangrove Gerygone *Gerygone levigaster*, a recent colonist of the Sydney region, which is only known from two other sites Sydney. Three other resident species are also noteworthy occurrences, in the Sydney Region, the Striated Heron *Butorides striatus*, Whistling Kite *Haliastur sphenurus* and Azure Kingfisher *Alcedo azurea*.

As the largest area of estuarine wetlands in Pittwater, Careel Bay provides habitat of high local conservation significance for a variety of waterbirds. These include migratory waders from the Northern Hemisphere such as the Eastern Curlew *Numenius madagascariensis*, Whimbrel *N. phaeopus* and Bar-tailed Godwit *Limosa lapponica*, whose conservation is the subject of international agreements. Careel Bay also has local significance as a temporary stopover for birds during migration, both waterbirds and bushbirds. The most significant migratory wader species at Careel Bay is the Eastern Curlew as the majority of the world population comes to Australia, and is regarded as being of special concern due to declining numbers.

Forty-seven species (45 native), or 39% of the total, are associated with the aquatic and intertidal habitats (including mangrove forest and saltmarsh). One hundred and one species (93 native) have been recorded during the 1990s. Seventy-two species (65 native) were recorded during the 1997 survey.

7.3.2 Birds of the Intertidal Mudflats and Adjacent Waters

Thirty three bird species were recorded on the mudflats and adjacent waters by Smith and Smith, 1997, including Silver Gull (which comprised 65% of all birds recorded), Pacific Black Duck, Little Pied Cormorant, Australian Pelican, White-faced Heron and Australian White Ibis which occurred regularly in moderate numbers. Species that occurred regularly but in small numbers were the Striated Heron, Eastern Curlew and Whimbrel.

Numbers and species of birds varied widely depending on the tide cycle, with an average of 183 birds of 13 species at low tide and 42 birds of four species at high tide. Mudflats are an important feeding area, as they are exposed at low tide.

As the tide rose, the gulls generally move across the bay to roost on the boats, while the ibis and herons moved into the mangroves and saltmarsh to roost and feed there. Pelicans tend to move into the bay in mid to late afternoon as they are fed at Careel Bay Boatshed. A range of sites at Careel Bay are used as high tide roosts, with different sites being favoured by different species. The sandspit north of Etival Street is used occasionally and briefly as a roost site and is expected to be a major roost site, however it appears that continual disturbance by people and dogs prevents birds roosting here for any length of time (Smith and Smith, 1997).

The study recorded marked differences between species in their use of different feeding zones on the mudflats and adjacent waters. Three zones were specially favoured for feeding, namely the *Zostera capricorni* seagrass beds when exposed at low tide (34%), the shallow inshore waters less than 10 metres from the shore (26%), and bare mudflats (26%).

A comparison of the numbers of foraging records obtained at different stages of the tide cycle shows a striking pattern of birds concentrating their feeding effort in the relatively brief period around low tide when the *Zostera* beds are exposed. These *Zostera* beds are clearly a critical food source for birds at Careel Bay (Smith and Smith, 1997).

7.3.3 Birds of the Mangrove Forest, Saltmarsh and Casuarina Forest

Forty bird species were recorded in the mangrove forest during the 1997 survey with the most common being the Pacific Black Duck, which foraged and roosted along the Careel Creek channel; the Silvereye and Yellow Thornbill, which foraged in the mangrove foliage; and the introduced Spotted Turtle-Dove, which roosted in the mangroves and fed in the adjoining parkland. The birds of the mangroves were a mixture of waterbirds and landbirds. Apart from the Pacific Black Duck, the most common waterbirds were the Australian White Ibis and White-faced Heron.

The most notable species recorded was the Mangrove Gerygone, which is known from only two other sites around Sydney.

More birds were recorded in the mangroves at low tide and in the morning. This largely reflects a well known tendency of small birds to be less active, moving around less and becoming more difficult to detect in the afternoon. Other waterbirds, however, tended to be more common at high tide, when they moved into the mangroves from the nearby mudflats.

Fewer birds and fewer species were recorded in the saltmarsh than in the mangrove and casuarina forests. The saltmarsh is the chief roost site of the Bush Stone-Curlew a nocturnal species, and they also nest there (Appendix 1). Because of its many low mangroves, the saltmarsh is also regularly frequented by Mangrove Gerygones.

Twenty-six species were recorded in the casuarina forest, only one of which was a waterbird. The most common were the Silvereye, Yellow Thornbill and Spotted Turtle-Dove. Only half as many birds were recorded in afternoon counts as in the morning, reflecting the same pattern of small forest birds becoming less active in the afternoon (Smith and Smith, 1997.

7.3.4 Bird Changes

Differences have become apparent over the last twenty five years in particular, more species and greater numbers of migratory waders were recorded in 1972 than 1997. Waders that breed mainly in northern Siberia migrate to spend non-breeding months in Australia. Five species recorded in 1972 were most common (Red-necked Stint, Grey-tailed Tattler, Bar-tailed Godwit, Eastern Curlew and Whimbrel). In the 1997 study found low numbers of Eastern Curlew, Whimbrel and Bar-tailed Godwit. The Great Cormorant whilst common in 1972 still occasionally visits; the Yellow-billed Spoonbill has not been recorded since the late 1980's; nor has the Straw-necked Ibis since 1972. The Pheasant Coucal, which once had a well established population in the northern beaches area, its stronghold in the Sydney region, has gradually disappeared from many of its former haunts and is now seldom reported around Sydney. It formerly occurred at Careel Bay, where Steege (1988) commented on its declining numbers in the 1980s. Similarly, Barrenjoey Peninsula was formerly the stronghold of the Scaly-breasted Lorikeet in the Sydney region; once common in the area, this species is now rare.

On the other side of the scale, a number of the native birds now resident at Careel Bay have increased in number or were unknown in the Sydney region 60 years ago. These include Silver Gull, Pacific Black Duck, Australian Pelican which have increased in number, and Crested Pigeon, Long-billed Corella, Little Corella and Mangrove , Australian Pelican which have increased in number, and Crested Pigeon, Long-billed Corella, Little Corella and Mangrove Gerygone.

Variegated Wrens were recorded in the salt marsh in 1972, but were noted in an area of Lantana near George Street near the boatshed (Martin, pers. Comm)

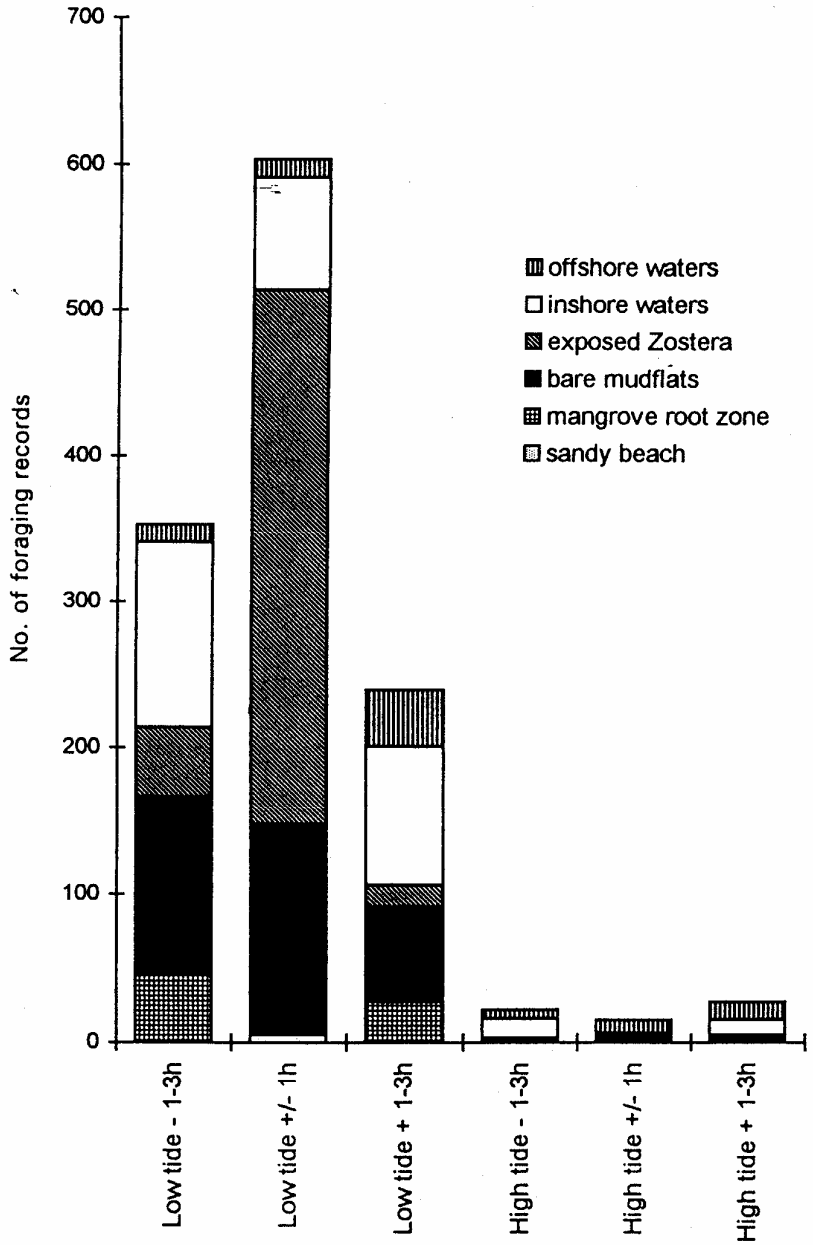


Figure 9. Feeding zones and relative feeding effort of birds on the mudflats and adjacent waters at different stages of the tide cycle. Foraging records for all species combined. Survey effort was approximately equal for each tide stage.

Figure 9. Bird Feeding Zones

7.4 Management Issues

7.4.1 Introduced Predators

Foxes are known from the surrounding area, and although no signs of foxes were seen during the 1997 survey, they are known to predate on Bush Stone-curlews at all stages of their life cycle from eggs to adults. Potential predators also include cats and stray dogs.

7.4.2 Disturbance of Waterbirds by People and Dogs

Disturbance to Feeding on Mudflats

Birds feeding on the intertidal mudflats or roosting on the sandspit north of Etival Street are subject to high levels of disturbance.

During Smith & Smith's 1997 survey of 48 counts (covering all tide phases, all times of day, work days, weekends and school holidays), there was an average of 10 people and 6 dogs per count, with no counts when there were no people and one count when there were no dogs.
The most common activity was walking especially exercising dogs. Other activities were fishing, bait collecting, boating, swimming, sunbathing, picknicking, bike riding.

> *"Many people come down to the mudflats after a session in the dog exercise area. Many others, however, avoid the dog exercise area entirely and take their dogs directly to the mudflats."*
>
> *"Despite signs at the end of Etival Street warning that dogs must be leashed when on the mudflats, 97% of all dogs seen there were unleashed. Some dogs caused no disturbance to the birds at all, but there were many observed instances of dogs chasing birds on the mudflats. Individual dogs can and did cause considerable disturbance of the birds' feeding activities. In one example, an unaccompanied dog was seen running back and forth along most of the length of the mudflats for at least half an hour, flushing every bird it could find."*
>
> Smith and Smith 1997

Little is known of the levels of disturbance that can be tolerated by waders and other waterbirds during feeding, their response to continual disturbance nor the effect it has on their survival. The impacts of disturbance on migratory waders' feeding could restrict their accumulation of large fat reserves. This occurs between February to April, as the wades feed to increase weight for their return migratory flights. Lane, 1987 (in Smith and Smith, 1997) recorded increases in weight prior to migration of 28% to 72%.

Should weight increase not occur due to disturbed feeding, this could lead to high mortality levels during migration or prevent them from migrating.

The birds concentrate their feeding around low tide and one unleashed dog on the mudflats could substantially disrupt the birds food intake for the entire tide cycle. Under even low disturbance regime, they feed during the day and night suggesting that they cannot obtain sufficient food in a single tide cycle.

Disturbance to High Tide Roosts

Waders and other waterbirds favour flat open high tide roost sites where they can see all around and can easily take off. Waders disturbed at high tide roosts are less likely to return to the site after flushing (Burger, 1981). Smith and Smith, 1997, considered that the sandspit north of Etival Street should be a major roost site, but birds resting briefly were flushed by the constant stream of people and dogs passing by.

7.4.3 Interference of Silver Gulls with Other Waterbirds

Smith and Smith compared the numbers of Silver Gulls at Careel Bay, which were 20-30 in 1972 (Hutchings and Recher 1974) and had increased to 227 during the 1997 survey. This may pose serious problems for other birds using the site relating to a corresponding decline in the numbers of migratory waders there as gulls regularly steal food from, and prey on the eggs and chicks of other waterbirds. Rapid expansion of gull populations is linked to greater availability of food waste is a problem because of the effects on other native species, for air safety and human health reasons (Smith 1992, 1995).

7.4.5 Interbreeding of Mallards with Pacific Black Ducks

The introduced Mallard freely hybridises with the native Pacific Black Duck in Australia and New Zealand, producing fertile offspring, resulting in genetic dilution of Pacific Black Duck populations and is highly undesirable (Marchant and Higgins 1990) . Interbreeding between the two species has been observed at Careel Bay (K. Martin). The mixed pairs, and pairs of Mallards, nest in waterfront gardens on the western side of the bay, while pairs of Pacific Black Ducks nest along Careel Creek.

7.4.6 Restoration and Enhancement of Habitat

Restoration of saltmarsh as critical habitat for Bush Stone-curlews will be required if saltmarsh is entirely

replaced by mangroves, however, at present the low layer of mangroves provides excellent cover for the birds and should be retained in the short term but closely monitored.

The feasibility of providing an artificial high tide roost site for the birds should be investigated to replace the now virtually unusable sandspit roost site. The design and location of any such artificial roost site, and its potential adverse environmental impacts, would need to be carefully considered.

Additional dead logs and branches should be provided on the mudflats as high tide roost sites. The ones that are there now are well used and valuable roost sites, especially for Little Pied Cormorants, and as hunting perches by Sacred Kingfisher.

7.4.7 Reduced Food Resources

Although Chapman and Underwood concluded that invertebrate populations of Careel Bay are within the range of natural variability, the impacts on the wetland may have reduced the abundance and diversity of organisms present since 1972.

Management objectives

- to conserve the native faunal species diversity, abundance and distribution
- to conserve, restore and/or enhance wetland habitats and wildlife corridors
- to control and manage pest animals and recreational activities displacing wildlife
- protect the resident pair of Bush Stone-curlews and enhance their breeding habitat

Performance Targets (in priority order)

- Control fox predation around the Careel Bay wetlands as Bush stone-curlews are particularly vulnerable feeding, roosting and nesting on the ground. Fox control is the highest priority.
- Stray cats and dogs should be systematically targetted and removed. A community education program on responsible pet ownership should be implemented targeting local cat and dog owner around Careel Bay, and stressing the special need in this area for people to control their pets' instinctive hunting behaviour.
- Monitor the mangrove expansion over saltmarsh in relation to Bush Stone-curlew habitat; no mangrove removal is recommended at this stage.
- Investigate ways to reduce impacts on bird species from dog activities. Smith and Smith recommend relocation of the dog exercise area. Other options could include prohibiting dogs from the mudflats and sandspit and trialling a proposal to separate the dog exercise area from the conservation area.
- Increase community awareness of the value of the Careel Bay wetlands to birds and the problems with disturbing their feeding on the mudflats and their high tide roosts, using pamphlets, displays, media releases and official community volunteer wardens to educate visitors.
- Enforce dog regulations when there is blatant activities that are clearly disrupting the birds, or when unaccompanied dogs are found on the mudflats.
- Investigate the provision of an artificial high tide roost site and provide additional snags on the mudflats as high tide roosts.
- Disrupt Silver Gull breeding activity on moored and similar sites in Careel Bay and other locations around Pittwater to reduce gull numbers to more natural levels in the local area. Control artificial food sources by reducing gull access to food wastes in local parks and commercial centres.
- Removal of the colony of introduced Mallards and/or educate residents not to protect hatchlings and to allow predation by Kites etc.
- Ensure that the saltmarsh habitat of the Bush Stone-curlews is not disturbed by any activities including any boardwalk construction which should avoid the two large saltmarsh areas or be restricted to their landward edge, and by promoting edge planting to dissuade entry by dogs and people.
- Undertake monitoring of invertebrate populations to detect adverse impacts as proposed by Chapman and Underwood.
- Promote the planting of indigenous vegetation in areas surrounding Careel Bay to enhance wildlife habitat and corridor values and provide incentive for the community to plant them on their properties.
- Include information on the impacts of chemicals such as herbicides and pesticides on the wetlands, especially on entering the food chain of this fish nursery.
- Promote planting of understorey and continue weeding to enhance habitat of Variegated Wren.

8.0 HERITAGE AND COMMUNITY ISSUES

8.1 Aboriginal Heritage Values

A shell midden has been recorded on the south-western side of the wetlands. Aboriginal shell middens are also known from the area to the north of the Careel Bay Wetlands and contain shells including Sydney Cockle.

8.2 Community Issues

8.2.1 Education and Research

Careel Bay estuarine wetland has great potential as an education and research site. It provides a number of significant features already described and a number of management issues requiring further research. The universities of Sydney, Macquarie and New South Wales have utilised Careel Bay for undergraduate and postgraduate student research.

The enthusiasm shown by the local community for the conservation of the Pittwater region suggests that there is great opportunity for raising community perception of the consequences of living in the catchment of an environmentally sensitive area. Community groups such as the Friends of Careel Bay Bush Regeneration Group are currently weeding between the tennis courts and Barrenjoey Road. Pittwater Council will continue to support such work.

Pittwater Council's Coastal Environment Centre is an environment information awareness and education facility that has utilised Careel Bay for environmental education and can play a significant role in focussing community awareness on Careel Bay through school and community education.

8.2.2 Recreational Users

Pittwater Council surveyed users to determine numbers and purposes of the people surveyed. The Careel Bay Recreational Use Survey was designed by the University of Sydney's Institute of Marine Ecology and carried out in 1996 and 1997 by trained volunteers. Data was collected from three sites, with information collected including firstly counts of numbers of people in the area, people fishing, collecting bait and unleashed dogs. Secondly, individuals or groups of people present were interviewed with respect to where they lived, frequency of visits, reasons for visiting and knowledge of Careel Bay. Field volunteers spent one hour at each site on the day between 11 am and 8 pm during low tide. The sampling was carried out with replicates during school holidays and school term, weekends and weekdays at the three locations (mouth of Careel Bay at Etival Street, eastern side saltpan near tennis courts, and western side near public wharf).

The Institute of Marine Ecology analysed the data and found that over 50% of users of the Bay were locals that visited more frequently than every 3-6 months.

Most people (88%) were aware that Careel Bay is an environmentally sensitive area. The activities undertaken included: boating 45%, exercise 42%, exercise pets 35%, fishing 29%, bait collection 10% and bird watching 10%.

The number of unleashed dogs at the end of Etival Street was observed to be significantly more than at any other area of the Bay.

Of the 222 anglers surveyed, most used the area near the wharf on the western side with 24% collecting bait locally.

Raising public awareness and setting new standards for best practice by the public can be complex as it can be difficult to communicate effectively with all community members as well as influence sectors of the community.

Marketing and promotion are an important part of how information is disseminated to different sectors of the community. Exhibitions should be prepared by qualified persons with experience in presenting information and should integrate interpretative information with high quality photography and graphics. Various government departments have education officers who, together with Pittwater Council's Coastal Environment Centre, can participate in campaigns to focus the public on the issues.

Council and local community groups can apply for funding to help improve and maintain the integrity of Careel Bay wetlands.

8.2.3 Access

Access paths provide the community with the opportunity to explore and appreciate natural areas and are necessary for the management of Careel Bay. Formal access does not currently exist in the estuarine wetland. Selection of a number of access points and tracks should be sufficient to allow entry from a number of points but minimised so they can be well managed. They also perform the dual function of guiding visitors through the wetlands and by providing such paths, reducing unwanted effects of unfettered access, thereby protecting plant communities, sensitive habitats for significant species, maintaining the aesthetic qualities and to controlling erosion.

during this period could have a substantial effect on the birds' food intake for the entire tide cycle.

8.2.4 Cultural practices

As the wetland is surrounded by urban development it is subject to a range of activities by the local and wider community within the catchment. These activities can impact on the wetland function in the short term and also lead to long-term changes and degradation. An ongoing community education program is required to reinforce on previous messages about the values and required management of saltmarsh and mangrove wetlands.

Fertiliser and detergent use

Fertilisers and detergents which contain phosphorus and nitrogen are used throughout the catchment for lawn maintenance and car washing and higher levels have been detected in wet weather.

Community awareness should include information on minimsing their use in the catchment as a target to protect the wetlands.

Perception of Wetland: litter, garden refuse, bike riding on saltpan

Council has been active in raising community awareness of wetland values with 70% of users interviewed being aware it is a senstive area. There are a number of indications however that such programs should continue and expand. For example, the saltmarsh and mangrove areas contain significant amounts of litter some of which is brought in by wind

and water flow. However, some of the litter, such as car parts, is obviously deposited by people. A range of garden refuse has been deposited along fences at the back of adjacent properties. Similarly a small area of the saltmarsh had been mowed, which appear to be an attempt to tidy up the wetland. Such actions indicate a lack of awareness of the significant nature of the saltmarsh and its rarity within Pittwater and NSW as a whole. In addition, children's bike riding on the saltpan indicates their need for bike riding areas but is an enjoyment of the area which damages the saltmarsh.

Unleashed Dogs on Mudflats and Sandspit

Bird species feeding on the intertidal mudflats or roosting on the sandspit north of Etival Street are subject to high levels of disturbance by people and dogs, with many people bringing their dogs onto the mudflats. Despite signs at the end of Etival Street warning that dogs must be leashed when on the mudflats, 97% of all dogs were unleashed, as recorded by Smith and Smith during 48 timed counts. As bird species concentrate their feeding around low tide, a single troublesome dog loose on the mudflats

Disturbance of the bird species at their high tide roosts is a matter of concern with the sandspit north of Etival Street being rendered unusable as a regular roost site because of the constant disturbance.

8.2.5 Community programs

Council has undertaken a number of community programs dealing with the Careel Bay Wetlands. These include:

- developing and distributing a brochure on birds frequenting the wetland;
- liaising with local residents;
- erecting interpretative signage;
- conducting a field day;

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- undertaking a wetland user survey;
- facilitating Clean Up Australia removing rubbish;
- facilitating wader studies by Royal Australian Ornithologists Union (RAOU);
- facilitating stream watch activities in the wetland;
- encouraging the wetland for use as an educational and research resource; and
- educational use by the Coastal Environment Centre.

Educational measures should also advise that disturbances to species of waders and waterbirds should not occur on the Etival Street mudflats, especially from February to April when the migratory birds are building up fat for the northbound migration.

Educational and recreational activities which are compatible with the ecological sustainability of the habitats should be encouraged via CEC and school programs. Facilities could be expanded to increase the educational value of the habitat. These include:

- boardwalk;
- bird refuge islet;
- interpretative signage;
- brochure on special wetland values indicating need for protection
- clean up campaigns.

- Expand existing bush regeneration group (southern end)

Management Objectives

- To raise community awareness about the natural and cultural conservation significance of the estuarine wetland.
- To guide human activities so the wetland can continue to support the full range of flora and fauna species.
- To provide appropriate access for people to enjoy the area whilst not disturbing the species present and to protect sensitive areas.
- To inform neighbours of ways of minimising pollution of the wetland.
- To facilitate community and scientific education and research.
- To provide community programs that target specific issues (eg. weeds, species protection, saltmarsh, etc.)

Performance Targets

Education and Research

- Continue to promote community, school and educational education and research on the Careel Bay wetlands
- Produce a brochure on estuarine wetland vegetation and its significance
- Hold a seminar or workshop on the wetlands which is open to the public

Recreational Users & Access

- Construct a network track for the community through the a variety of plant communities of the wetland and avoids sensitive areas, that is in part wheelchair accessible and that links with existing bridges and the the proposed bicycle track
- Investigate solutions to the conflicts between species protection and unleashed dogs
- Establish an informal planting of sedges to limit the public access into the salt marsh zones of the southern side of the Bay

Cultural Practices

- Review and erect warning signs, that better reflect the sensitive areas and prohibited activities.
- Implement community awareness campaigns through a household campaign promoting practices to reduce pollution in waterways
- Prepare interpretive signs that foster community education of the Careel Bay wetland.
- Contact commercial organisations to determine waste management practices currently in use and advise organisations on best management practices.
- Continue clearing of existing litter through activities such as Clean Up Australia, or direct requests to local residents to remove garden refuse.
- Increase public awareness of the value of the Careel Bay wetlands to birds and the problem of excessive disturbance of feeding and roosting birds.

Future Management Options

- Construct an access tracks linking to the north and west of the bay
- Improve all track surfaces to enable wheel chair access

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APPENDIX 1

GLOSSARY OF TECHNICAL TERMS

Algae	Non-rooted aquatic plants, specifically non-vascular photosynthetic organisms with unicellular reproductive organs, including phytoplankton and seaweeds.
Advective Transport	The transport of dissolved material by water movement,
Aerobic Bacteria	Bacteria that obtain metabolic energy by aerobic (oxygen requiring) respiration.
Algal Bloom	The excessive growth of phytoplankton, generally caused by high nutrient levels. Can result in deoxygenation of the water mass, leading to the death of aquatic flora and fauna.
Amenity	Those features of an estuary that foster its use for various purposes, eg. clear waters and sandy beaches make beach-side recreation attractive.
Amphipods	Laterally compressed crustacea, eg. sand hoppers.
Anaerobic Bacteria	Bacteria that obtain metabolic energy by a variety of non-aerobic (not oxygen dependent) pathways, including the reduction of nitrates ('denitrification') and/or sulphates.
Angiosperms	Flowering plants.
Annual Exceedance Probability (AEP)	Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded; it would occur quite often and would be relatively small. A 1% AEP flood has a low probability of occurrence or being exceeded; it would be fairly rare and would be relatively large.
Annual Exceedance Probability	The chance or likelihood that an event of a nominated size or greater (eg. flood discharge) will occur in any year.
Aquaculture	The farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants.
Arbovirus	A virus transmitted by blood sucking arthropods, eg insects.
Assimilation	The ability of waterbodies to utilise, by various organisms (including vegetation), organic matter and nutrients as food for their growth.
Australian Height Datum (AHD)	A common national plane of level corresponding approximately to mean sea level.
Balanced Development	The weighing of ecological, social and economic consequences in determining the nature, location and degree of estuarine development.
Baseline Monitoring	A monitoring program aimed at determining long-term and possibly pre-disturbance levels and variation in some parameter of interest, eg. dissolved oxygen.
Bed Load	That portion of the total sediment load that flowing water moves along the bed by the rolling of saltating of sediment particles.
Benthos, Benthic Organisms	Organisms living in or on the bed of a waterbody.
Bio-deposition	The formation and deposition of sediment particles by biological processes, the removal, aggregation and secretion of clay particles by filter feeders.
Biodiversity	The natural diversity of life forms comprising ecosystem diversity, species diversity and genetic diversity.
Biological Oxygen Demand	Oxygen required by aerobic bacteria in metabolising detritus.
Biomass	The mass of living material contained in a system of interest (includes both plant and animal matter).
Biota	Living organisms.
Bird (In the context of the National Parks and Wildlife Act, 1974)	"Any bird that is native to, or is of a species that periodically or occasionally migrates to, Australia, and includes the eggs and the young thereof and the skin, feathers or any other part thereof."
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main stream.
Cetaceans	Whales and Dolphins.
Chemoautotroph	A bacterium which uses a chemical reaction instead of light as the energy source needed to convert carbon dioxide into organic molecules. Examples are nitrifying bacteria and sulphur bacteria, which are important in nutrient cycling through sediments.
Conservation	All the processes of looking after a place so as to retain its natural significance. It includes protection, maintenance and monitoring, and may, according to circumstance, include conservation management measures, preservation, restoration, enhancement, reinstatement, regeneration or modification or a combination of more than one of these.
Crown Land	Crown lands are those lands, including the beds of creeks, rivers, estuaries and the ocean, that remain by title under the administration of the New South Wales Department of Conservation and Land Management. Such lands may be vacant, occupied under licence or reserved. Occupied or reserved Crown land can be managed by the Department of Conservation and Land Management, Councils or Trusts.

Degradation	A reduction in the area of estuarine habitat; or in the well-being, health and viability of estuarine ecosystems; or in estuarine amenity.
Denitrification	See anaerobic bacteria.
Detention Basin	Facility for detaining runoff and releasing it at a controlled rate.
Detritivores	Organisms that feed on detritus, eg. protozoans, worms.
Detritus	All non-living organic material, including animal waste products and the remains of animals, plants and micro-organisms, together with the associated microbial community (bacteria and fungi).
Diatoms	Single celled water plants.
Discharge	Volumetric flow rate of water, typically measured in terms of cubic metres per second (m^2/s),
Diffuse Source Pollution	Pollution originating from a widespread area, e.g. urban stormwater runoff, agricultural runoff.
Dispersive Transport	The transport of dissolved matter through the estuary by vertical, lateral and longitudinal mixing associated with velocity shear.
Dissolved Oxygen	Atmospheric oxygen that dissolves in water. The solubility of oxygen in water depends upon temperature and salinity.
Diurnal	A daily variation, as in day or night.
Ebb Tide	The outgoing tidal movement of water within an estuary.
Ecologically Sustainable Development	Development that meets the needs of the present community without compromising the ability of future generations to meet their own needs.
Ecosystem	A community of living organisms, together with the environment in which they live and with which they interact.
Eddies	Large, circular, swirling movements of water, often metres or tens of metres across.
Edge Effect	The effect of external influences on internal processes in naturally vegetated areas, which increase as the perimeter to area ratio increases.
Effluent	The liquid discharge after sewage treatment.
Elevated Half-Tide Levels	An increase in half-tide level caused by the 'trapping' of tidal water in upstream estuary reaches.
Entrance Bar	A deposit of sand or silt across the entrance to an estuary. The material may be either fluvial or marine in origin.
Environmental Impact Statement (In the context of the Environmental Planning & Assessment Act, 1979)	"An assessment of the impact of a proposed development."
Epibenthic Organisms	Organisms living on the bed of a waterbody.
Epibiota	Organisms (plants and animals) attached to other organisms.
Epiphytic	(Of living organisms) attached to and growing on the surface of a plant, but not obtaining food or nutrients from the plant.
Estuarine Processes	Those processes that affect the physical, chemical and biological behaviour of an estuary, eg. predation, water movement, sediment movement, water quality, etc.
Estuarine Resources	The totality of the animal, vegetable and mineral matter associated with an estuary and its environs, including estuarine waters, together with the amenity of the estuary.
Estuary	An enclosed or semi-enclosed body of water having an open or intermittently open connection to coastal waters in which water levels vary in a periodic fashion in response to ocean tides.
Estuary Management Process	A sequence of activities starting with the formation of an Estuary Management Committee and culminating in the implementation of an Estuary Management Plan that will foster the balanced and sustainable use of estuaries.
Eutrophication	The build-up of nutrient levels in a water body leading to the excessive growth of aquatic plants, which in turn depletes dissolved oxygen levels in the waterbody.
Event Monitoring	The monitoring of some parameter during a particular physical, chemical or biological event of interest, eg. the variation of turbidity levels in an estuary during the passage of a flood, the effect of dredging on the distribution of a certain species of fish.

Exotic Species	An introduced species
Faecal Coliforms	A group of bacteria, the presence of which indicates the possibility of contamination by warm blooded animals.
Fauna (In the context of the National Parks & Wildlife Act, 1974)	"Any mammal, bird, reptile or protected amphibian".
Fauna Impact Statement (In the context of the Endangered Fauna (Interim Protection Act), 1991)	"An assessment of the likely consequences of some proposed development on affected fauna".
Feral	Non-indigenous animals that have adapted to live in a wild state and compete with native fauna.
Fire Regime	Fire frequency, season, intensity and size.
Fish (In the context of the Fisheries & Oyster Farms Act, 1935)	"All or any of the varieties of marine, estuarine or freshwater fishes (whether indigenous or not) and their young, fry and spawn, and unless the contrary intention be expressly stated or the context otherwise requires, includes crustacea and oysters and all marine, estuarine and freshwater animal life, and any part of a fish as hereinbefore defined, but does not include any species of whales".
Flocculate	The coalescence, through physical and chemical processes, of individual suspended particles into larger particles ('flocs').
Flood	High stream flow which overtops the natural or artificial banks in any part of a stream or river.
Flood Mitigation Works	Structures that are designed
Flood Tide	The incoming tidal movement of water within an estuary.
Flooding	The State Emergency Service uses the following definition in flood warnings: **Minor flooding** causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this glass of loading, on the reference gauge, is the initial flood level and the upper limit is determined by local conditions. **Moderate flooding** is when low lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic bridges must be covered. The range on the reference gauge is determined by local conditions. **Major flooding** is when extensive rural areas are flooded with properties, villages and towns isolated and/or appreciable urban areas are flooded. The threshold for this class of flooding is the upper limit of moderate flooding.
Floodplain	The portion of a river valley, adjacent to the river channel, which is covered with water when the river overflows during floods.
Fluvial	Pertaining to non-tidal flows.
Fluvial Processes	The erosive and transport processes that deliver terrestrial sediment to creeks, rivers, estuaries and coastal waters.
Fluvial Sediments	Land based sediments carried to estuarine waters by rivers.
Foreshore	The area of shore between low and high tide marks and land adjacent thereto.
Fortnightly Tides	The variation in half-tide levels caused by the monthly cycle of Spring and Neap Tides.
Geomorphology	The study of the origin, characteristics and development of land forms.
Gravitational Circulation	A residual circulation in the lower reaches of an estuary characterised by landward flowing bottom currents and ocean flowing surface currents, driven by the gravitational forces associated with differences in salinity levels along the estuary.
Gross Pollutant Trap	Settling basin to allow removal of coarse sediments, floating debris and trash.
Habitat	The places in which an organism lives and grows. Many estuarine organisms require different habitats at different stages of their life cycles.
Half-Tide Level	The average of successive high tide and low tide levels.
Heavy Metals	Generally, those metals that occur in Groups 1B to VIIIB of the Periodic Table with atomic numbers between 21 and 84, but excluding Rare Earth elements, Heavy metals generally have a specific gravity of 5.0 or more and include chromium, iron, nickel, copper, zinc, silver, cadmium, platinum, gold, mercury and lead. Although essential in trace concentrations, some heavy metals are toxic to aquatic organisms at higher concentrations, eg. mercury, lead, copper and zinc. Even when present in sub-lethal concentrations, heavy metals may adversely affect the health of aquatic organisms.

Humic Acid	Acidity resulting from the decomposition of organic material.
Hydraulic Regime	The variation of estuarine discharges in response to seasonal freshwater inflows and diurnal tides.
Hydrology	The study of water, on or under the land.
Hydrolyse	Decompose by chemical reaction with water.
Hydrophobic	Water repelling.
Hypersaline	Having a salinity greater than seawater (ie. above 35 parts per thousand). Generally caused by salt concentration through evaporation.
Indigenous	Native or original to the area, not introduced from outside a particular region or environment.
Induration	The cementing together of sand particles by natural physical and chemical processes.
Intertidal	Pertaining to those areas of land covered by water at high tide, but exposed at low tide, eg. intertidal habitat.
Introduced Species	Flora and fauna species not native to Australia.
Invertebrate	Animal without a backbone, eg. jellyfish.
Isohaline	A line connecting parts of the water mass having the same salinity, ie. a contour of equal salinity levels.
Land Assessment (In the context of the Crown Lands Act, 1989)	"Determination of the suitability of a parcel of land for various land-uses". (Based on land capability).
Large-Scale Boundary Effects	The promotion of mixing in estuarine waters caused by the presence of large boundary features, such as headlands, bays and channels, that disturb flood and ebb tide flow patterns and provide storage for waters on the flood tide and release of these waters on the ebb, and so facilitate mixing across the estuary.
Levee	A man-made embankment or wall built to exclude floodwaters, or a natural embankment adjacent to a waterway built by the deposition of silt from floodwaters.
Littoral Drift Processes	Wave, current and wind processes that facilitate the transport of sediments along a shoreline.
Littoral Zone	An area of the coastline in which sediment movement by wave, current and wind action is prevalent.
Macroalgae	Small to large attached algae of several types (red, brown and green). Green algae may become detached and accumulate in shallow waters.
Macrophytes	Rooted plants which grow in water either submerged or emergent above the water line.
Macrophytes (aquatic)	Rooted aquatic plants, eg. Eelgrass.
Mammal (In the context of the National Parks & Wildlife Act, 1974)	"Any mammal, whether native, introduced or imported and includes an aquatic or amphibious mammal, the eggs and the young of a mammal, and the skin or any other part of a mammal, but does not include any introduced or imported domestic mammal or any rat or mouse not native to Australia".
Management Plan	A document, as appropriate, both written and diagrammatic information describing how a particular area of land is to be used and managed to achieve definite objectives. It may also include description and discussion of various issues, problems, features and values of the area, the specific management measures which are to apply and the means and timing by which the plan will be implemented.
Mangroves	An intertidal plan community dominated by trees.
Marine Mammal (In the context of the National Parks & Wildlife Act, 1974)	"A mammal of a species named in Part 5 of Schedule 12."
Marine Sediments	Sediments in coastal waters moved along the coast by littoral processes.
Marine Transgression	When the sea level retreats
Mollusc	A large phylum of animals, mostly aquatic, including mussels, snails and octopus, which are soft-bodied, often with a hard shell, unsegmented, and having a head and muscular foot.

Native Plant (In the context of the National Parks & Wildlife Act, 1974)	"Any tree shrub, fern, creeper, vine, palm or plant that is native to New South Wales, and includes the flower and any other part thereof".
Native Plant Species	Native Australian species which are not necessarily indigenous to a particular area.
Neap Tides	Tides with the smallest range in a monthly cycle. Neap tides occur when the sun and moon lie at right angles relative tot he earth (the gravitational effects of the moon and sun act in opposition on the ocean).
Nematode	A non-segmented threadlike round worm.
Nutrients	The elements that, in excess, lead to excessive growth of vegetation. In most cases the term "nutrients" refers to nitrogen and phosphorus compounds.
Passive Recreation	Activities which do not have any major impact on the environment.
Pelagic Organisms	Organisms living in the water column of the ocean and capable of moving independently of currents.
Pest Plant	An exotic or alien plant species which has an undesirable effect on the wetland.
Phase Lag	Difference in time of the occurrence between high (or low water) and maximum flood (or ebb) velocity at some point in an estuary.
Phytoplankton	Microscopic free-floating aquatic plants (algae).
Pinnipeds	Seals.
Pneumatophores	Air breathing roots.
Point-Source Pollution	Specific localised source of pollution, eg. sewage effluent discharge, industrial discharge.
Pollute (In the context of the Clean Waters Act, 1970)	a) To place in or on, or otherwise introduce into or onto, the waters (whether through an act or omission) any matter, whether solid, liquid or gaseous, so that the physical, chemical or biological condition of the waters is changed; or b) To place in or on, or otherwise introduce into or onto, the waters (whether through an act or omission) any refuse, litter, debris or other matter, whether solid or liquid or gaseous, so that the change in the condition of the waters or the refuse, litter, debris or other matter, either alone or together with any other refuse, litter, debris or matter present in the waters makes, or is likely to make, the waters unclean, noxious, poisonous or impure, detrimental to the health, safety, welfare or property of persons, undrinkable for farm animals, poisonous or harmful to aquatic life, animals, birds or fish in or around the waters or unsuitable for use in irrigation, or obstructs or interferes with, or is likely to obstruct or interfere with persons in the exercise of enjoyment of any right in relation to the waters; or c) To place in or on, or otherwise introduce into or onto, the waters (whether through an act or omission) any matter, whether solid, liquid or gaseous, that is of a prescribed nature, description or class or that does not comply with any standard prescribed in respect of that matter".
Polychaete	A segmented worm with bristles.
Poorly-Mixed Estuary	An estuary characterised by poor vertical mixing, pronounced vertical salinity gradients and a discrete body of saltwater (a salt wedge) underlying freshwater.
Protected Fauna (In the context of the National Parks & Wildlife Act, 1974)	"Fauna of a species not named in Schedule 11".
Protected Native Plant (In the context of the National Parks & Wildlife Act, 1974)	"A native plant of a species named in Schedule 13."
Prototype Models	The use of the estuary itself to monitor some physical, chemical or biological process of interest.
Public Lands	Public lands in New South Wales are those lands which by title (and usually day to day administration and management) are under control of any Commonwealth, State or Local Government agency. Examples of Public lands include national parks, state forests, railway corridors, public roads and Crown land.
Receiving Waters	Waterbodies which receive discharges (often runoff and treated sewage).
Recruitment	The addition of new members to an existing population, such as the settling of planktonic fish and crustacean larvae into seagrass beds.
Remnant	An original or surviving piece of vegetation.
Reptile (In the context of the National Parks & Wildlife Act, 1974)	"A snake, lizard, crocodile, tortoise, turtle or other member of the class reptilia (whether native, introduced or imported), and includes the eggs and the young thereof and the skin or any other part thereof".
Residual Sediment Flux	The net upstream or downstream movement of sediment over a tidal cycle, often determined by tidal distortion and gravitational circulation.
Revetments	Walls built parallel to the shoreline to limit shoreline recession.
Riparian Vegetation	Vegetation growing along banks of rivers, including the brackish upstream reaches of an estuary.

Runoff	The amount of rainfall which ends up as streamflow. Also known as rainfall excess.
Salinity	The total mass of dissolved salts per unit mass of water. Seawater has a salinity of about 35g/kg or 35 parts per thousand.
Sewage	Waste matter carried in sewers.
Sewerage	The removal of waste matter by sewers.
Species Diversity	The variety of species in the area.
Stormwater Flooding	Inundation resulting from the incapacity of an urban stormwater drainage system to handle runoff.
Stratigraphy	That branch of geology dealing with the ordering of rocks into their relative ages.
Sub-Aerial Sand Barrier	A sand barrier with crest level above high tide; usually vegetated.
Super-Elevation	See Storm Surge.
Surface Pollutants	Floating pollutants that do not mix effectively with water, eg. oil.
Surfactants	Substances that reduce the surface tension of water and promote 'wetting'.
Suspended Sediment Load	That portion of the total sediment load held in suspension by turbulent velocity fluctuations and transported by flowing water.
Swale	A topographic depression in a dune system that may retain water.
Tailings	The residue of mined ores after the target mineral has been extracted.
Tidal Amplification	The increase in the tidal range at upstream locations caused by the tidal resonance of the estuarine waterbody, or by a narrowing of the estuary channel.
Tidal Celerity	The speed of travel of the tidal wave along estuaries. Celerity depends upon the depth of water; the deeper the water, the greater the celerity.
Tidal Delta	The build-up of shoals in the lower reaches of an estuary due to the gradual accumulation of marine sands transported into the estuary through its entrance.
Tidal Distortion	The distortion of the tidal variation of water levels in shallow estuaries caused by the differences in the celerity of rising (faster) and falling (slower) water levels.
Tidal Exchange	The proportion of the tidal prism that is flushed away and replaced with 'fresh' coastal water each tide cycle.
Tidal Excursion	The distance travelled by a water particle from low water slack to high water slack and vice versa.
Tidal lag	The delay between the state of the tide at the estuary mouth (eg. high water slack) and the same state of tide at an upstream location.
Tidal Limit	The most upstream location where a tidal rise and fall of water levels is discernible. The location of the tidal limit changes with freshwater inflows and tidal range.
Tidal Loops	Inter-connecting channels between two tidal systems or across a large delta. Tidal Loops can generate a complicated pattern of residual flows that facilitate advective and dispersive transport.
Tidal Planes	A series of water levels that define standard tides, e.g. "Mean High Water Spring' (MHWS) refers to the average high water level of Spring Tides.
Tidal Prism	The total volume of water moving past a fixed point on an estuary during each flood tide or ebb tide.
Tidal Propagation	The movement of the tidal wave into and out of an estuary.
Tidal Pumping	The generation of Elevated Half-Tide Levels because of the greater celerity of the flood tide compared to the ebb tide.
Tidal Range	The difference between successive high water and low water levels. Tidal range is maximum during Spring Tides and minimum during Neap Tides.
Tidal Trapping	The process whereby a discrete body of water is trapped over shallow shoal areas on the flood tide and separated from other water moving up the estuary. This facilitates mixing.
Tidally Averaged Models	Models that predict estuarine behaviour over periods greater than a tidal cycle, ie. the temporal resolution is of the order of days, weeks or months.
Tidally Varying Models	Numerical models that predict estuarine behaviour within a tidal cycle, ie. the temporal resolution is of the order of minutes or hours.
Tides	The regular rise and fall in sea level in response to the gravitational attraction of the sun, moon and planets.
Total Catchment Management (In the context of the Catchment Management Act, 1989)	"The coordinated and sustainable use of land, water, vegetation and other natural resources on a water catchment basis so as to balance resource utilisation and conservation".
Training Walls	Walls constructed at the entrances of estuaries to improve navigability.
Turbidity	A measure of the ability of water to absorb light.

Vegetation Structure	The physical characteristics of the vegetation such as height and density.
Velocity Shear	The differential movement of neighbouring parcels of water brought about by velocity gradients. Velocity shear causes dispersive mixing, the greater the shear (velocity gradient), the greater the mixing.
Vertebrate	Animal with a backbone, eg. fish, birds.
Water Quality	The suitability of the water for various purposes, as measured by the concentration or level of a wide variety of contaminants.
Water Table	The plane which forms the upper surface of the zone of groundwater saturation.
Waters (In the context of the Clean Waters Act, 1970)	"Any river, stream, lake, lagoon, swamp, wetlands, unconfined surface water, natural or artificial watercourse, dam or tidal waters (including the sea) or part thereof, and includes waters stored in artificial works, water in water mains, water pipes and water channels, and any underground or artesian water, or any part thereof".
Well-Mixed Estuary	Estuary characterised by strong vertical mixing and weak or non-existent vertical salinity gradients.
Wildlife (In the context of the National Parks & Wildlife Act, 1974)	"Fauna and native plants",
Wind Shear	The stress exerted on the water's surface by wind blowing over the water. Wind shear causes the water to 'pile up' against downwind shores and generates secondary currents.
Wrack Zone	That area of the foreshore where flotsam and jetsam are deposited.

APPENDIX 2

BENTHIC FAUNA

List of infauna and epifauna found in cores, quadrats and searches at Careel Bay in July and September, 1996 and additional species found at Bundeena, Patonga and Woolaware Bay (Chapman and Underwood, 1997)

Shore	**Classification**	**Species**
Careel Bay	**Phylum-Mollusca**	
	Class-Gastropoda	
	Subclass-Prosobranchia	
	Family-Acmaeidae	*Patelloida mimula*
	Assimineidae	*Assiminea buccinoides*
		Assiminea sp.
	Batillariidae	*Batillaria australis*
		Pyrazus ebeninus
	Hydrobiidae	*Tatea huonensis*
		Tatea rufilabris
	Littorinidae	*Bembicium auratum*
		Littoraria luteola
	Muricidae	*Bedeva hanleyi*
	Nassariidae	*Nassarius burchardii*
		N. jonasi
	Naticidae	*Polinices sordidus*
	Trochidae	*Austrocochlea porcata*
		Thalotia conica
	Vitrinellidae	*Pseudliotia micans*
	Subclass-Pulmonata	
	Amphibolidae	*Salinator fragilis*
		S. solida
	Ellobiidae	*Melosidula zonata*
		Ophicardelus quoyi
	Subclass-Opisthobranchia	
	Class-Bivalvia	
	Family-Arcidae	*Anadara trapezia*
	Laternulidae	*Laternula tasmanica*
		(2 morpho-species)
	Leptonidae	*Arthritica helmsi*
	Mactridae	*Notospisula trigonella*
	Ostreidae	*Saccostrea commercialis*
	Tellinidae	*Tellina deltoidalis*
	Veneridae	*Eumarcia fumigata*
		(2 morpho-species)
	Phylum-Annelida	
	Class-Polychaeta	
	Family-Ampharetidae	
	Capitellidae	
	Chaetopteridae	
	Cirratulidae	
	Glyceridae	
	Lumbrineridae	
	Magelonidae	
	Maldanidae	
	Nephtyidae	
	Nereididae	

	Opheliidae	
	Orbiniidae	
	Oweniidae	
	Paraonidae	
	Phyllodocidae	
	Sabellidae	
	Spionidae	
	Spirorbidae	
	Syllidae	
	Class-Oligochaeta	
	Phylum-Crustacea	
	Class-Malacostraca	
	Order- Amphipoda	
	Suborder-Gammaridea	(13 morpho-species)
	Caprellidea	
	Order-Decapoda	
	Family-Penaiedae	
	Infraorder-Caridea	
	Infraorder-Thalassinidae	
	Infraorder-Anomura	
	Infraorder-Brachyura	*Sesarma erythrodactyla*
		Heloecius cordiformis
		Paragrapsus laevis
		Myctyris longicarpus
		Macrophthalmus sp.
		(1 morpho-species)
	Order-Mysidacea	
	Tanaidacea	
	Phylum-Arthropoda	
	Class-Insecta	
	Order-Collembola	
	Order-Diptera	
	Phylum-Nemertea	
	Phylum-Nematoda	
	Phylum-Chordata	
	Order-Osteichthyes	
Bundeena and	**Phylum-Mollusca**	
Patonga	**Class-Gastropoda**	
	Subclass Prosobranchia	
	Family-Cerithiidae	*Bittium* sp.
	Hydrobiidae	*Aschoris victoriae*
	Naticidae	*Polinices conicus*
	Neritidae	*Neritina oualaniensis*
	Class-Bivalvia	
	Family-Lucinidae	(1 morpho-species)
	Phylum-Annelida	
	Class-Polychaeta	
	Family-Dorvilleidae	
	Eunicidae	
	Hesionidae	
	Sigalionidae	
	Terebellidae	

	Phylum-Crustacea	
	Class-Ostracoda	
	Class-Maxillpoda	
	Subclass-Copepoda	
	Class-Malacostraca	
	Order-Amphipoda	
	Suborder-Gammaridea	(2 morpho-species)
	Order-Isopoda	
	Suborder-Anthuridea	
	Suborder-Flabellifera	(3 morpho-species)
	Phylum-Phoronida	
	Phylum Cnidaria	
	Order-Actiniaria	
	Phylum-Echinodermata	
Woolaware Bay	**Phylum-Echinodermata**	
	Class-Asteroidea	
	Phylum-Mollusca	
	Class-Bivalvia	
	Laternulidae	*Laternula* sp.
	Family-Mytilidae	*Xenostrobus securis*
	Psammobiidae	*Sanguinolaria donacioides*

APPENDIX 3

BIRD LIST

Annotated list of bird species recorded from Careel Bay and its immediate catchment (P & J Smith, 1997).

Species nomenclature and family order follow Christidis and Boles (1994). Introduced species are marked with an asterisk.

Swans, Geese and Ducks (Family Anatidae)

1. Grey Teal *Anas gracilis*
Recorded in 1972 (Hutchings and Recher 1974).

2. *Mallard *Anas platyrhynchos*
Well established colony on western side of bay, including typical Mallards and various domestic forms. Noted by Steege (1988) as a fairly recent occurrence. Maximum count 31 during 1997 survey. Nest in waterfront gardens and interbreed with Pacific Black Ducks (K. Martin).

3. Pacific Black Duck *Anas superciliosa*
Regularly recorded during 1997 survey, maximum count 30. Apparently less common in 1972 (Hutchings and Recher 1974). Careel Ck, intertidal mudflats and adjacent waters. Nesting recorded along Careel Ck, also nest and interbreed with Mallards in waterfront gardens on western side of bay (K. Martin).

4. *Domestic Goose *Anser anser*
One free-living pair on western side of bay. One bird was released there in 1993, the other later (K. Martin).

5. Musk Duck *Biziura lobata*
One seen swimming in bay on 22.1.72 (P. Smith).

6. Australian Wood Duck *Chenonetta jubata*
Recorded in August-September 1994 (K. Martin).

7. Black Swan *Cygnus atratus*
Recorded by Steege (1988) as seen occasionally but becoming rare. Not recorded in bay during 1990s (K. Martin).

Penguins (Family Spheniscidae)

8. Little Penguin *Eudyptula minor*
Single birds, pairs or small groups seen swimming in the bay throughout the year (K. Martin). Nest on nearby Lion Island, which has the largest breeding colony in the Sydney region (Roberts 1993).

Petrels and Shearwaters (Family Procellariidae)

9. Southern Giant-Petrel *Macronectes giganteus*
One occurrence at Sand Point reported by Steege (1988).

10. Short-tailed Shearwater *Puffinus tenuirostris*
Occasional weak or dead birds found in bay in spring and early summer (K. Martin). Large numbers migrate southwards along the NSW coast at this time of year, on passage to their main breeding grounds in Bass Strait and Tasmania.

Gannets and Boobies (Family Sulidae)

11. Australasian Gannet *Morus serrator*
Recorded in September-October 1993 (K. Martin).

Darters (Family Anhingidae)

12. Darter *Anhinga melanogaster*
Recorded in 1994/95 (K. Martin)

Cormorants (Family Phalacrocoracidae)

13. Great Cormorant *Phalacrocorax carbo*
Occasionally recorded in bay (K. Martin). Apparently more common in 1972 (Hutchings and Recher 1974).

14. Little Pied Cormorant *Phalacrocorax melanoleucos*
Regularly recorded during 1997 survey, maximum count 28. Bay and mudflats.

15. Little Black Cormorant *Phalacrocorax sulcirostris*
Recorded infrequently in bay during 1997 survey, maximum count 3. Usually occurs in larger flocks (K. Martin).

16. Pied Cormorant *Phalacrocorax varius*
Occasionally recorded in bay (K. Martin, G. Bickley).

Pelicans (Family Pelecanidae)

17. Australian Pelican *Pelecanus conspicillatus*
Regularly recorded in bay during 1997 survey, maximum count 25. Gather in afternoon at Careel Bay Boatshed, where they are fed. Apparently less common in 1972 (Hutchings and Recher 1974).

Herons, Bitterns and Egrets (Family Ardeidae)

18. Great Egret *Ardea alba*
Only recorded once during 1997 survey (15.4.97), but reported to be a frequent visitor to mudflats in recent years, usually single birds (K. Martin).

19. Cattle Egret *Ardea ibis*
Three seen on mudflats 15.4.97. Recorded previously in December 1993 (K. Martin).

20. Intermediate Egret *Ardea intermedia*
Recorded on mudflats a number of times in recent years (G. Bickley).

21. Striated Heron *Butorides striatus*
Regularly recorded during 1997 survey, maximum count 4. Both adults and juveniles seen. Mudflats and mangroves. Probably resident, but perhaps only one pair and their young. Nesting recorded previously in mangroves near dog exercise area (K. Martin).

22. Little Egret *Egretta garzetta*
One seen on mudflats 24.3.97 and 3.5.97.

23. White-faced Heron *Egretta novaehollandiae*
Regularly recorded during 1997 survey, maximum count 14. Mudflats, mangroves and saltmarsh.

24. Eastern Reef Egret *Egretta sacra*
Recorded by Steege (1988) as foraging occasionally on rocky shores in the bay.

25. Little Bittern *Ixobrychus minutus*
Recorded by Steege (1988) as a very rare visitor to Careel Bay not seen in recent years.

Ibis and Spoonbills (Family Threskiornithidae)

26. Yellow-billed Spoonbill *Platalea flavipes*
Recorded on mudflats in earlier years (Hutchings and Recher 1974, Steege 1988). Also recorded by K. Martin, but not since late 1980s.

27. Royal Spoonbill *Platalea regia*
Two birds frequented the mudflats during second half of 1997 survey. Regularly recorded in bay (Hutchings and Recher 1974, Steege 1988, K. Martin, G. Bickley).

28. Australian White Ibis *Threskiornis molucca*
Regularly recorded during 1997 survey, maximum count 28. Mudflats, mangroves and saltmarsh.

29. Straw-necked Ibis *Threskiornis spinicollis*
Recorded on mudflats in 1972 (Hutchings and Recher 1974). An unusual habitat for the species.

Hawks, Eagles and Osprey (Family Accipitridae)

30. Brown Goshawk *Accipiter fasciatus*
One seen hunting low over saltmarsh and mangroves on three occasions during 1997 survey.

31. White-bellied Sea-Eagle *Haliaeetus leucogaster*
Single birds occasionally seen flying over bay during 1997 survey. Apparently resident in district, nesting on western side of Pittwater (K. Martin).

32. Whistling Kite *Haliastur sphenurus*
Single birds often seen flying over during 1997 survey. A resident pair ranges over most of Pittwater and formerly nested in tall Spotted Gum *Eucalyptus maculata* trees on Stokes Point peninsula (Martin 1992). Current nest site unknown (K. Martin).

33. Little Eagle *Hieraaetus morphnoides*
Recorded by Steege (1988).

Falcons (Family Falconidae)

34. Nankeen Kestrel *Falco cenchroides*
One flying over Hitchcock Park on 3.5.97. Apparently resident in Palm Beach-Avalon area, nesting on cliffs near Bangalley Head (K. Martin).

35. Peregrine Falcon *Falco peregrinus*
One flying over on 4.4.97. Apparently resident in district, nesting on cliffs near Whale Beach (K. Martin).

Rails, Crakes and Waterhen (Family Rallidae)

36. Dusky Moorhen *Gallinula tenebrosa*
Recorded by both Hutchings and Recher (1974) and Steege (1988). Not recorded by K. Martin during 1990s.

Curlews, Sandpipers and Allies (Family Scolopacidae)

37. Red-necked Stint *Calidris ruficollis*
Recorded in 1972 (Hutchings and Recher 1974). A non-breeding spring-summer migrant to Australia from Siberia.

38. Grey-tailed Tattler *Heteroscelus brevipes*
Recorded in 1972 (Hutchings and Recher 1974). A non-breeding spring-summer migrant to Australia from Siberia.

39. Bar-tailed Godwit *Limosa lapponica*
Regularly recorded on mudflats in 1972, with numbers in the range 10-20 (Hutchings and Recher 1974). Not recorded during 1997 survey, but has occasionally been observed during the 1990s, occurring in groups of 4-6 in early summer (K. Martin). A non-breeding spring-summer migrant to Australia from Siberia and Alaska.

40. Eastern Curlew *Numenius madagascariensis*
Regularly recorded on mudflats during 1997 survey, maximum count 5. Also frequently recorded in 1972, but numbers then in the range 10-20 (Hutchings and Recher 1974). A non-breeding spring-summer migrant to Australia from Siberia, Mongolia and Manchuria. Recorded throughout the year in monthly wader counts by G. Bickley since July 1994 (Appendix 3). Birds that remain in Australia over winter are not uncommon and are believed to be mainly young birds that have not yet reached breeding age (Smith 1991).

41. Whimbrel *Numenius phaeopus*
A single bird regularly recorded on mudflats during 1997 survey. Also recorded by Hutchings and Recher (1974) and Steege (1988). A non-breeding spring-summer migrant to Australia from Siberia.

Stone-curlews (Family Burhinidae)

42. Bush Stone-curlew *Burhinus grallarius*
One pair regularly recorded during 1997 survey, roosting in saltmarsh during the day and foraging at night on mudflats. Also appeared to be foraging in dog exercise area and probably forage in saltmarsh as well. Old eggshell found in western saltmarsh 20.2.97, apparently hatched successfully, but no sign of young accompanying adults during survey. Resident at Careel Bay since at least 1952 (Hindwood 1971, Hutchings and Recher 1974, Steege 1988). One live and two dead chicks found in western saltmarsh in early January 1996 (K. Martin). Surviving chick raised by WIRES carer and eventually released at Rileys Island, Brisbane Water, after an initial, unsuccessful attempt to release it at Careel Bay. In recent years heard a couple of times calling during the day from dense vegetation on eastern side of Careel Ck and may roost here as well as in saltmarsh; often heard calling at night from vicinity of mudflats and dog exercise area (K. Martin). Known in the past to visit Avalon Golf Course at night to feed (E. Hoskin per K. Martin) and may still do so.

Oystercatchers (Family Haematopodidae)

43. Pied Oystercatcher *Haematopus longirostris*
Recorded by Steege (1988).

Lapwings, Plovers and Dotterels (Family Charadriidae)

44. Masked Lapwing *Vanellus miles*
Recorded on mudflats several times during 1997 survey, both day and night, maximum count 13 (roosting on sandspit at night). Occurs throughout the year and forages in open grassy areas as well as mudflats (K. Martin).

Gulls and Terns (Family Laridae)

45. Silver Gull *Larus novaehollandiae*
Regularly recorded bay and mudflats during 1997 survey, maximum count 227. By comparison, numbers recorded in 1972 only 20-30 (Hutchings and Recher 1974). Nests in bay on little-used boats (K. Martin), one of several new nesting colonies found near Sydney in 1980s. Nesting unknown in region (County of Cumberland) before 1983 (Hoskin *et al*. 1993).

46. Crested Tern *Sterna bergii*
Regularly recorded during 1997 survey, maximum count 16. Bay and mudflats.

47. White-fronted Tern *Sterna striata*
Recorded in 1972 (Hutchings and Recher 1974).

Pigeons and Doves (Family Columbidae)

48. *Rock Dove *Columba livia*
Occasionally seen in residential areas during 1997 survey, once on mudflats.

49. Bar-shouldered Dove *Geopelia humeralis*
Heard calling in Hitchcock Park on 17.3.97. Rare in Sydney region, but numbers increasing as part of a general southwards expansion along the NSW coast since 1960 (Roberts 1993).

50. Peaceful Dove *Geopelia striata*
Recorded by Steege (1988) at Iluka Rd.

51. Crested Pigeon *Ocyphaps lophotes*
Regularly recorded during 1997 survey in parkland and residential areas, occasionally mudflats and saltmarsh. Unknown in Sydney region before 1940, now very common (Roberts 1993). A general expansion of this inland species into coastal regions has occurred throughout Australia.

52. *Spotted Turtle-Dove *Streptopelia chinensis*
Regularly recorded during 1997 survey. Common in many habitats, including residential areas, parkland, eucalypt forest, casuarina forest, mangroves and saltmarsh.

Cockatoos (Family Cacatuidae)

53. Sulphur-crested Cockatoo *Cacatua galerita*
Regularly recorded during 1997 survey in residential areas, parkland or flying over. Up to about 40 birds seen together, either alone or in mixed flock with Little Corellas.

54. Galah *Cacatua roseicapilla*
Regularly recorded during 1997 survey, maximum count 17. Parkland, residential areas or flying over. Unknown in Sydney region before 1940s, now very common (Hoskin *et al*. 1991, Roberts 1993). Galahs have expanded their distribution from the dry inland into coastal regions all around Australia.

55. Long-billed Corella *Cacatua tenuirostris*
Two birds seen with Sulphur-crested Cockatoos and Little Corellas on 13.3.97. This inland species has become established in the Sydney region only since 1984, apparently following the release of many birds by fauna dealers (Roberts 1993).

56. Little Corella *Cacatua sanguinea*
Regularly recorded during 1997 survey in numbers up to about 80. Mainly in residential areas or flying over. More numerous on western side of bay. Unknown in Sydney region before 1950s, now moderately common, the population apparently being derived from aviary escapees (Hoskin *et al*. 1991, Roberts 1993). Numbers have been increasing at Careel Bay during the 1990s (K. Martin).

57. Glossy Black-Cockatoo *Calyptorhynchus lathami*
Occasionally seen during 1990s, either flying over or at McKay Reserve (K. Martin, Smith and Smith 1992a). Probably come across Pittwater from Ku-ring-gai Chase National Park to feed on the seeds of Forest Oaks *Allocasuarina torulosa* and Black She-oaks *A. littoralis*.

58. Cockatiel *Nymphicus hollandicus*
One seen on 20.2.97, probably an aviary escapee.

Parrots (Family Psittacidae)

59. Australian King-Parrot *Alisterus scapularis*
Recorded at Stapleton Park in 1994 (Pittwater Council 1994).

60. Crimson Rosella *Platycercus elegans*
Occasionally recorded in parkland and residential areas during 1997 survey. More common in eucalypt forest at McKay Reserve (Smith and Smith 1992a) and Stapleton Park (Pittwater Council 1994).

61. Eastern Rosella *Platycercus eximius*
Only recorded once during 1997 survey. Parkland and residential areas. Also recorded in eucalypt forest at McKay Reserve (Smith and Smith 1992a).

62. Scaly-breasted Lorikeet *Trichoglossus chlorolepidotus*
Formerly a common species around Careel Bay (Steege 1988, P. Smith visit 22.1.72). Recorded at Stapleton Park in 1989 (P. Smith), but no records since.

63. Rainbow Lorikeet *Trichoglossus haematodus*
One of the most abundant species during 1997 survey. Residential areas, parkland and flying over. Also common in eucalypt forest at McKay Reserve and Stapleton Park (Smith and Smith 1992a, Pittwater Council 1994).

Cuckoos (Family Cuculidae)

64. Fan-tailed Cuckoo *Cacomantis flabelliformis*
Not recorded during 1997 survey, but regularly recorded in eucalypt forest at McKay Reserve in winter 1992 (Smith and Smith 1992a). Recorded in saltmarsh at Careel Bay by Hattersley *et al*. (1973).

65. Common Koel *Eudynamys scolopacea*
Recorded at start of 1997 survey (20.2.97). A regular spring-summer migrant to the area (Steege 1988).

66. Channel-billed Cuckoo *Scythrops novaehollandiae*
Not recorded during 1997 survey, but a regular spring-summer migrant to the area in recent years (K. Martin). Has become noticeably more abundant around Sydney during the 1990s (Roberts 1993). First recorded at Avalon in 1991-92 season, breeding first recorded there in 1992-93 season (Larkins 1994).

Coucals (Family Centropodidae)

67. Pheasant Coucal *Centropus phasianinus*
Recorded by Steege (1988) as becoming uncommon at Careel Bay. Not recorded during 1990s. The northern beaches area was once the stronghold of this species in the Sydney region, but there have been few recent records.

Hawk Owls (Family Strigidae)

68. Southern Boobook *Ninox novaeseelandiae*
Not recorded during 1997 survey, but often heard at night around the bay in recent years (K. Martin).

Barn Owls (Family Tytonidae)

69. Barn Owl *Tyto alba*
Recorded by Steege (1988) as a rare visitor.

Frogmouths (Family Podargidae)

70. Tawny Frogmouth *Podargus strigoides*
Not recorded during 1997 survey, but occasionally recorded around the bay (K. Martin, Smith and Smith 1992a).

Swifts (Family Apodidae)

71. White-throated Needletail *Hirundapus caudacutus*
Seen hawking over mangroves and saltmarsh on 3.4.97. A regular non-breeding spring-summer migrant to the area (Steege 1988, K. Martin).

True Kingfishers (Family Alcedinidae)

72. Azure Kingfisher *Alcedo azurea*
One seen on Careel Ck 13.4.97. Probably a resident pair along creek. Also recorded by Hutchings and Recher (1974), Steege (1988) and K. Martin.

Forest Kingfishers (Family Halcyonidae)

73. Laughing Kookaburra *Dacelo novaeguineae*
Regularly recorded during 1997 survey. Residential areas, parkland, casuarina forest and mangroves. Also common in eucalypt forest at McKay Reserve (Smith and Smith 1992a).

74. Sacred Kingfisher *Todiramphus sanctus*
Regularly recorded during 1997 survey. Mudflats, mangroves and saltmarsh. Probably a resident pair. Listed as a spring-summer migrant by Steege (1988), but known to overwinter (K. Martin, Morris and Burton 1996). Although Sacred Kingfishers inhabiting eucalypt forest and woodland in the Sydney region are migratory, birds inhabiting mangroves are sedentary (Hindwood 1935).

Rollers (Family Coraciidae)

75. Dollarbird *Eurystomus orientalis*
Recorded in Hitchcock Park at start of 1997 survey (20.2.97). A regular spring-summer migrant to the area (Steege 1988, K. Martin).

Fairy-wrens, Emu-wrens and Grasswrens (Family Maluridae)

76. Superb Fairy-wren *Malurus cyaneus*
Common during 1997 survey in residential areas, parkland, casuarina forest, mangroves and saltmarsh.

77. Variegated Fairy-wren *Malurus lamberti*
Not recorded during 1997 survey, but common in eucalypt forest at McKay Reserve in winter 1992 (Smith and Smith 1992a). Recorded in Careel Bay saltmarsh by Hattersley *et al*. (1973).

Pardalotes, Thornbills and Allies (Family Pardalotidae)

78. Yellow-rumped Thornbill *Acanthiza chrysorrhoa*
Small group (4+) seen in Hitchcock Park several times during 1997 survey.

79. Striated Thornbill *Acanthiza lineata*
Recorded in saltmarsh in 1972 by Hattersley *et al*. (1973).

80. Yellow Thornbill *Acanthiza nana*
Common in mangroves and casuarina forest during 1997 survey.

81. Brown Thornbill *Acanthiza pusilla*
Recorded in casuarina forest on one occasion during 1997 survey. Common in eucalypt forest at McKay Reserve and Stapleton Park (Smith and Smith 1992a, Pittwater Council 1994).

82. Mangrove Gerygone *Gerygone levigaster*
Regularly recorded during 1997 survey in mangroves and saltmarsh. Probably 2+ pairs present. First recorded at Careel Bay 24.9.91 (Morris and Burton 1993). This species has been steadily extending its range southwards along the NSW coast since the 1940s, when it was first recorded for the State (McGill 1984). The first record for the Sydney region was in 1982 at Botany Bay.

83. Brown Gerygone *Gerygone mouki*
Small group seen in eucalypt forest with a rainforest understorey along Dark Gully Creek in McKay Reserve in winter 1992 (Smith and Smith 1992a).

84. Spotted Pardalote *Pardalotus punctatus*
Common during 1997 survey in residential areas, parkland and casuarina forest. Common and nesting in eucalypt forest at McKay Reserve in winter 1992 (Smith and Smith 1992a).

85. White-browed Scrubwren *Sericornis frontalis*
Twice recorded in casuarina forest during 1997 survey. More common in eucalypt forest at McKay Reserve and Stapleton Park (Smith and Smith 1992a, Pittwater Council 1994).

Honeyeaters (Family Meliphagidae)

86. Red Wattlebird *Anthochaera carunculata*
Common in residential areas and parkland during 1997 survey. Also common in eucalypt forest at McKay Reserve (Smith and Smith 1992a).

87. Little Wattlebird *Anthochaera chrysoptera*
Common in residential areas and parkland during 1997 survey.

88. Yellow-faced Honeyeater *Lichenostomus chrysops*
Recorded in eucalypt forest at McKay Reserve in winter 1992 (Smith and Smith 1992a) and at Stapleton Park in winter 1994 (Pittwater Council 1994).

89. Noisy Miner *Manorina melanocephala*
Common in residential areas and parkland during 1997 survey. Also common in eucalypt forest at McKay Reserve (Smith and Smith 1992a).

90. Noisy Friarbird *Philemon corniculatus*
Recorded in eucalypt forest at McKay Reserve in winter 1992 (Smith and Smith 1992a).

91. White-cheeked Honeyeater *Phylidonyris nigra*
Single bird seen a number of times in mangroves during 1997 survey. More common in heathland outside the study area (Bangalley Head, Barrenjoey Head).

Australo-Papuan Robins (Family Petroicidae)

92. Rose Robin *Petroica rosea*
Recorded in casuarina forest a number of times in April 1997, probably birds passing through on migration.

Whistlers and Shrike-thrushes (Family Pachycephalidae)

93. Golden Whistler *Pachycephala pectoralis*
Recorded a number of times in casuarina forest and mangroves in April-May 1997. Common in eucalypt forest at McKay Reserve in winter 1992 (Smith and Smith 1992a). May breed locally, but many birds probably non-breeding autumn-winter migrants.

94. Rufous Whistler *Pachycephala rufiventris*
Recorded a number of times in casuarina forest and mangroves in April 1997, probably birds passing through on migration.

Monarchs, Fantails and Drongo (Family Dicruridae)

95. Spangled Drongo *Dicrurus bracteatus*
Not recorded during 1997 survey, but a winter-spring visitor in recent years (K. Martin).

96. Magpie-lark *Grallina cyanoleuca*
Regularly recorded during 1997 survey. Most common in parkland and residential areas, but also feeds on mudflats. Has been recorded nesting in the mangroves (K. Martin).

97. Black-faced Monarch *Monarcha melanopsis*
One immature bird seen in casuarina forest on 13.4.97, probably passing through on migration.

98. Spectacled Monarch *Monarcha trivirgatus*
One seen on edge of mangroves on 18.2.80 (Lindsey 1981). A rare visitor to the Sydney region.

99. Leaden Flycatcher *Myiagra rubecula*
Recorded in casuarina forest and mangroves on 3.4.97 and 13.4.97, probably birds passing through on migration.

100. Grey Fantail *Rhipidura fuliginosa*
Recorded in casuarina forest and mangroves a number of times in April-May 1997. Common in eucalypt forest at McKay Reserve in winter 1992 (Smith and Smith 1992a). Appears to be a non-breeding autumn-winter migrant to the area.

101. Willie Wagtail *Rhipidura leucophrys*
Regularly recorded during 1997 survey, most frequently in parkland and residential areas, but occasionally in other habitats.

102. Rufous Fantail *Rhipidura rufifrons*
One seen in casuarina forest on 4.4.97, probably passing through on migration.

Cuckoo-shrikes and Trillers (Family Campephagidae)

103. Black-faced Cuckoo-shrike *Coracina novaehollandiae*
Single birds often seen during 1997 survey in parkland, residential areas, casuarina forest and sometimes mangroves. Also recorded in eucalypt forest at McKay Reserve and Stapleton Park (Smith and Smith 1992a, Pittwater Council 1994).

Orioles and Figbirds (Family Oriolidae)

104. Olive-backed Oriole *Oriolus sagittatus*
Recorded on 22.1.72 (P. Smith).

Woodswallows, Butcherbirds and Currawongs (Family Artamidae)

105. Grey Butcherbird *Cracticus torquatus*
Often recorded during 1997 survey, chiefly in residential areas, occasionally parkland, casuarina forest and mangroves. Also recorded in eucalypt forest at McKay Reserve in winter 1992 (Smith and Smith 1992a).

106. Australian Magpie *Gymnorhina tibicen*
Common in parkland and residential areas during 1997 survey, occasionally other habitats.

107. Pied Currawong *Strepera graculina*
Regularly recorded during 1997 survey. Residential areas, parkland and casuarina forest. Also common in eucalypt forest at McKay Reserve and Stapleton Park (Smith and Smith 1992a, Pittwater Council 1994).

Crows and Ravens (Family Corvidae)

108. Australian Raven *Corvus coronoides*
Regularly recorded during 1997 survey. Occurs in most habitats, but mainly seen flying over. Often feeds on mudflats.

Sparrows, Grass-finches and Allies (Family Passeridae)

109. Red-browed Finch *Neochmia temporalis*
Recorded several times in eucalypt forest at McKay Reserve in winter 1992 (Smith and Smith 1992a).

110. *House Sparrow *Passer domesticus*
Not recorded during 1997 survey, but seen by us in residential areas in 1989 and more recently by K. Martin.

Flowerpeckers (Family Dicaeidae)

111. Mistletoebird *Dicaeum hirundinaceum*
Recorded a couple of times in euclalypt forest at McKay Reserve in winter 1992 (Smith and Smith 1992a).

Swallows and Martins (Family Hirundinidae)

112. Welcome Swallow *Hirundo neoxena*
Regularly recorded during 1997 survey. All habitats, usually hawking, sometimes perched. Has been recorded nesting on moored boats and jetties (K. Martin).

Bulbuls (Family Pycnonotidae)

113. *Red-whiskered Bulbul *Pycnonotus jocosus*
Regularly recorded during 1997 survey, mainly in parkland and residential areas.

White-eyes (Family Zosteropidae)

114. Silvereye *Zosterops lateralis*
Common during 1997 survey in residential areas, parkland, casuarina forest, mangroves and saltmarsh. Also common in eucalypt forest at McKay Reserve (Smith and Smith 1992a).

Starlings and Mynas (Family Sturnidae)

115. *Common Myna *Acridotheres tristis*
Common during 1997 survey in residential areas and parkland. Hundreds gather to roost at night in mangroves.

116. *Common Starling *Sturnus vulgaris*
Often recorded in Hitchcock Park during 1997 survey.

APPENDIX 4

BIRD COUNT RESULTS FOR MANGROVE FOREST, SALTMARSH AND CASUARINA FOREST

Table 1. Figures in the table are the number of counts in which the species was recorded (out of 8), with the numbers of birds in parentheses. * = introduced

Species	Mangrove forest (1ha)		Saltmarsh (3ha)		Casuarina forest (0.5ha)	
	Low tide +/- 3 hrs	High tide +/- 3 hrs	Low tide +/- 3 hrs	High tide +/- 3 hrs	Morning	Afternoon
*Mallard	1(1)	0	0	0	0	0
Pacific Black Duck	7(1-21)	4(1-8)	0	0	0	0
Little Pied Cormorant	0	1(1)	0	0	0	0
Striated Heron	0	2(1)	0	0	0	0
Little Egret	1(1)	0	0	0	0	0
White-faced Heron	2(2)	4(1-3)	0	1(1)	0	0
Australian White Ibis	3(1-6)	3(1-4)	3(1-12)	1(5)	0	0
Brown Goshawk	0	0	1(1)	2(1)	0	0
Whistling Kite	0	0	0	1(1)	0	0
Bush Stone-curlew	0	0	3(1-2)	4(1-2)	0	0
Crested Pigeon	0	0	2(1)	1(1)	0	0
*Spotted Turtle-Dove	7(1-2)	6(1-4)	2(1)	2(3-9)	4(1-2)	3(1-2)
White-throated Needletail	0	0	1(4)	0	0	0
Laughing Kookaburra	2(1)	2(1)	0	0	1(1)	1(1)
Sacred Kingfisher	1(1)	4(1-2)	1(1)	3(1)	0	0
Superb Fairy-wren	3(1-3)	1(1)	5(2-6)	2(2-4)	3(1-4)	0
Yellow-rumped Thornbill	0	0	0	0	2(1)	0
Yellow Thornbill	6(1-5)	2(2)	0	0	4(1-5)	4(1-3)
Mangrove Gerygone	6(1-2)	1(1)	3(1)	3(1-2)	0	0
Spotted Pardalote	0	0	0	0	4(1-2)	2(1)
White-browed Scrubwren	0	0	0	0	1(1)	1(2)
Red Wattlebird	0	0	0	1(1)	1(1)	0
Rose Robin	0	0	0	0	3(1)	0
Golden Whistler	1(1)	0	0	0	2(1-2)	0
Rufous Whistler	0	0	0	0	2(1)	0
Magpie-lark	0	1(1)	1(1)	0	1(1)	0
Black-faced Monarch	0	0	0	0	1(1)	0
Leaden Flycatcher	0	1(1)	0	0	1(1)	0
Grey Fantail	0	0	0	0	3(1)	1(1)
Willie Wagtail	2(1)	1(1)	1(1)	1(1)	0	1(1)
Black-faced Cuckoo-shrike	0	1(1)	0	0	1(1)	0
Grey Butcherbird	0	0	0	0	1(1)	0
Australian Magpie	0	0	0	1(1)	0	0
Pied Currawong	0	1(1)	0	0	3(1-2)	2(1)
Australian Raven	0	0	1(1)	1(1)	0	1(1)
Welcome Swallow	2(1-2)	2(1)	4(1-11)	5(1-20)	4(1)	0
*Red-whiskered Bulbul	0	0	0	0	1(1)	0
Silvereye	7(1-11)	7(1-9)	4(1-5)	3(1-2)	4(1-6)	3(2-5)
*Common Myna	0	1(2)	0	0	0	0

Bird densities recorded in counts of the mangrove forest, saltmarsh and casuarina forest. Data are means +/- one standard error (number of counts shown at base of column).

Comparison of waterbird records from Careel Bay in 1972 (Hutchings and Recher 1974), and 1997 (Smith & Smith).
A = always present, O = often present, X = occasional, 1 = 1-10, 2 = 10-20, 3 = 20-30, 4 = 30-100, 5 = 100+

Species	1972	1997
Grey Teal	X	
*Mallard		A2
Pacific Black Duck	X	A3
*Domestic Goose		A1
Great Cormorant	A3	
Little Pied Cormorant	A1	A2
Little Black Cormorant		X
Australian Pelican	O1	A3
Great Egret	A1	X
Cattle Egret		X
Little Egret		X
Striated Heron	A1	A1
White-faced Heron	A1	A2
Yellow-billed Spoonbill	O2	
Royal Spoonbill	O2	O1
Australian White Ibis	O3	A3
Straw-necked Ibis	O3	
White-bellied Sea-Eagle	X	X
Whistling Kite	X	X
Dusky Moorhen	X	
Red-necked Stint	X	
Grey-tailed Tattler	X	
Bar-tailed Godwit	O2	
Eastern Curlew	O2	A1
Whimbrel	X	A1
Bush Stone-curlew	A1	A1
Masked Lapwing	X	O1
Silver Gull	A3	A5
Crested Tern	A3	O2
White-fronted Tern	X	
Azure Kingfisher	X	X
Sacred Kingfisher	X	A1
Total species	**27**	**23**

Bird count results for intertidal mudflats and adjacent waters (Smith & Smith, 1997). Figures in the table are the number of counts in which the species was recorded (out of 8), with the numbers of birds in parentheses. * = introduced

Species	Low tide - 1-3 hrs	Low tide +/- 1 hr	Low tide + 1-3 hrs	High tide - 1-3 hrs	High tide +/- 1 hr	High tide + 1-3 hrs
*Mallard	3(7-19)	0	1(11)	2(3)	1(7)	4(5-10)
Pacific Black Duck	4(2-30)	3(2-7)	5(1-7)	4(2-7)	2(3-7)	5(2-7)
Little Pied Cormorant	6(1-19)	8(2-9)	7(1-7)	8(1-10)	8(2-11)	6(1-12)
Little Black Cormorant	1(2)	0	2(1-2)	0	2(2-3)	1(2)
Australian Pelican	7(2-25)	8(1-5)	7(1-22)	8(1-14)	5(9-18)	7(1-20)
Great Egret	1(1)	0	0	0	0	0
Cattle Egret	2(1)	0	2(3)	0	0	2(3)
Striated Heron	7(1-3)	7(1-4)	5(1-2)	1(1)	1(1)	1(2)
Little Egret	1(1)	1(1)	1(1)	0	0	0
White-faced Heron	8(3-9)	8(7-14)	7(1-8)	3(1-3)	1(1)	7(1-3)
Royal Spoonbill	2(1-2)	5(1-2)	3(2)	0	0	1(1)
Australian White Ibis	8(6-27)	8(2-28)	8(3-24)	3(1-2)	1(1)	1(1)
White-bellied Sea-Eagle	0	1(1)	0	0	0	0
Whistling Kite	2(1)	1(1)	1(1)	0	0	0
Eastern Curlew	6(1-5)	8(2-5)	6(2-4)	6(1-4)	0	1(2)
Whimbrel	8(1)	8(1)	8(1)	2(1)	0	2(1)
Masked Lapwing	2(4-8)	2(4-8)	2(2-6)	1(6)	0	0
Silver Gull	8(47-134)	8(83-227)	8(1-90)	8(8-44)	7(4-46)	8(3-148)
Crested Tern	1(3)	6(1-16)	2(2)	1(1)	0	2(1-2)
*Rock Dove	0	1(1)	0	0	0	0
Crested Pigeon	0	2(4)	2(1-10)	1(2)	1(2)	1(1)
Laughing Kookaburra	0	1(1)	0	0	0	0
Sacred Kingfisher	0	4(1-2)	3(1-2)	0	0	0
Magpie-lark	0	5(1-2)	1(1)	0	0	1(1)
Willie Wagtail	2(1-2)	1(1)	0	0	0	1(1)
Australian Magpie	0	1(1)	0	0	0	0
Australian Raven	1(1)	5(1-5)	1(1)	0	0	0
Welcome Swallow	3(1)	3(1-2)	3(1-19)	1(2)	3(1-3)	0
*Common Myna	0	0	0	1(1)	1(2)	0

High tide roost sites recorded during 1997 survey (Smith & Smith). * = introduced, O = occasional, F = frequent

Species	Mangroves	Saltmarsh	Snags on mudflats	Near by trees	Nearby gardens	Spit	Other beaches	Boats	Marina
*Mallard							F		
Pacific Black Duck	F								
Little Pied Cormorant	O		F					F	
Australian Pelican			O			O			F
Cattle Egret	O		O		O				
Striated Heron	F							O	
White-faced Heron	F	O	O		O	O		F	
Royal Spoonbill	F								
Australian White Ibis	F	F		F					
Eastern Curlew	F					O			
Whimbrel	F		O			O			
Bush Stone-curlew		F							
Masked Lapwing						O			
Silver Gull						F	F	F	F
Crested Tern								F	

APPENDIX 5

Vascular plant species recorded in mangrove forest, saltmarsh and casuarina forest at Careel Bay.

* = introduced, U = uncommon, M = moderately common, C = common, V = very common

Scientific name	Common name	Mangroves	Saltmarsh	Casuarinas
FERNS				
Blechnaceae				
Blechnum indicum	Swamp Water Fern			U
Dennstaedtiaceae				
Hypolepis muelleri	Harsh Ground Fern			C
Pteridium esculentum	Bracken			U
DICOTYLEDONS				
Aizoaceae				
Tetragonia tetragonoides	New Zealand Spinach		U	U
Apiaceae				
Apium prostratum	Sea Celery	U		U
**Hydrocotyle bonariensis*	Kurnell Curse			C
Hydrocotyle peduncularis				M
Asteraceae				
**Aster subulatus*	Bushy Starwort			M
**Conyza albida*	Tall Fleabane			M
**Delairea odorata*	Cape Ivy			U
Avicenniaceae				
Avicennia marina	Grey Mangrove	V	V	
Balsaminaceae				
**Impatiens walleriana*	Balsam			U
Casuarinaceae				
Casuarina glauca	Swamp Oak		U	V
Chenopodiaceae				
Atriplex australasica				U
Sarcocornia quinqueflora	Samphire	U	V	U
Suaeda australis	Seablite	U	U	M
Euphorbiaceae				
Glochidion ferdinandi	Cheese Tree			M
Omalanthus populifolius	Bleeding Heart			C
Fabaceae				
Kennedia rubicunda	Red Kennedy Pea			M
**Senna pendula*	Cassia			C
Lobeliaceae				
Lobelia alata	Angled Lobelia	U		M
Malvaceae				
**Lagunaria patersonii*	Norfolk Island Hibiscus			U
**Sida rhombifolia*	Paddy's Lucerne			U

Myrsinaceae				
Aegiceras corniculatum	River Mangrove	C	C	
Myrtaceae				
Eucalyptus robusta	Swamp Mahogany			M
Kunzea ambigua	Tick Bush			U
Melaleuca armillaris	Giant Honeywyrtle			U
Oleaceae				
**Ligustrum sinense*	Small-leaved Privet			U
Phytolaccaceae				
**Phytolacca octandra*	Inkweed			U
Pittosporaceae				
Pittosporum undulatum	Pittosporum			U
Polygonaceae				
Persicaria decipiens	Slender Knotweed			M
Persicaria hydropiper	Water Pepper			U
Primulaceae				
Samolus repens	Creeping Brookweed	U	C	
Proteaceae				
Banksia integrifolia	Coast Banksia			U
Sapindaceae				
Dodonaea triquetra	Common Hop Bush			U
Verbenaceae				
**Lantana camara*	Lantana			M
Violaceae				
Viola hederacea	Ivy-leaved Violet			C
Vitaceae				
Cayratia clematidea	Slender Grape			U
MONOCOTYLEDONS				
Anthericaceae				
**Chlorophytum comosum*	Ribbon Plant			U
Asparagaceae				
**Protasparagus aethiopicus*	Asparagus Fern			V
Commelinaceae				
Commelina cyanea	Scurvy Weed			C
Cyperaceae				
Baumea juncea	Bare Twig-rush			M
Cyperus polystachyos				U
Fimbristylis ferruginea				U
Gahnia clarkei	Tall Saw-sedge			C
Isolepis nodosa	Knobby Club-rush			U
**Isolepis prolifer*				U
Juncaceae				
Juncus kraussii	Sea Rush	U	M	U
Juncus continuus				U

Poaceae				
Agrostis avennacea	Blown Grass			U
**Cortaderia selloana*	Pampas Grass			U
**Ehrharta erecta*	Panic Veldtgrass			M
Entolasia marginata	Bordered Panic			C
Oplismenus aemulus	Basket Grass			C
**Paspalum dilatatum*	Paspalum			U
**Paspalum urvillei*	Vasey Grass			U
Paspalum vaginatum	Salt-water Couch			M
Phragmites australis	Common Reed		M	C
**Setaria gracilis*	Slender Pigeon Grass			M
Sporobolus virginicus	Marine Couch	U	C	U
**Stenotaphrum secundatum*	Buffalo Grass			C
Typhaceae				
Typha orientalis	Broad-leaved Cumbungi		U	U