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HOMEBUSH BAY ECOLOGICAL STUDIES

1993 – 1995

VOLUME I

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Homebush Bay Ecological Studies

1993–1995

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Olympic Co-ordination Authority
Private Bag 3
PO Homebush
Sydney, NSW 2140
AUSTRALIA

Phone: 61 2 735 4800
Fax: 61 2 735 4888

Department of Defence
PO Box E33
Queen Victoria Terrace
Canberra, ACT 2600
AUSTRALIA

Phone: 61 6 265 9111

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HOMEBUSH BAY ECOLOGICAL STUDIES

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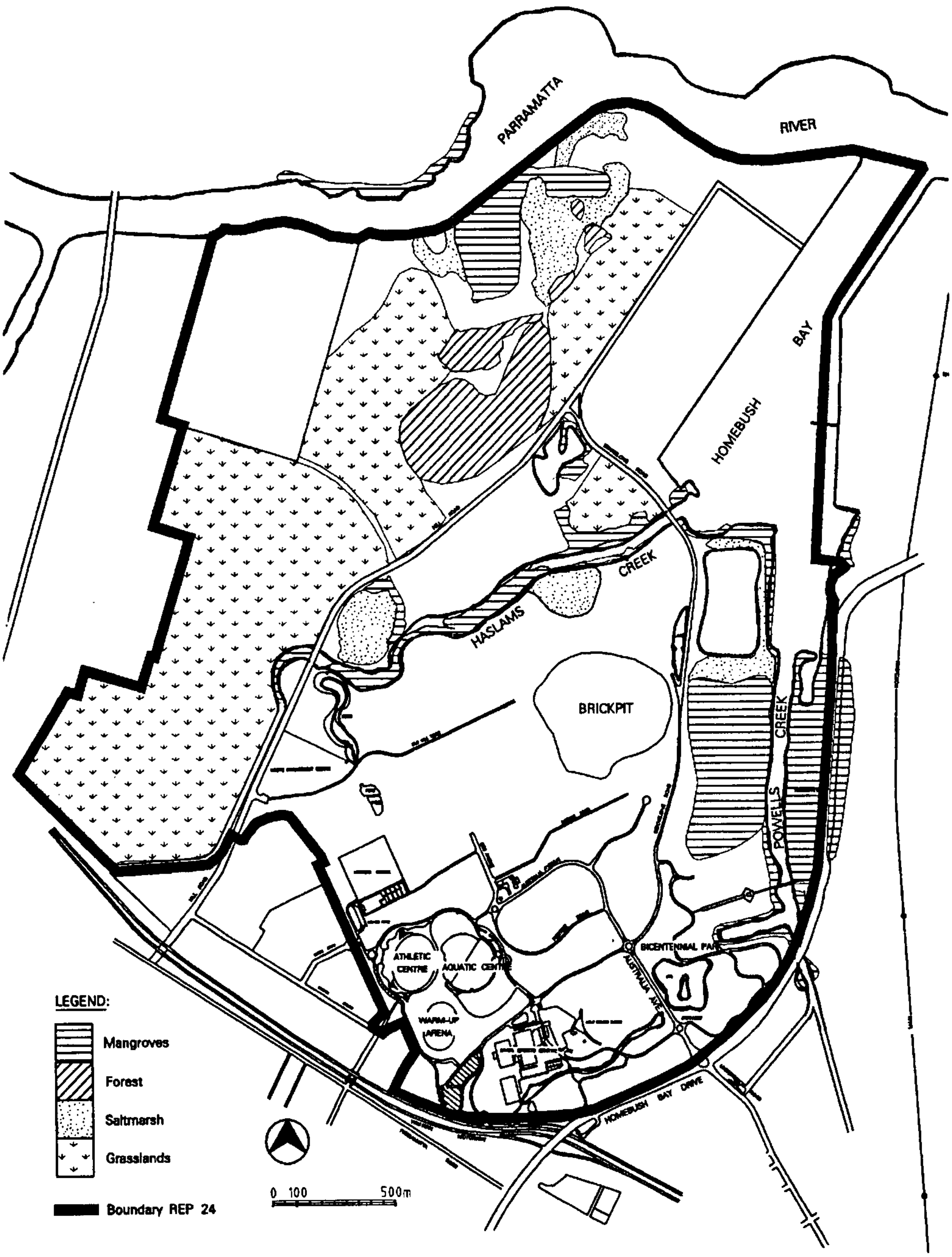

Figure 1. Homebush Bay showing the natural features

INTRODUCTION

HOMEBUSH BAY

Seven hundred and sixty hectares of land at the demographic and geographic heart of Sydney make-up the Homebush Bay Development Area (Figure 1, see also Figure 1 on page 7). Most of this land has been under State or Federal Government control and has been since the early 1900s when ownership of two large estates, Newington and 'Home Bush' was returned to the government. Until recently, an abattoir, brickworks, and armaments depot occupied the site. For over 60 years low-lying mangrove 'swamps' were progressively reclaimed and filled with a variety of materials.

The area has been earmarked for renewal since the mid-1980s when the privately developed business park, the Australia Centre was established at the site. This was followed by the opening of the State Sports Centre in 1984 and followed by the Bicentennial Park in 1988.

Development of Homebush Bay was originally planned to occur over a 10–15 year period towards the year 2010. However, the decision to use Homebush Bay as primary zone for the Sydney Olympics means that by the year 2000, many international standard sporting facilities must share the site with commercial, recreational and residential developments. The first phase of construction — the Sydney International Athletics Centre and International Aquatic Centre — has already been completed. An extensive program of remediation of contaminated land is also well underway.

A full assessment of the values (and constraints) of the site has been undertaken to allow development to occur alongside, and benefit from, the natural environment.

Values of Homebush Bay

Homebush Bay retains remnants of its original vegetation and ecosystems in a unique setting at the heart of urban Sydney. From the start, its redevelopment posed the challenge of rehabilitation of large tracts of degraded land and integration of the natural and built environments.

The values of these ecosystems have been recognised and included on the register of the National Estate and the protection of migratory wading birds, which frequent the wetlands, by international agreements with Japan and China.

The remnant Eucalypt and Casuarina Woolands and their associated mammal, reptile, amphibian and bird fauna are considered to be of national significance. The Homebush Bay wetlands form an essential link in the remaining coastal wetlands of Sydney, and as such form an important part of the coastal corridor of New South Wales.

OLYMPIC CO-ORDINATION AUTHORITY

The Olympic Co-ordination Authority (OCA) was formed in 1995 to provide most venues and facilities for the year 2000 Olympics and to manage the redevelopment of Homebush Bay.

The Authority will develop Homebush Bay in a manner consistent with the *Environmental Guidelines for the Summer Olympic Games*, a document produced by the Environment Sub-Committee of Sydney Olympics 2000 Bid Ltd, and presented to the International Olympic Committee (IOC) in September 1993. The Guidelines have been incorporated into *State Environmental Planning Policy* (SEPP) No 38 which applies to all Olympic Developments.

The Authority must also plan beyond the Games, to provide a new suburb with a unique mix of residential, commercial and sporting developments in an extensive parkland environment suitable for both active and passive recreation.

The OCA has set out to support Ecologically Sustainable Development (ESD) in an urban setting and encourage best practice in all facets of development at Homebush Bay. Best practice is site specific, particularly with regard to the natural environment, and the pursuit of best practice by urban and landscape designers and architects for the renewal of Homebush Bay must reflect Sydney's lifestyle and climate and the unique setting of the site.

The principles for implementation of ESD at Homebush Bay come under three key performance areas: conservation of species, conservation of resources and pollution control.

HOMEBUSH BAY ECOLOGICAL STUDIES

Jointly with the Commonwealth Department of Defence, the Olympic Co-ordination Authority has undertaken a comprehensive range of ecological studies of Homebush Bay. Separate studies have been commissioned by Bicentennial Park. From these studies, the most significant flora, fauna and ecosystems have been identified and are documented in Volumes I and II of the *Homebush Bay Ecological Studies*, 1993–1995.

Studies cover key species, particularly rare and/or endangered species, including their movement, distribution and interrelationship with other communities of Homebush Bay. Some studies are ongoing. The studies included in Volume I are as follows:

Fish Study
The Ecology Lab:
September 1994

The bay waters of Homebush Bay are home to a number of commercially important fish, prawns and crabs which include dusky flathead, yellowfin bream, silver biddy, king prawns, mud crab and blue swimmer crab. The mud flats appear to be the richest in species diversity, whereas the fish fauna of the wetlands were depauperate in comparison to the bay and the creeks. The assemblages of fish in Homebush Bay are similar to those in other parts of the upper estuary of the Parramatta River.

The Ecology and Management of Shorebirds (Aves:Charadrii)
The Australian Museum:
December 1994

The Australian Museum has completed a study on the ecology and management of shorebirds in the lagoons and intertidal mudflats of Homebush Bay. The study focused on the three most common species; Black-winged Stilt, Curlew Sandpiper and the Bar-tailed Godwit and also determined the relationships between bird densities, food abundance and the physical attributes of their habitats.

Wetlands Study
University of Technology:
May 1995

This study has addressed three aspects of the saltmarsh ecosystems of Homebush Bay; ecology, propagation trials and transplantation studies. The project has been successful in each of its three aspects and shows promise in the ability to recreate saltmarsh habitat at Homebush Bay. The study is ongoing and aims to also investigate the dynamic interaction of saltmarsh with mangroves.

Volume II contains the following studies:

Fish, Prawns and Crabs in the 2SM Pond
The Ecology Lab
August 1995

The plan to revitalise and recreate wetlands around Homebush Bay involves the monitoring of flora and fauna both before and after such remedial works. This study determined the fish, prawn and crab fauna in the 2SM pond and access channel before modification. The fish fauna in the pond was found to be significantly different from that in Haslams Creek. The presence of small juvenile fish in the 2SM pond indicates that the pond may be a suitable nursery habitat for fish of economic importance.

Homebush Bay Avifauna Study: Part 1 — Waterbirds
Royal Australasian Ornithologists Union
September 1993

Homebush Bay contains a unique mosaic of wetland habitats that support Sydney's most significant populations of waterbirds. The combination of saltmarsh, intertidal wetlands and freshwater wetlands provide habitat for many species of wading birds including Latham's Snipe, Pacific Golden Plover, Bar-tailed Godwits and Black-winged Stilts. The wetlands of Homebush Bay are an essential link to the remaining wetlands in the Sydney region and form part of the coastal corridor used by internationally protected migratory waders.

Homebush Bay Avifauna Study: Part 2 — Woodland birds
Royal Australasian Ornithologists Union
January 1994

The Homebush Bay site includes locally rare woodland communities that support a number of regionally rare species of birds such as the White-fronted Chat, Red-rumped Parrot, Osprey, White-bellied Sea-eagle, Marsh Harrier, Peregrine Falcon and Australian Hobby. The eucalypt woodland is a focus for many of the woodland birds providing roosting and breeding sites, while the surrounding grasslands and shrublands provide food resources for these species.

Fauna Impact Statement — Masterplan
The Australian Museum
November 1995

The endangered Green and Golden Bell Frog (*Litoria aurea*) has been observed throughout Homebush Bay. A Fauna Impact Study (FIS) was prepared to assess the impact of the development proposed in the 1995 Homebush Bay Masterplan on the continued survival of the frog. This report details the conditions required by two existing licences issued by the Director-General of National Parks and Wildlife which ensure the Green and Golden Bell Frog population at the site will be sustainable. Such ameliorative measures include the recreation of frog habitat, the provision of dispersal corridors and ongoing monitoring of frog populations.

Wetlands and Benthos
The Australian Museum
February 1993

This survey is significant in being the most comprehensive survey of macrofauna of the estuarine environments of the Homebush Bay. The survey covered all of the wetland sites of Homebush Bay including the Newington wetlands, the 2SM and 2KY aerials, Elcom ponds, the brickworks mangroves, Bicentennial Park and Mason Park. Although the mangroves and associated saltmarshes appear healthy the estuarine macrofauna biodiversity is depauperate. The absence of crabs and crab holes, oysters and barnacles at most sites was striking. The ponds and billabongs appeared to be eutrophic with very little fauna. Improved tidal flushing is recommended as the first step in the improvement of the biodiversity of the estuarine ecosystems.

Saltmarsh Vegetation Study
University of New South Wales
February 1993

This survey specifically identified saltmarsh flora of Homebush Bay and complements the information in the Vegetation Survey. Homebush Bay contains common saltmarsh species such as *Sarcocornia quinqueflora*, *Sueada australis*, *Juncus krausii*, *Juncus acutus*, *Cotula coronopifolia* as well as the rare plants, *Wilsona backhousei*, *Lampranthus tegens* and *Haloscarcia pergranulata*.

FISH STUDY

Fish Study

Marcus Lincoln Smith , G.A. White and P.M.H. Hawes
The Ecology Lab: Pty. Ltd.
14/28–34 Roseberry St.
Balgowlah, NSW 2093
September 1994

Summary

The Ecology Lab Pty Limited was commissioned by PSG (Property Services Group, Homebush Bay Corporation) in November 1992 to conduct a year-long study of the fish in Homebush Bay. Field work started in December 1992 with pilot investigations. Four major surveys were done from February to late October 1993 in Homebush Bay, two large creeks entering Homebush Bay and in two reference areas outside Homebush Bay. In addition, sampling was done once in parts of the wetland that were difficult to sample or believed to be poor habitat for fish. This report is Volume I of the Final Report and presents a summary of the methodology and results. *The Technical Report* (Volume II) provides detailed explanations of the methods (including statistical analyses) and results.

The brief for the fish study specified the following aim of the study:

> *"To determine the abundance and diversity of fish and the habitat utilisation of fish species in the study area."*

In achieving the aim specified for the study of fish, PSG envisaged that three tasks would constitute the scope of works for the study, including:

i a review of literature,

ii field investigations, and

iii interpretation and analysis of data.

Sampling for the present study was done in the wetlands of Homebush Bay and the Newington defence facility, in Haslams Creek and Powells Creek and on mud flats and in the navigation channel within Homebush Bay. In addition, sampling was done on mud flats in two nearby bays, Brays Bay and Majors Bay. These bays were considered as 'external references' and allowed the findings for Homebush Bay to be placed within a geographical context. Suitable external references were not available nearby for other habitats occurring in Homebush Bay, such as the creek habitats, navigation channel and saltmarshes.

Gill nets and a beam trawl were used to sample fish in the creek and bay habitats. Gill nets, a beam trawl, a seine net and dip nets were used to sample fish in the wetlands. All fish collected were identified and counted. Fish of economic value were also measured (fork length) to obtain information on the size frequency distributions of species occurring in Homebush Bay. Finally, counts were made of crustaceans (mostly decapods) collected during the study, as many of these were of economic value and therefore constituted part of the fisheries of the estuary.

Thirty-nine species of fish from 22 families with a total of 19273 individuals were recorded from Homebush Bay and the two external references. This diversity compares favourably with studies done in similar habitats elsewhere. Thirty-three species were recorded from Homebush Bay and/ or the surrounding wetlands. The most speciose family was the Gobiidae, with at least 11 species. All other families contained only one or two species. Nearly all the species recorded from Homebush Bay occur commonly in NSW estuaries. Three species of fish, a species of stingaree, luderick and a species of goby (which may be a previously undescribed species) were not listed as having been recorded previously from the waters west of Gladesville Bridge. In addition, two families of crustaceans of economic value (Portunidae and Penaeidae) were recorded, containing 6 species and a total of 861 individuals.

The gill nets yielded a total of 15 species of fish totalling 1944 individuals. All but two species were of economic value. The three most abundant species were sea mullet (accounting for 54% of the catch), yellowfin bream (28%) and flat-tail mullet (10%). Two species of crabs were collected, totalling 65 individuals. Blue swimmer crabs accounted for 85% of the crabs caught and mud crabs accounted for the other 15%.

The beam trawls yielded a total of at least 25 species of fish totalling 17 239 individuals. Seven species of fish were of economic value. The three most abundant species were Swan River goby (which accounted for 60% of the catch), exquisite goby (26%) and bridled goby (18%). Four species of prawns of economic value were collected by beam trawl, the most common being king prawns (73% of economically valuable prawns) and school prawns (26%). These two species form the basis for the prawn fishery in Sydney Harbour. In addition to economically valuable prawns, large numbers of at least 4 other species of crustaceans were collected.

Statistical analyses of the survey data for the bay and creek habitats indicated that variability in the fish and crustacean assemblage as a whole and in populations of species of fish and crustaceans often varied at relatively small spatial scales. Within Homebush Bay, Powells Creek and Haslams Creek had relatively distinctive assemblages and populations of fish were often smaller in the creek samples compared to the bay samples. In many cases, variability through time was inconsistent from one site to another, even within locations. This type of variability is not uncommon for estuarine and marine species. A comparison of Homebush, Brays and Majors Bays indicated that they all supported quite similar assemblages and populations of fish on mud flats. It was concluded that assemblages and populations of fish of mud flats in Homebush Bay are similar to those in other parts of the upper estuary.

An examination of the lengths of fish and crabs collected suggested that most of the fish of economic value in Homebush Bay are large juveniles or adults. Small juveniles of some fish were collected in the beam trawl, including dusky flathead, yellowfin bream and silver biddy.

The fish fauna of the Homebush Bay and Newington wetlands was depauperate compared to the bay and creek habitats. Six species of fish were recorded from the Homebush Bay wetlands, eel, blue eye, mosquito fish, sea mullet, oriental goby and Swan River goby. The areas considered most suitable as habitat for fish were a large pond near the 2SM radio tower which is connected to Haslams Creek and a large shallow bay to the east of — and draining into — Powells Creek. Many of the areas surveyed within the wetland are poor habitat for fish, probably due to inadequate water exchange with the estuary.

The mosquito fish was the only species of fish collected from the Newington wetland. It occurred in freshwater drainage channels and ponds in the north eastern part of the wetland. Several large ponds sampled amongst saltmarshes yielded no fish. As with the Homebush Bay wetlands, many of the areas in the Newington wetland are poor habitat for fish. This is probably due to limited water exchange with the estuary.

1 INTRODUCTION

1.1 BACKGROUND TO THE STUDY

The Homebush Bay development area is 12 kilometres from the city of Sydney and is fronted by the Parramatta River (Figure 1). It was first settled in 1806 and was owned privately until 1879. Between 1879 and 1907 most of the land was resumed by Government and used for a variety of purposes, including Naval armaments storage, abattoirs and brickworks. Most of the development area is still government owned. Much of the land surrounding the development area is highly developed, with factories, residential areas and transport infrastructure, including roads, rail, bridges and ferry services on the adjacent river.

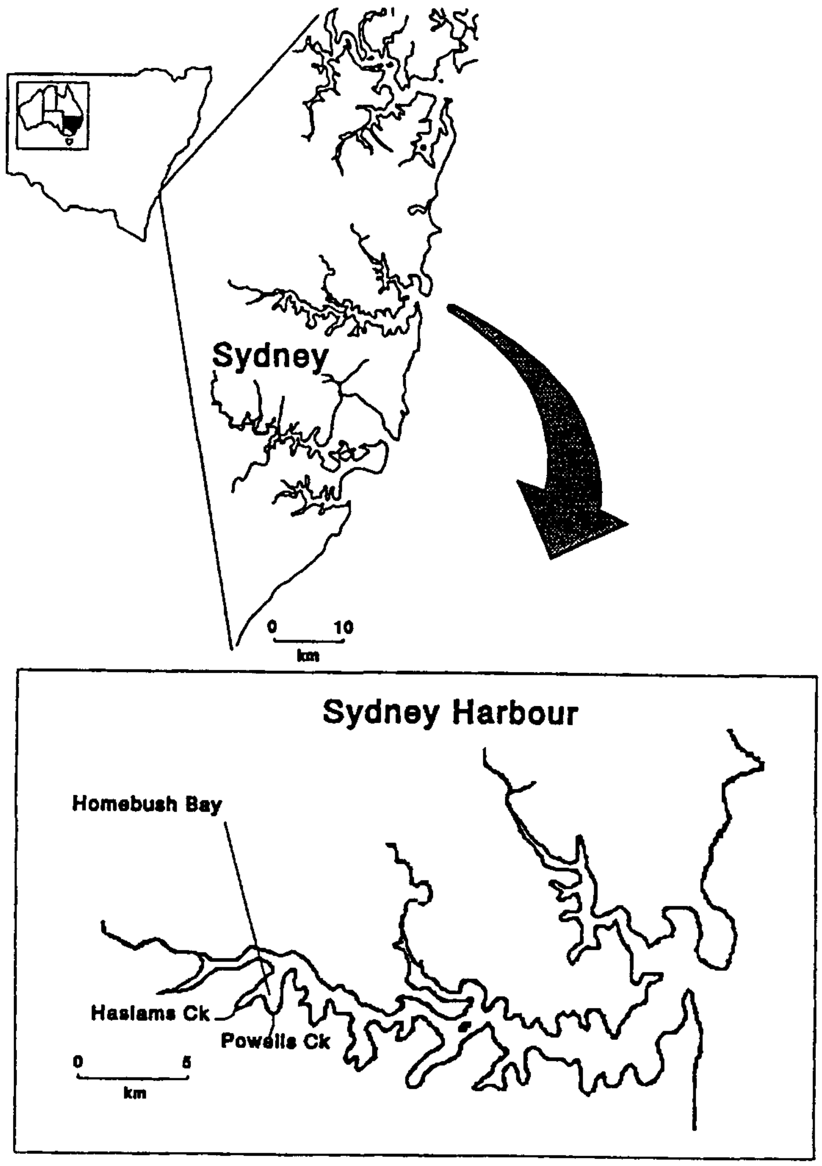

Figure 1. Regional setting of Homebush Bay.

There are, however, significant areas of natural habitat remaining in the development area, including large areas of woodlands, grasslands, wetlands (both saltmarshes and mangroves), tidal creeks, mud flats and bay waters.

In recent years the NSW Government has commenced a programme of renewal of Homebush Bay, establishing Bicentennial Park and the State Sports Centre, Athletic Centre and Aquatic Centre within the site. The decision in 1991 to proceed with a bid for the year 2000 Olympics and the subsequent winning of the bid in 1993 has instigated new phases of renewal and development. The NSW Government has directed that all new development will conform with principles of Ecologically Sustainable Development and, in line with this, environmental investigations have been undertaken and are planned.

NSW Property Services Group (PSG) is responsible for the masterplanning and development of the Homebush Bay area. Together with the Commonwealth Department of Defence, PSG has commissioned a series of ecological studies to provide an integrated assessment of natural communities in Homebush Bay with a view to preserving the natural environment.

PSG identified the need for an ecological study of the fish of the Homebush Bay area. Estuaries and wetlands are known generally to provide significant habitats for fish. As the largest remaining areas of mangroves in the Parramatta River occur in Homebush Bay, it is likely that the bay and its tributaries are a significant habitat for fish populations in the Parramatta River and throughout the estuary.

The Ecology Lab Pty Limited was commissioned by PSG in November 1992 to conduct a year-long study of the fish in Homebush Bay. Four major surveys were done from February 1993 to late October 1994 in Homebush Bay, two large creeks entering Homebush Bay and in two reference areas outside Homebush Bay. In addition, sampling was done once in parts of the wetland that were difficult to sample or believed to be poor habitat for fish.

1.2 Aim

The following aim of the study is:

> *'To determine the abundance and diversity of fish and the habitat utilisation of fish species in the study area.'*

1.3 Objectives

The objectives, as specified by PSG, were as follows:

i To determine the distribution and abundance of fish species present in the study area over a twelve-month period.
ii Identify habitat utilisation by species.
iii Identify the location of significant fish habitats in the study area.

1.4 Scope of Work

In achieving the aim and objectives specified for the study of fish, PSG envisaged that the following tasks would constitute the scope of works for the study:

Literature Review

a) Review existing literature on fish in the study area, detailing important issues and highlighting information deficiencies.
b) Include a reference list.
c) Submit a report on the above, including any revisions to the original research design.

Field work

a) Undertake field surveys over a twelve-month period to identify the distribution, abundance, seasonality and significance of fish populations in the study area.

Interpretation/Analysis of Data

a) Discuss the distribution of fish populations with reference to detailed plans.
b) Discuss the significance of the study site as a habitat for fish.
c) Highlight habitats that have special significance.

Submit a final report to PSG detailing the findings of the study.

1.5 Study Approach and Structure of the Report

The study was done in two main stages. Initially, the study area was visited to define habitats that should be sampled and to evaluate sampling methods. Once this had been done, four surveys were done, forming the main part of the study. In order to assess the significance of the fish habitat and fish populations of Homebush Bay (Task 3b), it was considered necessary to sample both within Homebush Bay and in similar reference areas. Therefore, as part of the main part of the study, Homebush Bay and similar habitats within Brays Bay and Majors/Yaralla Bays were sampled. In this way, the findings for Homebush Bay could be placed within a local geographical context.

This report is Volume I of the Final Report and it presents an overview of the study with the main findings and recommendations. The Technical Report (Volume II) provides additional information from the review of the literature and a detailed description of the methodology and results, including statistical analyses and additional figures. Both reports are intended to be stand-alone documents.

This report is structured in line with the study brief. The next section provides a review of existing information and an assessment of important issues and deficiencies. Section 3 describes the sampling methodology used for the field study and Section 4 describes the results of the study. Section 5 discusses the results in terms of significance of the area, Section 6 lists references referred to in both Volumes I and II.

2 REVIEW OF EXISTING INFORMATION

2.1 FISH HABITATS

Estuaries are often conveniently defined as waterways connected to the ocean which have a measurable reduction in salinity due to the influx of freshwater, typically from rivers. Sydney Harbour, also known as the Parramatta River estuary and Port Jackson, is a drowned river valley (West *et al.* 1985), with several rivers and many small creeks draining into the estuary. Two creeks drain into Homebush Bay, Powells Creek which drains into the south eastern corner of the bay, and Haslams Creek, which drains into the south western corner (Figure 1). These creeks are lined with mangroves, which contrasts with much of the shoreline of the bay, which is lined with stone seawalls.

In New South Wales, estuaries generally have a common set of features which are often considered as relatively discreet habitats, utilised by a variety of plants and animals, including fish (Middleton 1985). The most common of these habitats include seagrass beds, mangrove forests, saltmarshes, rocky reefs and soft sand or mud substrata. Despite very extensive waterway development, Sydney Harbour contains areas of all these habitats. Moreover, the harbour contains large areas of seawalls and jetties, which function as fish habitat similar to rocky reefs (Burchmore *et al.* 1985, Lincoln Smith *et al.* 1992).

In Sydney Harbour, it has been estimated that there are approximately 1.286 km^2 of seagrasses, virtually all of which occurs to the east of the Sydney Harbour Bridge in Port Jackson, to the east of the Spit Bridge in Middle Harbour, or in North Harbour, near Manly (West *et al.* 1985; Figure 2). West *et al.* (1985) estimated that 1.475 km^2 of mangroves occurred in Sydney Harbour. Most of the mangroves occur in the upper reaches of the estuary, specifically, in the Lane Cove River, in Tarban Creek, in the Parramatta River west of the Gladesville Bridge and in Middle Harbour west of the Spit Bridge (Figure 2). The single largest stand of mangroves in the estuary occurs in the wetlands around Homebush Bay (Figure 2). Saltmarshes occupy an area of about 0.073 km^2 in Sydney Harbour (West *et al.* 1985), all of which appear to be confined to lands surrounding Homebush Bay (Figure 2). It is possible, however, that there are other, albeit very much smaller, saltmarshes in Sydney Harbour, given the relatively large scale of mapping used by West and his co-workers.

In summary, habitats common to many estuaries in NSW occur in Sydney Harbour, despite its very extensive modification by humans. Homebush Bay contains some of these habitats, including mangrove forests, saltmarshes, artificial seawalls and unvegetated muddy areas, but there are no seagrasses in the bay. The habitats of the bay are discussed in more detail in Section 3.1.

2.2 FISH

2.2.1 Fish Occurring in Mangrove, Saltmarsh and Mud Habitats

Scientists have recognised for some time that different estuarine habitats tend to support different assemblages of fish (e.g. SPCC 1981a). There is also some information on assemblages of fish associated with the major types of habitat occurring in and around Homebush Bay, namely, areas of mangroves, saltmarshes and unvegetated muddy substrata.

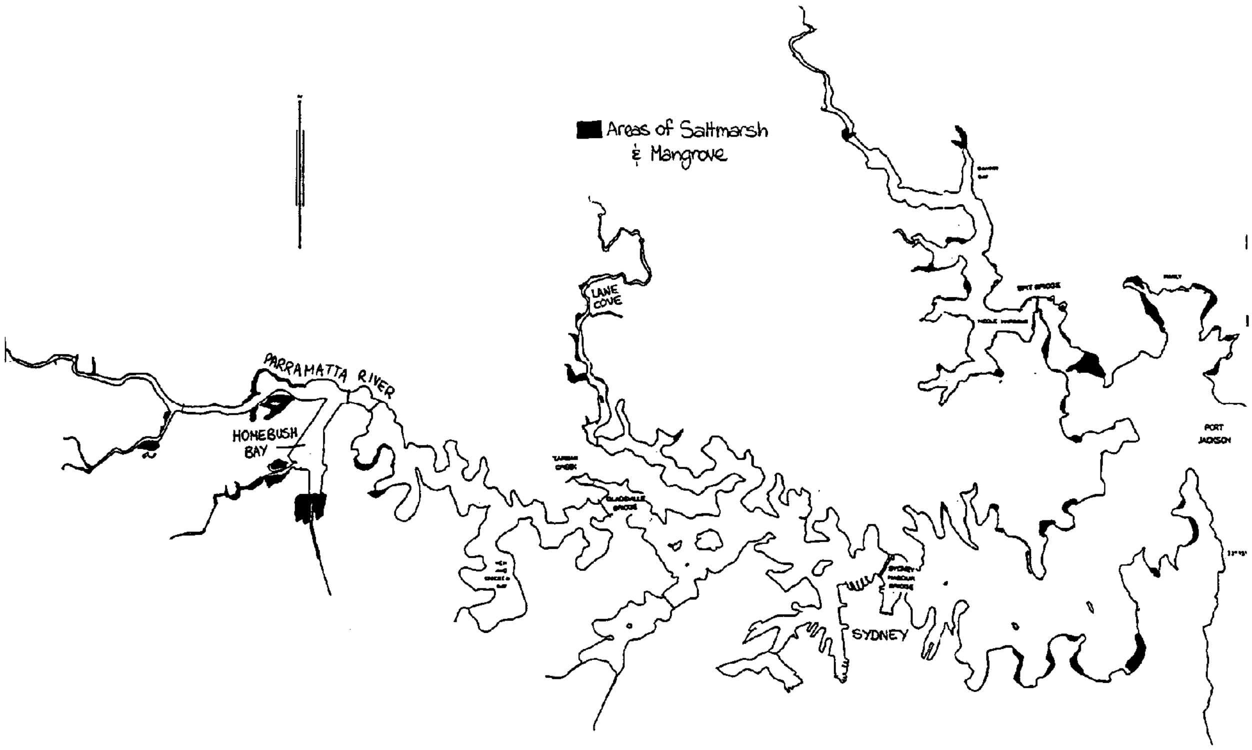

Figure 2. The distribution of mangroves and saltmarshes in Sydney Harbour (modified from West *et al.* 1985).

2.2.1.1 *Mangroves*

The fish fauna of tropical and sub-tropical mangroves has been documented in several studies (Stephenson and Dredge 1976, Beumer 1978, Blaber 1980, Quinn 1980, Hutchings and Saenger 1987) but far less is known of the fishes occurring in mangroves of temperate regions, such as Sydney. According to Hutchings and Saenger (1987), there are few fish which are unique to mangroves, rather they represent a proportion of fishes occurring in a variety of habitats within an estuary. According to these authors, mangroves fulfil an important role as a nursery habitat for many species of fish, including species of economic value.

SPCC (1981a) and Bell *et al.* (1984) reported a study conducted bimonthly over two years in a 'mangrove channel' on the southern shores of Botany Bay. The channel was a very small tidal creek, draining water from the mangroves. Fish poison (rotenone) was poured into the water several hundred metres from the mouth of the creek and dead fish were carried towards the net in the ebb current, where they were scooped up in dip nets. The study was limited because only one creek was sampled and because replicate samples were unavailable at each sampling time.

Sampling by Bell *et al.* (1984) over two years yielded 46 species of fish belonging to 24 families. Six species dominated the assemblage and another four were relatively common. Fourteen species were of economic value to local fisheries. The six numerically dominant species were Port Jackson perchlets, luderick, blue eye, flat-tail mullet, toadfish and silver biddy (Bell *et al.* 1984). The fish fauna of the mangrove contained many species also found in other habitats within Botany Bay at the time of sampling (SPCC 1981a). In fact, only two species collected from the creek were not recorded in other habitats.

The numbers of fish species and individuals in the mangrove creek varied seasonally, with peaks in numbers lagging behind water temperature by four months. The peaks were considered to be the result of relatively restricted periods of recruitment of several abundant temporary residents (Bell *et al.* 1984). Bell and his co-workers concluded that mangrove habitats in temperate Australia are, as in tropical and sub-tropical areas, important nursery areas for fishes inhabiting adjacent habitats. It would also seem likely, on the basis of available habitat, that Homebush Bay would provide nursery areas for fish.

2.2.1.2 *Saltmarshes*

We are not aware of any studies done on the fish fauna of saltmarshes in the Sydney region, although some very limited work has been done at Wallis Lake, on the north coast of NSW (Gibbs 1985) and more detailed studies have been done on saltmarshes on Coomera Island, in Moreton Bay, southern Queensland (Morton *et al.* 1987, 1988).

In general, there are two types of water bodies within saltmarshes, a) ponds formed in depressions among the saltmarshes and b) channels which flood and drain the saltmarshes at extreme high tides or during rainfall. The ponds in saltmarshes constitute a very harsh environment. They are generally flushed only during extreme high tides, they may dry-up during neap tides or droughts and they are subject to great variation in temperature and salinity (Morton *et al.* 1988).

Gibbs (1985) sampled several ponds within a saltmarsh at the southern end of Wallis Lake. He recorded a variety of species of fish, some of which are of economic value. Examples include silver biddy and yellowfin bream. These fish were present as small juveniles, suggesting that the ponds were being used as a nursery habitat (Gibbs 1985).

Morton *et al.* (1987) sampled a large channel draining a saltmarsh monthly over a year. The saltmarsh plants were dominated by *Sporobolus virginicus* and *Sarcocornia quinqueflora*, species which also occur at Homebush Bay. Nineteen species of fish from 14 families were collected during the study. Species which dominated the catch included toadfish, yellowfin bream, yellow perchlets, flat-tail mullet and fan-tail mullet.

Morton *et al.* (1988) sampled ponds within the same saltmarsh as Morton *et al.* (1987) over the same 12 months using a dip net. Far fewer species were recorded in the ponds than the channel. Of the eight or so species collected from the ponds, abundance was dominated by mosquito fish, blue eye and one or more species of gobies. The mosquito fish is an exotic species introduced from Central America. The blue eye is a common freshwater and brackish species on Australia's east coast and gobies constitute one of the most speciose estuarine groups in Australia.

Morton *et al.* (1988) examined the stomach contents of the three dominant fish taxa. They found that in all taxa the larvae of mosquito (*Aedes vigilax* and *Aedes alternans*) were a very significant food item, particularly in summer. They also concluded, however, that fish were unlikely to be an effective biological control for mosquitoes in saltmarshes and mangroves, due to variability in fish populations caused by the harsh pond environment. Other food items found in the fish were numerous other insects, spiders and crustaceans.

The limited information available suggested that some saltmarshes in eastern Australia support relatively few species of fish and that these are also common in other estuarine and freshwater habitats. There is conflicting evidence regarding the role of saltmarshes as a nursery habitat for species of fish of economic importance.

2.2.1.3 Muddy, Unvegetated Substratum

There are often large areas of muddy, unvegetated substrata within estuaries, including the upper estuary of Sydney Harbour. In Homebush Bay there is a large mud flat and a deep muddy navigation channel. Two studies done on the fish inhabiting shallow muddy substrata in the Sydney region (which we might expect to be similar in some respects to the mud flat in Homebush Bay) were by NSW Fisheries in Botany Bay (SPCC 1981a) and The Ecology Lab in Sanbrook Inlet, at Brooklyn, in the Hawkesbury River (The Ecology Lab 1989a).

SPCC (1981a) sampled the shallow mud habitat in Woolooware Bay and the Cooks River. They selected the former site as an area of relatively little pollution and the latter which is highly polluted. Thirty-eight species of fish were collected from this habitat (both sites combined), half of which were of economic value. It was considered that all the adults of commercial species in this habitat were transients, foraging in this and other shallow habitats within Botany Bay.

The Ecology Lab (1989a) sampled a shallow mud bank at the western end of Sanbrook Inlet. Sampling was done on a single occasion, in January/February 1988. The fish fauna collected in Sanbrook Inlet was quite similar to that reported by SPCC (1981a). The main species of commercial value collected included dusky flathead, sand and trumpeter whiting, yellowfin bream, tailor, flat-tail mullet, silver biddy and several species of flatfish.

In addition to fish, both SPCC (1981a) and The Ecology Lab (1989a) sampled large numbers of crustaceans, many of which were of economic value. The main species collected included blue swimmer crabs, mud crabs, king prawns, school prawns and greasyback prawns.

2.2.2 *Fish Reported in and Around Homebush Bay*

Information on fishes occurring in and around Homebush was obtained from several sources. No significant studies of fish had been done in Homebush Bay prior to the present study (Webster and Katchka 1992). There are, however, several studies which have been done on fish in Sydney Harbour, some of which have been in the vicinity of Homebush Bay (Paxton and Collett 1975, Paxton *et al.* in prep, Henry 1984, The Ecology Lab 1986, 1989). There are also records of fish collected from the upper Parramatta River which are held by the Australian Museum, Sydney.

Paxton and Collett (1975) described the fish occurring between Gladesville Bridge and Parramatta Weir. Their work was part of a seven year study of the fish of Sydney Harbour, beginning in 1972 (Paxton *et al.* in prep). Fish were sampled throughout the estuary using a small otter trawl, however, gill nets, dip nets and seines were used in some areas where the trawl could not be used, due to obstructions on the seafloor (J. Paxton, *pers. comm.*).

Paxton *et al.* (in prep) differentiated the Parramatta River estuary into three broad zones on the basis of fish occurrence and abundance. The area to the east of Bradleys Head, defined as the outer estuary, was classified as marine, because it has hydrological characteristics similar to the adjacent coastal waters. Between Bradleys Head and Gladesville Bridge was the central estuary, while the upper estuary, including Homebush Bay, extended west from Gladesville Bridge. Paxton *et al.* (in prep.) found that the numbers of fish species declined with distance up the estuary, away from the ocean. They considered that the upper estuary was characterised by a fish assemblage of about 25 species.

For the present study, a list was compiled of fish recorded in the upper area of the Parramatta River, defined following Paxton *et al.* (in press) as the waters upstream of the Gladesville Bridge. A total of 96 species of fish from 43 families have been recorded in this section of the estuary. According to Dr John Paxton (Australian Museum), over 500 species of fish have been recorded from the whole of the estuary, thus the list of species compiled represents less than 20% of the species previously recorded from the whole estuary.

Most of the species recorded from the upper area of the estuary are common in the estuaries of New South Wales. A few species are more common in tropical areas. Others, such as galaxias, goldfish and mosquito fish and several species of gudgeons, occur typically in fresh and/or brackish water. Three species, goldfish, mosquito fish and oriental goby are exotic species which have been introduced into Australian waters. Goldfish and mosquito fish were introduced from aquaria but the oriental goby is believed to have been introduced in ballast water discharged into the harbour from ships (Middleton 1982). One species notable by its absence is the luderick. This species occurs throughout estuaries (M. Lincoln Smith, pers. obs.) and was reported to be abundant in a small mangrove channel in Botany Bay (Bell *et al.* 1984).

2.3 FISHING

Commercial fishing in Sydney Harbour utilises a variety of methods, including otter trawling for prawns (mostly king and school prawns), trapping for rock lobster and seining, gill netting, trapping and linefishing for a variety of fish (Henry 1984). Several fishing closures apply currently to the estuary west of Gladesville Bridge. Traditionally, commercial fishing using nets was banned from May 1st to August 31st every year. In the period November 1st to March 31st, commercial fishers were allowed to trawl for prawns in many parts of Sydney Harbour, although there was total closure on commercial fishing in Duck River.

New closures on commercial fishing have been imposed. These include a total ban on all forms of fishing in Homebush Bay (and, as before, in Duck River) and a ban on the taking of finfish for sale from any waters west of Gladesville Bridge (NSW Fisheries, pers. comm.). Commercial fishers are still allowed to trawl for prawns in the main river channel west of Gladesville Bridge, in the prescribed season. These new closures have been imposed until 1999, when they will be reviewed (NSW Fisheries, *pers. comm.*).

Henry (1984) surveyed recreational fishing ('angling') in Sydney Harbour monthly for a year. He divided the estuary into 12 geographical zones and, in each zone, made estimates of the number of anglers, their catch per unit of effort and the catch itself. Zone 1 extended from Ryde Bridge to Silverwater Bridge and therefore included Homebush Bay. This zone ranked lowest of the 12 surveyed, with no fishing reported there. During the present study anglers were observed around Ryde Bridge, however, these observations and Henry's (1984) study suggest that angling is not popular in the area encompassing Homebush Bay. In addition, a closure has now been imposed on recreational fishing in Homebush Bay and Duck River and is not due to be lifted until 1999 (NSW Fisheries, *pers. comm.*).

2.4 CONCLUSIONS

The major aquatic habitats likely to be utilised by fish which occur in and around Homebush Bay include mangrove-lined creeks and channels, saltmarshes and mud channels and banks in the open parts of the bay. Minor habitats include some freshwater lakes, derelict ships and artificial seawalls. Studies done of these habitats elsewhere demonstrate that they can support assemblages of fish.

There are two major deficiencies with the existing information. The first and most obvious is that there is virtually no information of value on the fishes of Homebush Bay. Therefore, if these fish assemblages within the bay are to be preserved and/or enhanced, it is crucial that the assemblages be described and quantified before management decisions are formulated.

The second limitation is that it is very difficult to generalise about the types of assemblages that should occur in mangrove, saltmarsh or muddy unvegetated habitats because the existing studies are often confined to a single site (e.g. Bell *et al.* 1984, Morton *et al.* 1987, 1988, The Ecology Lab 1989).

3 SAMPLING METHODOLOGY

3.1 INITIAL INVESTIGATIONS

3.1.1 Description of Study Area and Selection of Study Sites

3.1.1.1 Homebush Bay and Creeks

Homebush Bay was visited by boat and the Homebush and Newington wetlands were visited on foot during November and December 1992. At this time, major habitats were defined and sample sites selected. The major habitats in Homebush Bay considered were the main channels in Haslams Creek and Powells Creek, which are lined with mangroves (Plate 1b), a large mudflat on the eastern side of Homebush Bay which was largely exposed to the air at low tide and a narrow navigation channel, up to 4 m below Indian Spring Low Water (ISLW), along the western side of the bay (Figure 3).

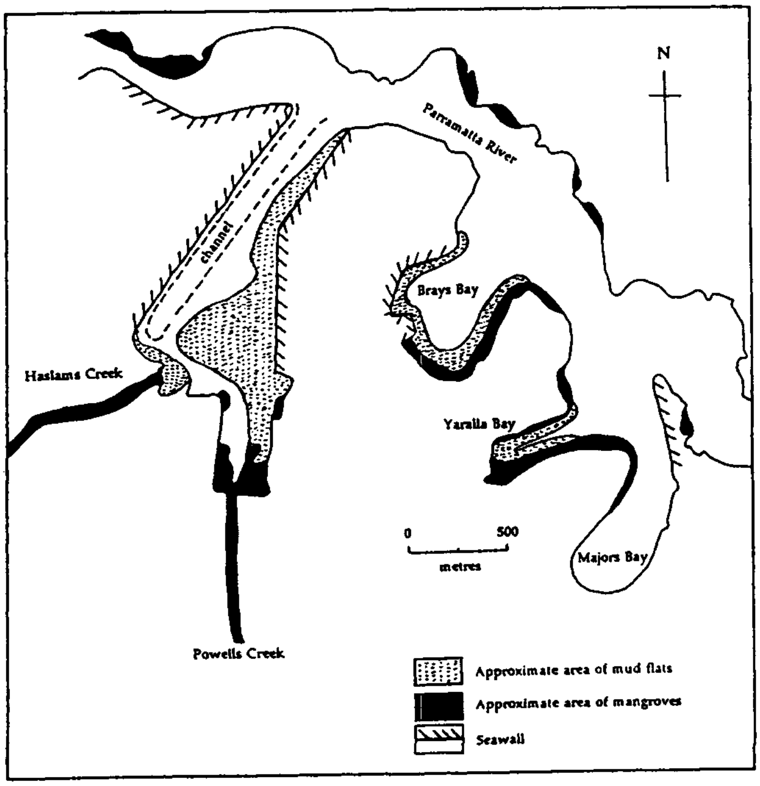

Figure 3. Major habitats sampled in Homebush Bay, Brays Bay and Majors Bay.

At the time of the site visit, sites in surrounding areas were inspected as potential reference sites. Four types of reference sites were considered: saltmarshes, mangrove-lined creeks, deep channels and mud flats. No suitable reference areas were found for the first three types, but large mud flats occurred in Brays Bay, Yaralla Bay and Majors Bay (Figure 3) and these were considered to be appropriate reference bays for the mud flats in Homebush Bay. Yaralla and Majors Bays share the same entrance to the main estuary and these were considered as one reference bay, referred to hereafter for convenience simply as Majors Bay (Figure 3).

Plate 1. View up Haslams Creek (Site G8, Figure 4). Mangroves, which line the creek, provide shelter and food for a variety of organisms including fish, crustaceans and birds.

Within each of the locations sampled two sites were selected to study (Figures 4 and 5) using two sampling methods, gill nets and beam trawl (Sections 3.1.2 and 3.2). Using gill nets, two sites were sampled within the navigation channel of Homebush Bay (sites G1 & G2), two sites on the mud flat adjacent to seawalls (G3 & G4) and two sites each in Powells Creek and Haslams Creek (G6 & G7; G8 & G9). In addition, one site was sampled on mud flats adjacent to mangroves (G5) but, due to the relatively large size of the nets (see Sections 3.1.2 and 3.2) the area was too small to allocate two sites for sampling (Figure 4). Gill nets were also deployed on mud flats at two sites each in Brays Bay (G10 & G11) and Majors Bay (G12 & G13 — see Figure 4). One of the sites in each bay was adjacent to mangroves, the other was adjacent to seawall.

The beam trawl effectively sampled a smaller area than the gill nets and more sites could be allocated for sampling within each location (Figure 5). In Homebush Bay, sampling was done at two sites within two locations within the navigation channel (sites B9 & B10, near the entrance to the bay; B11 & B12, near the southern end of the channel), two sites within two locations on the mud flat along the seawall (B1 & B2; B3 & B4), two sites within one location on mud flats adjacent to mangroves (B5 & B6) and two sites each in Powells Creek and Haslams Creek (B21 & B22; B23 & B24). Beam trawls were also done on mud flats at two sites within two locations in Brays Bay and Majors Bay (Figure 5). Two sites in each bay were adjacent to seawall (B15 & B16 in Brays Bay; B19 and B20 in Majors Bay) and two were adjacent to mangroves (B13 & B14 in Brays Bay; B17 & B18 in Majors Bay). Following the first survey, four sites were eliminated from the beam trawling to maintain the study schedule: B1, B4, B9 and B12 (see Volume II for further details).

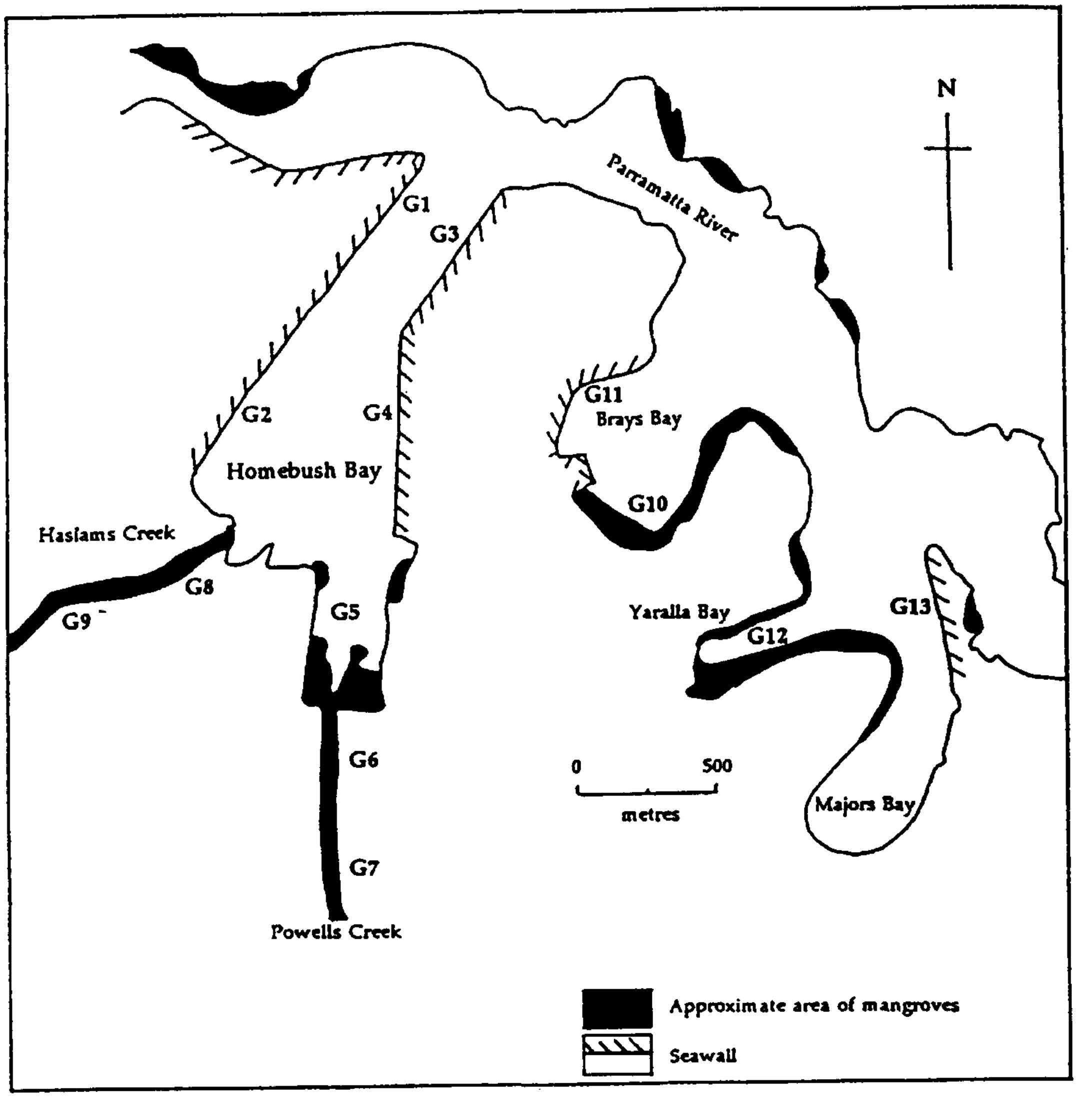

Figure 4. Locations of sampling sites for gill netting.

3.1.1.2 *Homebush Bay Wetlands*

The Homebush Bay wetlands contain drainage channels, shallow tidal ponds (e.g. near the 2SM tower and the waterbird refuge) and freshwater ponds, such as Bicentennial Lake (Figure 6). During initial investigations, very few fish were observed within any of these water bodies. It was therefore decided to focus more on bay and creek habitats (which could be sampled quantitatively with more confidence) and to do a one-off survey of water bodies in the Homebush Bay wetlands.

3.1.1.3 *Newington Wetland*

Newington wetland has several aquatic habitats, including mangrove forests with shallow water bodies (generally < 0.5 m deep), ponds scattered in the saltmarshes (0.1–0.2 m deep), large open water bodies (0.2–0.5 m deep), a small brackish pond and freshwater drainage channels (Figure

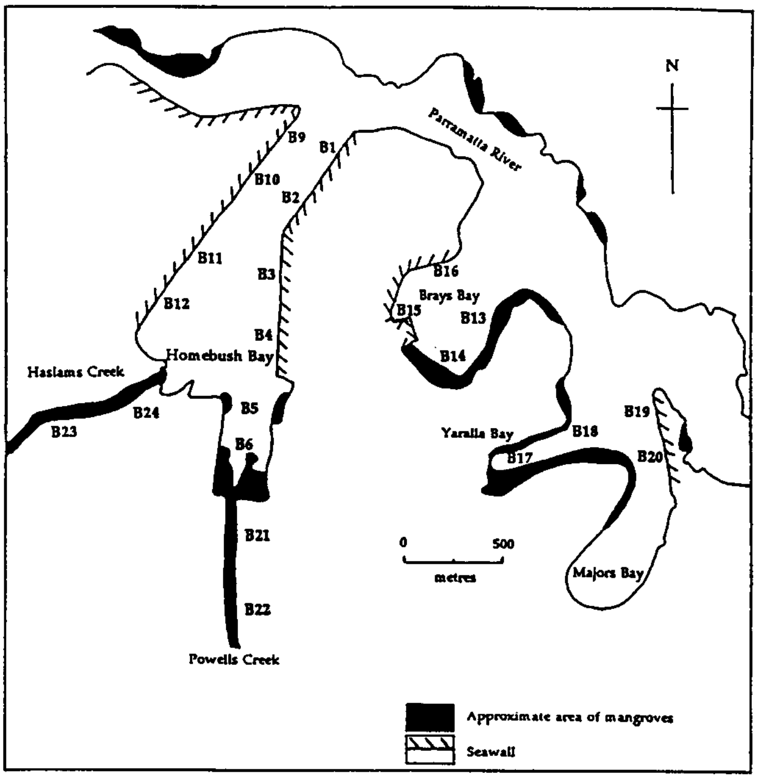

Figure 5. Locations of the sampling sites for beam trawling. Note sites B1, B4, B9 and B12 were sampled only during Survey 1.

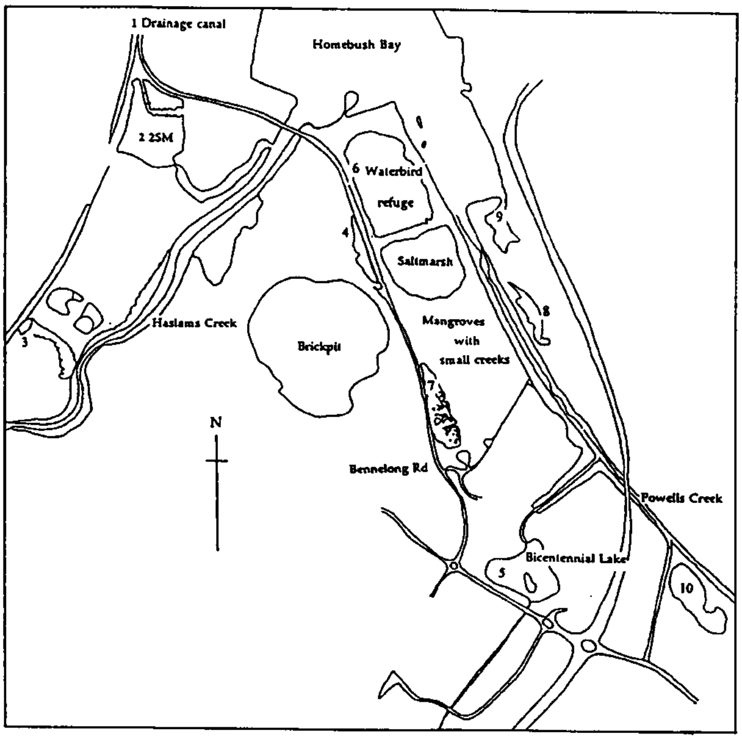

Figure 6. Sites (1–11) investigated in Homebush Bay Wetlands. .

7). Water flow into the wetland is via freshwater runoff from the drainage channels or via tidal exchange with the Parramatta River from two small pipes ('main tidal flood gate' in Figure 7).

During initial investigations water bodies were visited in the saltmarshes and around mangroves and no fish were observed. Moreover, given the very limited exchange of water with the estuary, it was concluded that the fish assemblages of the Newington wetland would be very limited. On this basis, it was decided to do a one-off survey of seven sites in water bodies in the wetland and at several other sites within freshwater drainage channels.

3.2 SAMPLING PROCEDURES

3.2.1 Sampling Times

Fish in Homebush Bay and at external references were sampled on four occasions during 1993 (Table 1). All sampling in the bay and creek habitats was done during the day during the upper half of the tide. Sampling was done in the Homebush Bay wetlands between late October and early December, 1993 and the Newington wetland was sampled in August 1993 (Table 1).

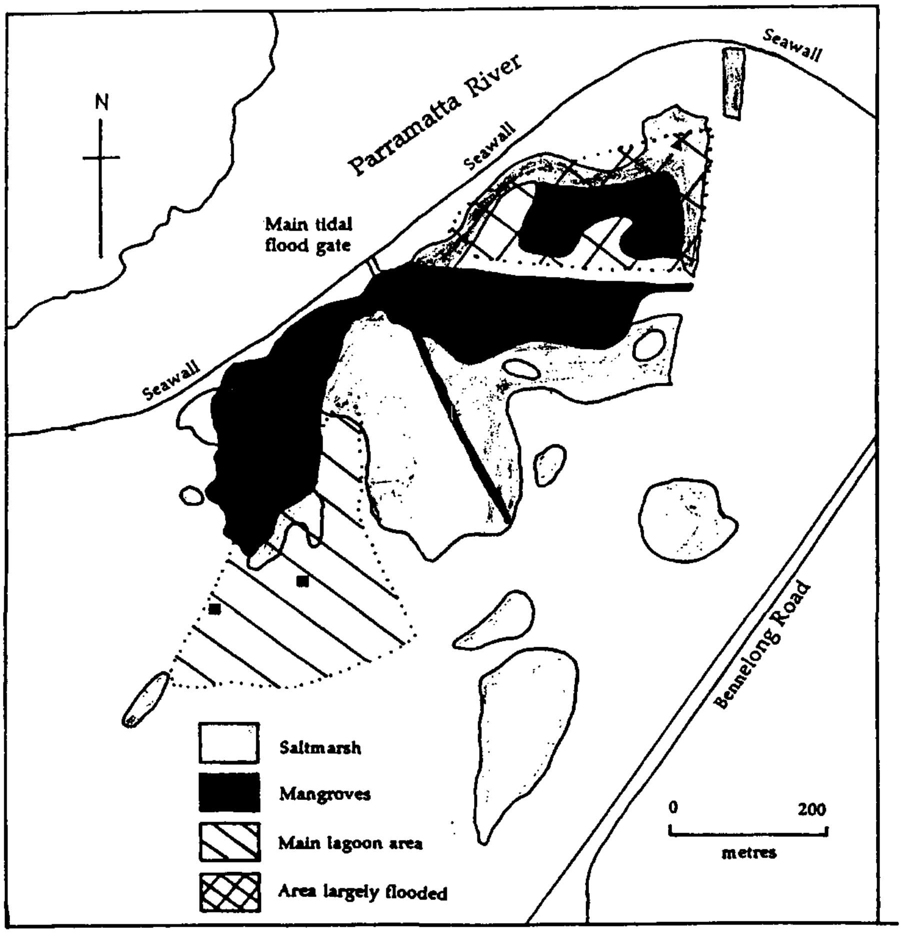

Figure 7. Sampling sites in Newington wetlands. Squares indicate areas sampled by seine, triangles indicate areas sampled by dip net.

Table 1 Dates of the sampling in Homebush Bay and reference locations.

	Survey 1		Survey 2		Survey 3		Survey 4	
	Commenced	Completed	Commenced	Completed	Commenced	Completed	Commenced	Completed
Homebush Bay: Gill Netting	9-Mar-93	11-Mar-93	22-Jun-93	25-Jun-93	5-Aug-93	10-Aug-93	5-Oct-93	8-Oct93
Beam Trawling	23-Feb-93	26-Feb-93	7-Jun-93	9-Jun-93	27-Jul-93	28-Jul-93	20-Sep-93	22-Sep.93
Homebush Wetlands: All methods							28-Oct-93	6-Dec-93
Newington Wetlands: Seine and dip net					20-Aug-93	20-Aug-93		

3.2.2 Field and Laboratory Procedures

3.2.2.1 Gill Nets

Gill nets are generally rectangular panels of net which form a wall (Plate 2). Fish swim into the net and become tangled by their gills or spines. They tend to catch relatively large, bottom-dwelling fish, pelagic fish, and crabs. Three gill nets (replicates) were deployed from a small, outboard-powered punt at every site on every sampling occasion. Gill nets deployed in the creeks were 30 m long, while those elsewhere were 60 m long (see Volume II). Gill nets were also deployed in the Homebush Bay wetland, at Sites 2 and 10 (Figure 6).

As each gill net was retrieved, fish and crabs were identified and counted. The lengths of species of fish of economic value were measured from the tip of the head to the fork of the tail fin (known as fork length, or LCF), so that an estimate could be made of life history stage (after SPCC 1981b). The width across the carapace was measured for all crabs of economic value.

3.2.2.2 Beam Trawl

A beam trawl is a cone-shaped net used to collect small, bottom-dwelling fish and prawns (Plate 3). The trawl used was 1 m wide at the base of the cone (the net opening) and 1.5 m long from the opening to the apex of the cone. The net was supported by a 1.2 m long steel pipe which has a small rope bridle that was connected to the back of the boat by a 25 m long rope. The rope was extended to 50 m for deep sites in the navigation channel at the western side of Homebush Bay to ensure that the net sampled the bottom. The beam trawl was towed behind the back of a punt at a speed of about 1 knot for a time interval of four minutes.

Each sample was washed before being brought aboard the punt. The contents of each trawl were placed in a plastic bag with dilute formalin (about 10% formalin in bay water), sealed and returned to the laboratory. There the fish and crustaceans were sorted, identified and counted. Species of fish of economic value were also measured (LCF).

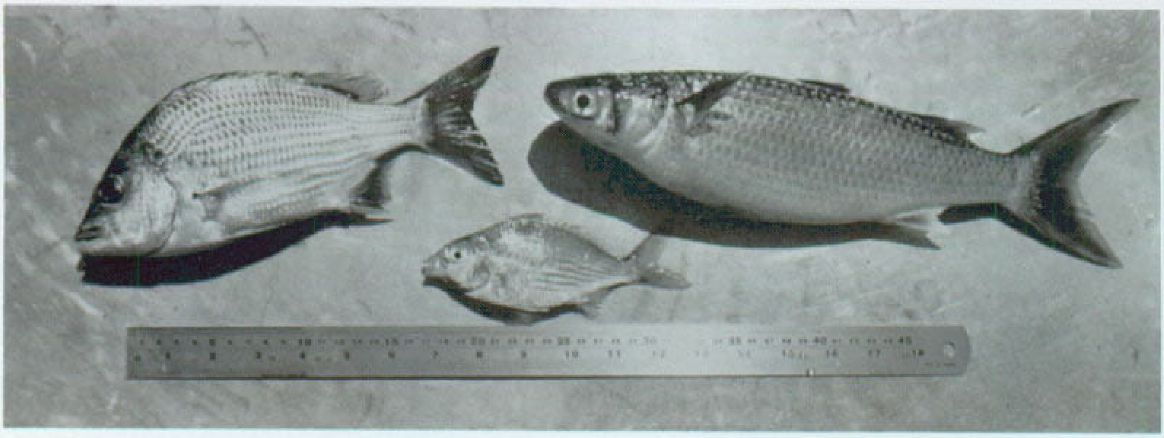

Plate 2. a) Three economically important species of fish which were commonly caught in the gill nets during the study. From left to right the fish are: yellowfin bream (*Acanthopagrus australis*), silver biddy (*Gerres ovatus*) and sea mullet (*Mugil cephalus*).
b) Checking the catch in a gill net in Brays Bay. The fish in the net is a mullet.

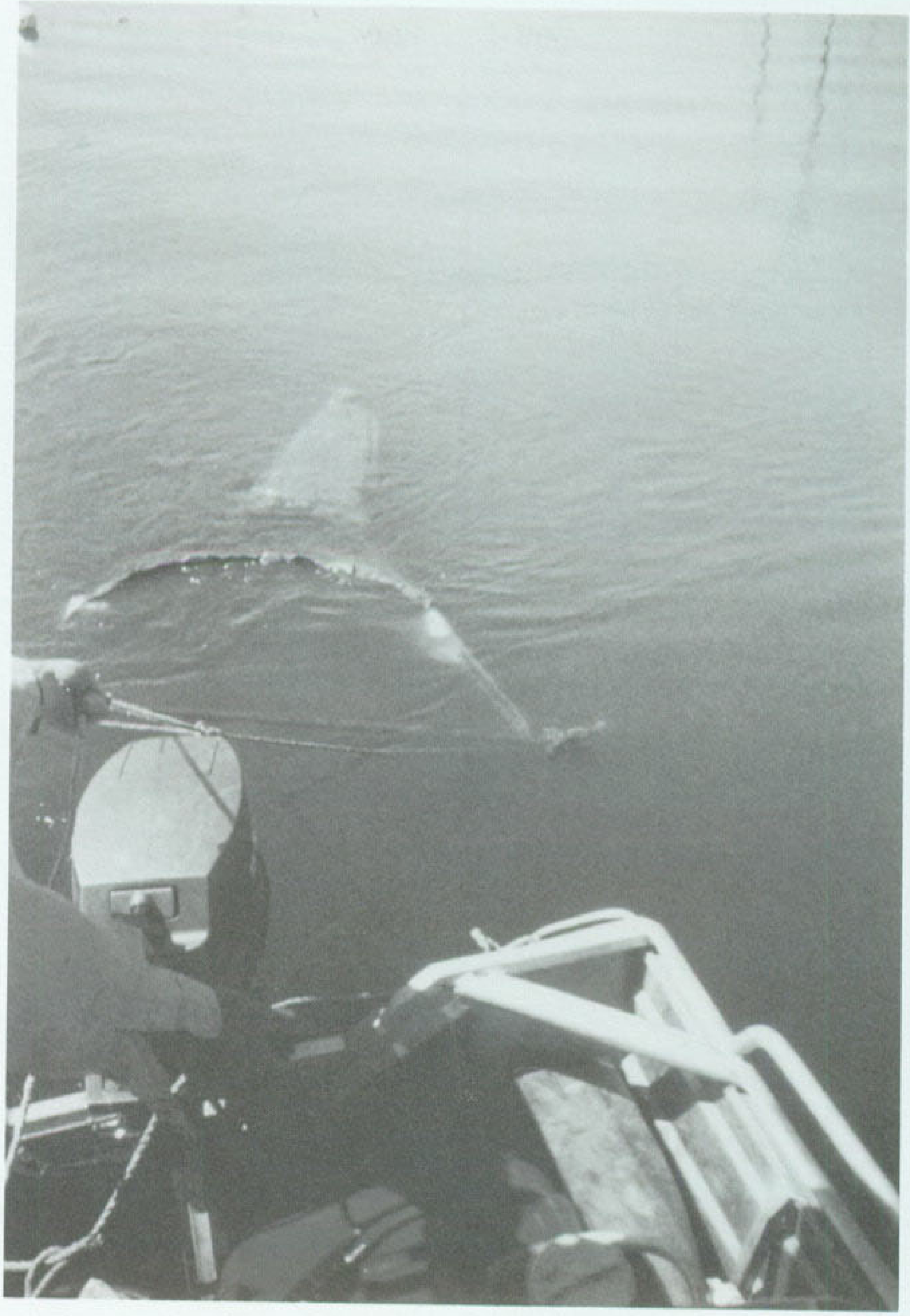

Plate 3. The beam trawl is released behind the boat and then towed slowly along the bottom capturing small fish and invertebrates in its path.

3.2.2.3 *Seine Net and Dip Net*

A beach seine is a rectangular panel of net which forms a wall. It is usually deployed from a boat in a semicircle away from the shore. Once the net is deployed, it is hauled back onto the shore trapping fish between the net and the shoreline. In the Homebush Bay wetlands, the net used was 10 m long, 1 m deep and had 2 mm mesh throughout. This was used at Site 2 (Figure 6). In the Newington wetland a longer net was used because the water bodies of interest were larger (Figure 7). The net used there was 25 m long, 2 m deep and had 8 mm mesh throughout. The sampling done in both wetlands was qualitative and the number of replicates varied among sites. A dip net was used to make qualitative collections of small fish at a number of sites within the wetlands. The dip net consisted of a conical bag with an opening of about 0.4 m and about 0.5 m long, with 1 mm mesh throughout. Fish collected by seine and dip net were preserved in dilute formalin and returned to the laboratory and processed as described above.

3.3 Summary of Study Designs and Procedures for Statistical Analysis

The data collected for the bay and creek habitats were examined separately for the gill net samples and the beam trawl samples at two levels. First, variation was examined among various locations through time for the entire *assemblage*, that is all species of fish and crustaceans together. The statistical procedures, which are known as *multivariate analyses*, distil a measure of the assemblage from all the constituent species. Second, data were examined by comparing variation among sites through time for particular *species* of fish or crustaceans using *univariate analyses*. These analyses compared the average abundance of a species among sites and/or times in association with the variance within and among the sites and/or times being compared. The main univariate procedure used was analysis of variance (ANOVA), which compared the numbers of species of fish and crustaceans, the total number of individuals (all species combined) and the abundance of several of the most common species. ANOVA allowed an examination of variability for several factors, including survey times, the three bays studied, habitats/locations within Homebush Bay, sites within locations and statistical interactions between many of these factors. Details of all these analyses are presented in Volume II.

4 Results

4.1 Fish Recorded in Homebush Bay During the Study Period

4.1.1 Diversity and Abundance of Fish and Crustaceans

Twenty-two families of fish containing 39 species and a total 19 273 individuals were recorded from Homebush Bay and the two external reference areas during the four surveys done in 1993 (Table 2). Thirty-three species were recorded in Homebush Bay and/or the surrounding wetlands. The most speciose family was the Gobiidae, with at least 11 species. All other families contained only one or two species. Three species of fish, an unidentified species of stingaree, luderick and an unidentified species of goby, were not listed as having been recorded previously from the waters west of Gladesville Bridge (Table 2). The latter may be an undescribed species of goby (D. Hoese, Australian Museum, *pers. comm.*) and samples of this fish have been given the Museum for further study. In addition to the fish, two families of crustaceans of economic value were recorded, containing 6 species and a total of 861 individuals (Table 3).

The gill nets yielded a total of 15 species of fish totalling 1 944 individuals (Table 3). All but two species were of economic value. The three most abundant species were sea mullet (which accounted for 54% of the catch), yellowfin bream (28%) and flat-tail mullet (10%). Two species of crabs were collected, totalling 65 individuals (Table 3). Blue swimmer crabs accounted for 85% of the crabs caught and mud crabs, accounted for the other 15%.

The beam trawls yielded a total of at least 25 species of fish totalling 17 239 individuals (Table 4). Seven species of fish were of economic value. The three most abundant species were Swan River goby (which accounted for 60% of the catch), exquisite goby (26%) and bridled goby (18%). Four species of prawns of economic value were collected by beam trawl, the most common being king prawns (73% of economically valuable prawns) and school prawns (26%). These species of prawns form the basis for the prawn fishery in Sydney Harbour. In addition to these prawns, large numbers of at least 4 other species of crustaceans were collected (Table 4).

4.2 Gill Net Samples in Bay and Creek Habitats

4.2.1 Comparison of Habitats Within Homebush Bay

Assemblages of fish and crabs sampled by gill nets appeared to differ in the creeks (where fish counts were multiplied by two to allow for the small net length — see Section 3.2.2.) compared to other habitats in Homebush Bay, but showed little variation among surveys. The analysis of assemblages that was used also provided an assessment of which species contributed most to the differences in assemblages at different places or times. In this case, sea mullet contributed most to the differences in assemblages between locations in comparisons between creeks and mud flats, creeks and the channel and mud flats and the channel. Flat-tail mullet also contributed to differences between the creeks and the bay habitats, as it occurred on the flats and the channel but not in the creeks. Similarly, the presence of more yellowfin bream in the bay habitats than the creeks further contributed to the distinctive assemblage in the creeks.

Considering species and individuals, numbers varied through time, but the variation was often inconsistent from one site to the next, even within locations. For example, yellowfin bream tended to be least abundant in the creeks, but variation through time was inconsistent among

Table 2 Species of fish recorded by all methods in Homebush Bay, wetlands and at refernce bays during 1993 study. Note, eels (Anguillidae) were seen but not caught. Species not listed as occurring west of Gladesville Bridge (i.e. in Table 1) marked with an asterisk.

				Homebush Bay		Wetlands		External References	
				Creeks	Bay	Homebush	Newington	Brays	Majors
Urolophidae	*Urolophus*	sp.	Stingaree*						+
Anguillidae	*Anguilla*	sp.	Eel		+	+		+	+
Clupeidae	*Herklotsichthys*	*castelnaui*	Southern herring		+				
	Hyperlophus	*vittatus*	Sandy sprat					+	+
Engraulidae	*Engraulis*	*australis*	Anchovy		+			+	
Poeciliidae	*Gambusia*	*affinis*	Mosquito fish			+	+		
Pseudomugilidae	*Pseudomugil*	*signifer*	Blue eye			+			
Syngnathidae	*Urocampus*	*carinirostris*	Snub nose pipefish			+			
Scorpaenidae	*Centropogon*	*australis*	Eastern fortesque					+	+
Platycephalidae	*Platycephalus*	*fuscus*	Dusky flathead		+			+	+
Ambassidae	*Ambassis*	*jacksoniensis*	Port Jackson perchlet	+	+				
Sillaginidae	*Sillago*	*ciliata*	Sand whiting		+				+
Pomatomidae	*Pomatomus*	*saltatrix*	Tailor		+			+	+
Carangidae	*Pseudocaranx*	*dentex*	Silver trevally		+				
	Trachurus	*novaezelandiae*	Yellowtail		+				
Gerridae	*Gerres*	*subfasciatus*	Silver biddy	+	+			+	+
Sparidae	*Acanthopagrus*	*australis*	Yellowfin bream	+	+			+	+
Girellidae	*Girella*	*tricuspidata*	Luderick*	+					+

Table 2 Species of fish recorded by all methods in Homebush Bay, wetlands and at refernce bays during 1993 study. Note, eels (Anguillidae) were seen but not caught. Species not listed as occurring west of Gladesville Bridge (i.e. in Table 1) marked with an asterisk.

				Homebush Bay		Wetlands		External References	
				Creeks	Bay	Homebush	Newington	Brays	Majors
Mugilidae	*Liza*	*argentea*	Flat-tail mullet		+			+	+
	Mugil	*cephalus*	Sea mullet	+	+			+	+
			Unidentified mullet			+			
Gobiidae	*Acanthogobius*	*flavimanus*	Oriental goby	+	+	+		+	+
	Arenigobius	*nov. sp.*	Possibly new species*	+	+			+	+
	Arenigobius	*bifrenatus*	Bridled goby	+	+			+	+
	Favonigobius	*exquisitus*	Exquisite goby	+	+			+	+
	Favonigobius	*lateralis*	Long finned goby	+					
	Favonigobius	*tamarensis*	Tamar River goby	+	+			+	+
	Favonigobius	sp.	Goby		+			+	+
	Gobipterus	*semivestitta*	Transparent goby		+			+	+
	Mugilogobius	*stigmaticus*	Goby	+	+				
	Pseudogobius	*olorum*	Swan River goby	+	+	+		+	+
	Redigobius	*macrostoma*	Large mouth goby	+	+			+	+
			Unidentified gobies		+			+	+
Eleotridae	*Phylipnodon*	*grandiceps*	Flathead gudgeon	+	+				
	Phylipnodon	sp.	Dwarf flathead gudgeon		+				

Table 2 **Species of fish recorded by all methods in Homebush Bay, wetlands and at refernce bays during 1993 study. Note, eels (Anguillidae) were seen but not caught. Species not listed as occurring west of Gladesville Bridge (i.e. in Table 1) marked with an asterisk.**

				Homebush Bay		Wetlands		External References	
				Creeks	Bay	Homebush	Newington	Brays	Majors
Bothidae	*Pseudorhombus*	*arsius*	Large-tooth flounder					+	+
	Pseudorhombus	*jenynsii*	Small-tooth flounder		+			+	+
Monacanthidae	*Monacanthus*	*chinensis*	Fan belly leatherjacket						+
Tetraodontidae			Unidentified toadfish					+	
Number of species				**16**	**28**	**6**	**1**	**23**	**25**
Total									**39**
Crustaceans of economic value									
Portunidae	*Portunus*	*pelagicus*	Blue-swimmer crab		+			+	+
	Scylla	*serrata*	Mud crab	+	+			+	+
Penaeidae	*Metapenaeus*	*macleayi*	School prawn	+	+			+	+
	Penaeus	*endeavouri*	Endeavour prawn	+	+				+
	Penaeus	*esculentus*	Tiger prawn		+				
	Penaeus	*plebejus*	King prawn	+	+			+	+
Number of species				**4**	**6**			**4**	**5**
Total									**6**

Table 3 Fish and crustaceans collected in Homebush Bay and reference bays during each survey (S1–S4) by gill netting. Species of economic value marked with an asterisk.

Family	Species	Common name	S1	S2	S3	S4	Total
FISH							
Urolophidae	*Urolophus sp.*	Stingaree	2	0	0	0	**2**
Clupeidae	*Herklotsichthys castelnaui*	Southern herring*	1	0	0	0	**1**
Engraulidae	*Engraulis australis*	Anchovy*	2	0	0	0	**2**
Platycephalidae	*Platycephhalus fuscus*	Dusky flathead*	20	4	8	25	**57**
Sillaginidae	*Sillago ciliata*	Sand whiting*	5	0	12	8	**25**
Pomatomidae	*Pomatomus saltatrix*	Tailor*	13	0	3	8	**24**
Carangidae	*Pseudocaranx dentex*	Trevally*	0	1	0	0	**1**
	Trachurus novaezelandiae	Yellowtail*	1	0	0	0	**1**
Sparidae	*Acanthopagrus australis*	Yellowfin bream*	162	26	112	239	**539**
Girellidae	*Girella tricuspidata*	Luderick*	0	0	1	2	**3**
Gerreidae	*Gerres subfasciatus*	Silver biddy*	37	0	4	9	**50**
Mugilidae	*Mugil cephalus*	Sea mullet*	245	157	417	230	**1049**
	Liza argenta	Flat-tail mullet*	1	112	73	1	**187**
Gobiidae	*Acanthogobius flavimanus*	Oriental goby	1	0	0	0	**1**
Bothidae	*Pseudorhombus jenynsii*	Small-tooth flounder	1	0	0	1	**2**
Total Abundance			**492**	**300**	**630**	**523**	**1944**
Number of Species			**13**	**5**	**8**	**9**	**15**
CRUSTACEANS							
Portunidae	*Scylla serrata*	Mud crab*	10	0	0	0	**10**
	Portunus pelagicus	Blue swimmer crab*	23	2	0	30	**55**
Total Abundance			**33**	**2**	**0**	**30**	**65**
Number of Species			**2**	**1**	**0**	**1**	**2**

sites. Comparing sites within locations during each survey, the abundance of yellowfin bream was different at sites in Haslams Creek and on the mud flat during Survey 1, in the channel and on the mud flat during Survey 3, and in Haslams Creek, in the channel and on the mud flat in Survey 4. Abundance of yellowfin bream in Powells Creek was statistically similar throughout the study (Figure 8).

The total abundance of fish showed consistent variation among locations through time, but varied inconsistently between sites within locations. There was a trend for more fish to occur on the mud flats than in the creeks, with abundance in the navigation channel intermediate (Figure 9). Comparing sites within locations, sites varied during each survey. In Survey 1, there were more fish at sites G8 than G9, in Haslams Creek. In Survey 2, sites varied within the channel and the mud flat. In Survey 3, however, they varied within the creeks. In the last survey, more fish were collected at G1 than G2 (channel), but variation between sites within the other locations was more consistent (Figure 10).

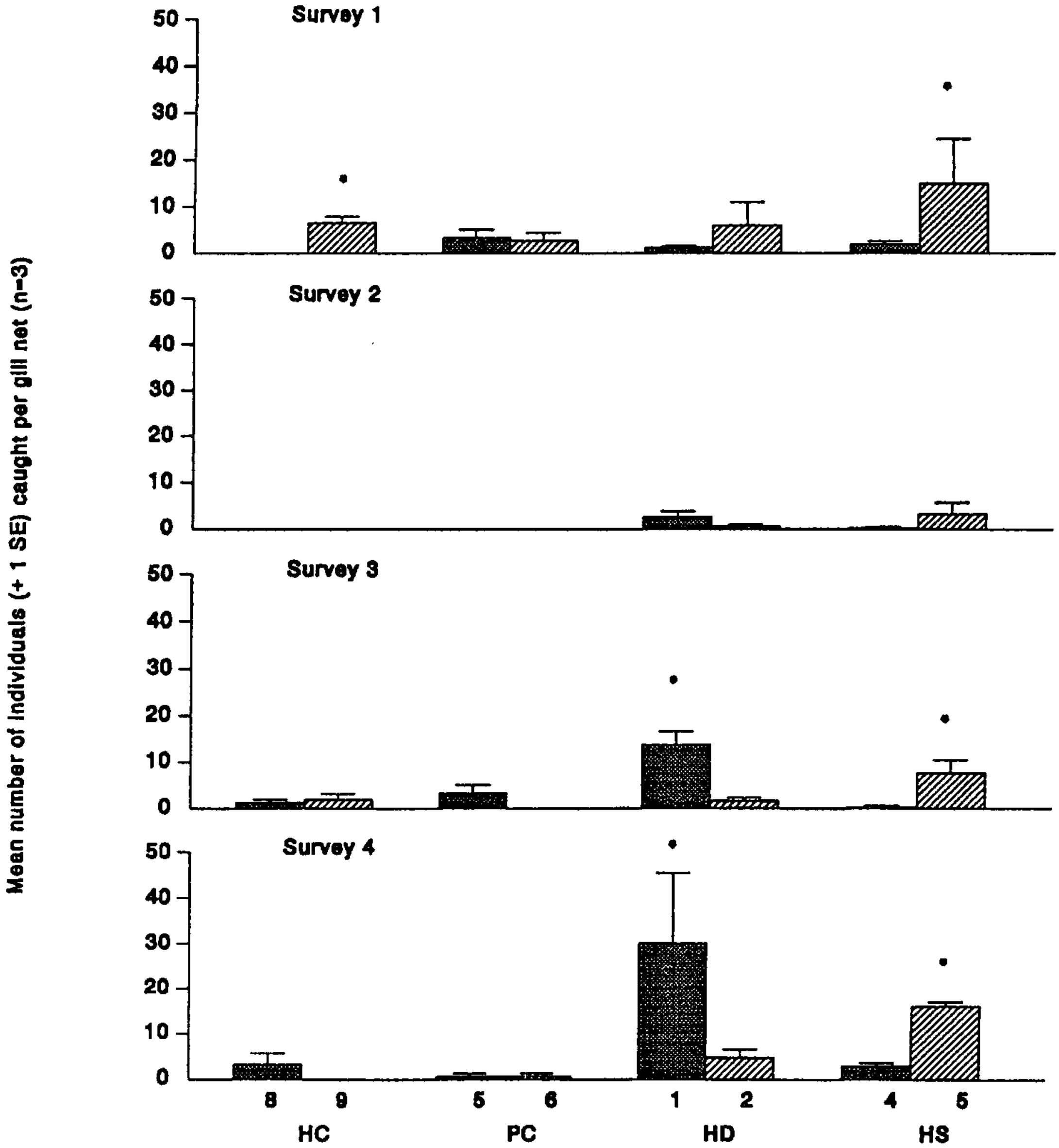

Figure 8. Abundance of yellowfin bream collected by gill netting at sites within Homebush Bay. HC= Haslams Creek, PC= Powells creek, HD= navigation channel. HS= mud flats. See Fig. 4 for position of sites. Astericks indicate significantly more fish at one site than the other site within a location.

The number of species of fish varied significantly among locations, independent of the time of sampling; fewer species were collected in the creeks than the bay habitats (Figure 11). At a smaller spatial scale, however, variation in species richness between sites within locations varied inconsistently through time. Examining variation through time at each site, species richness was consistent and relatively large at sites in Powells Creek and within the channel and mud flat locations throughout the study. In Haslams Creek, however, there were more species of fish collected at one site (G8) during Surveys 3 and 4 than at other the times and at G9 there was trend for more species during Surveys 1 and 4 than Survey 2.

Comparing sites during each survey, significant variation between sites occurred in Haslams Creek in Surveys 1 and 3 and in Powells Creek in Survey 3 (Figure 12). Therefore, it is

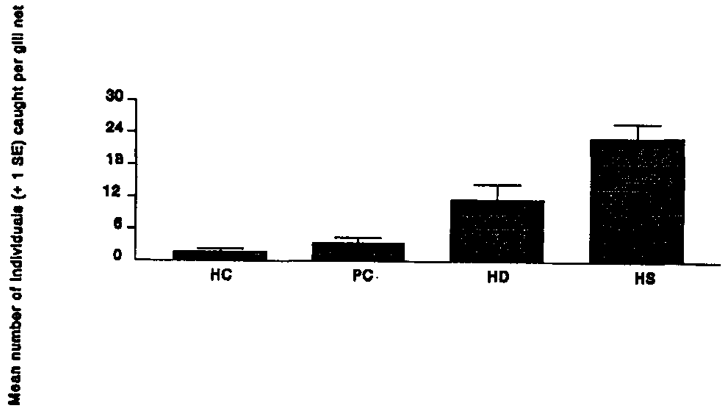

Figure 9. Total abundance of fish collected by gill netting from locations within Homebush Bay (surveys and sites pooled, n=24). HC= Haslams Creek, PC= Powells Creek, HD= navigation channel. HS= mud flats. See Fig. 4 for position of sites.

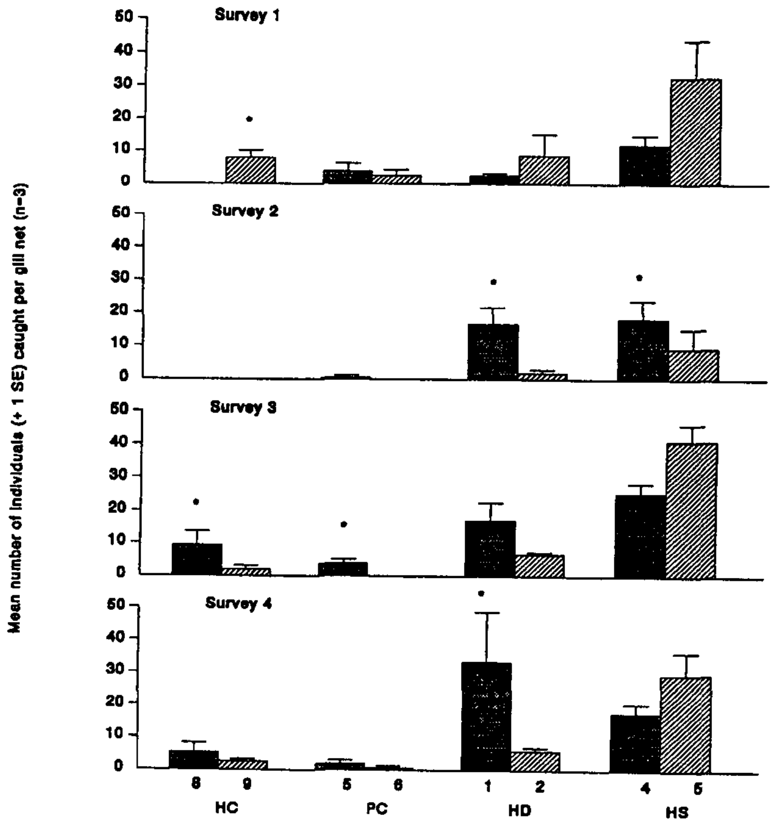

Figure 10. Total pooled of fish collected by gill netting from locations within Homebush Bay (surveys and sites polled, n=24). HC= Haslams Creek, PC= Powells Creek, HD= navigation channel. HS= mud flats. See Fig. 4 for position of sites. Asterisks indicate statistically significantly more fish at one site than the other site within a location.

concluded from this analysis that the number of species of fish was relatively consistent between sites within locations through time, with the exception of Haslams Creek and, to a lesser extent, Powells Creek.

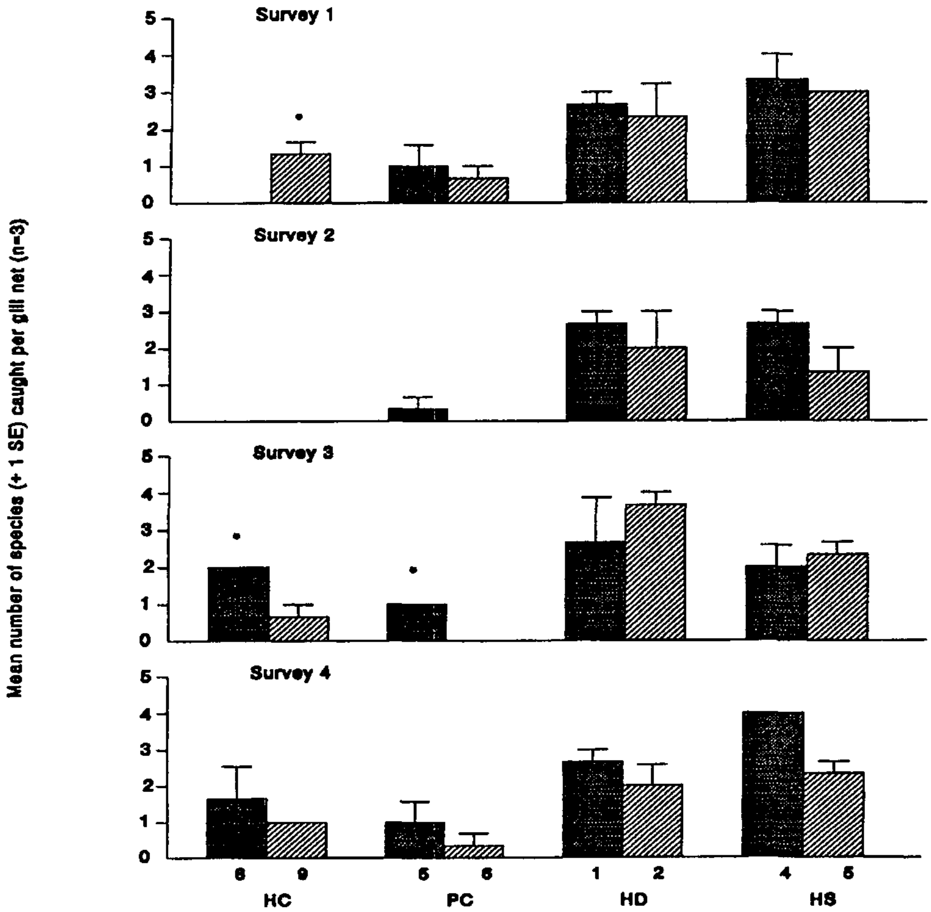

Figure 11. Total pooled of fish collected by gill netting from locations within Homebush Bay (surveys and site: polled, n=24). HC= Haslams Creek, PC= Powells Creek, HD= navigation channel. HS= mud flats See Fig. 4 for position of sites. Asterisks indicate statistically significantly more fish at one site thar the other site within a location.

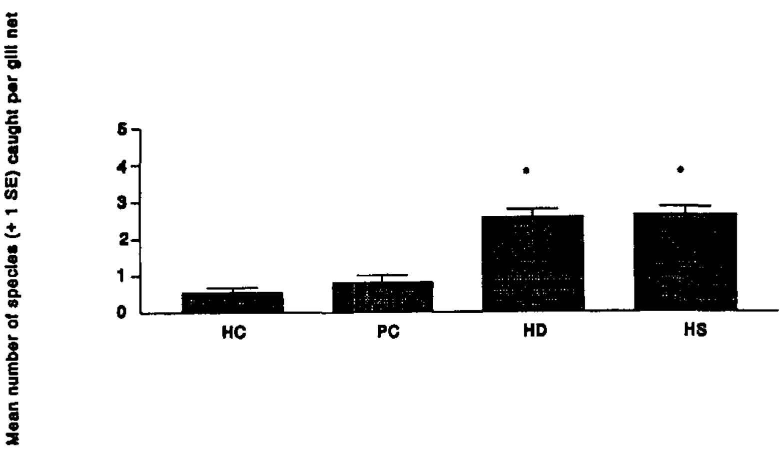

Figure 12. Total abundance of fish collected by gill netting from locations within Homebush Bay. HC= Haslams Creek, PC= Powells Creek, HD= navigation channel. HS= mud flats. See Fig. 4 for position of sites. Asterisks indicate statistically significantly more fish at one site than the other site within a location.

Table 4 **Fish and crustaceans collected in Homebush Bay and reference bays during each survey (S1–S4) by beam trawling. Species of commercial and/or recreational value marked with an asterisk.**

Family	Species	Common name	S1	S2	S3	S4	Total
FISH							
Clupeidae	*Hyperlophus vittatus*	Sandy sprat*	0	0	0	106	**106**
Syngnathidae	*Urocampus carinirostris*	Snub-nosed pipefish	1	0	0	0	**1**
Scorpaenidae	*Centropogon australis*	Eastern Fortescue	1	1	0	3	**5**
Platycephalidae	*Platycephalus fuscus*	Dusky flathead*	8	6	4	6	**24**
Ambassidae	*Ambassis jacksoniensis*	Glass perchlet	0	9	1	1	**11**
Sparidae	*Acanthopagrus australis*	Yellowfin bream*	0	1	1	2	**4**
Gerreidae	*Gerres subfasciatus*	Silver biddy*	2	8	1	0	**11**
Gobiidae	*Arenigobius spp.*	Bridled goby	882	473	367	150	**1872**
	Arenigobius n. sp.	Goby	80	10	8	8	**106**
	Pseudogobius olorum	Swan River goby	2192	3660	2799	1617	**10268**
	Favonigobius tamarensis	Tamar River goby	86	23	72	158	**339**
	Favonigobius exquisitus	Exquisite goby	375	973	950	387	**2685**
	Favonigobius lateralis	Goby	0	1	0	0	**1**
	Favonigobius sp.	Goby	17	3	1	0	**21**
	Redigobius macrostoma	Largemouth goby	148	303	209	153	**813**
	Gobiopterus semivestitus	Transparent goby	34	221	136	278	**667**
	Acanthogobius flavimanus	Oriental goby	2	1	0	264	**267**
	Mugilogobius stigmaticus	Goby	0	7	4	0	**11**
	—	Unidentified gobies	11	1	3	0	**15**
Eleotridae	*Philyponodon grandiceps*	Flathead gudgeon	1	2	0	0	**3**
	Philyponodon sp.	Dwarf Flathead gudgeon	1	0	0	0	**1**
Bothidae	*Pseudorhombus jenynsii*	Small-tooth flounder*	1	0	0	0	**1**
	Pseudorhombus arsius	Large-tooth flounder*	2	3	0	0	**5**
Monacanthidae	*Monacanthus chinensis*	Fan-bellied leatherjacket	1	0	0	0	**1**
Tetraodontidae	—	Unidentified toad fish	1	0	0	0	**1**
Total Abundance			**3846**	**5706**	**4556**	**3131**	**17239**
Number of Species			**20**	**19**	**14**	**13**	**25**
CRUSTACEANS							
Penaidae	*Penaeus plebejus*	Eastern King prawn*	267	54	89	175	**585**
	Penaeus esculentus	Tiger prawn*	2	0	0	0	**2**
	Metapenaeus macleayi	NSW school prawn*	68	38	42	55	**203**
	Metapenaeus cf. endeavouri	Endeavour prawn*	1	2	0	0	**3**
	—	Unidentified Penaeidae	1	0	2	0	**3**
Sergestidae		Sergestid prawn	234	0	1194	118	**1456**
Hippolytidae		Carid shrimp	25	0	26	2	**53**
Alpheidae		Alpheid shrimp	21	0	18	12	**51**
Mysidae		Mysid shrimp	29	0	50	1971	**2050**
Total Abundance			**648**	**94**	**1331**	**2333**	**4406**
Number of Species			**9**	**3**	**7**	**6**	**9**

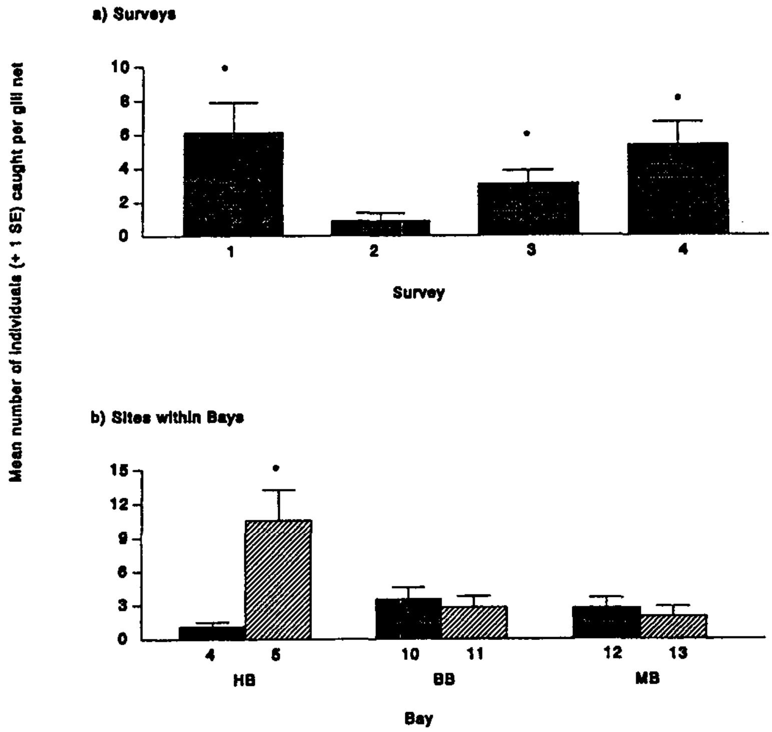

Figure 13. Abundance of yellowfin bream collected by gill netting from mudflats in Homebush Bay (HB), Brays Bay (BB) and Majors Bay (MB). a) Abundance during each survey (bays and sites (bays) pooled, n=18). b) Abundance at each site within bays (surveys pooled, n=12). Asterisks indicate abundance per survey or site within location was greater than survey, or other site within the the bay without an asterisk. See Fig. 4 for position of sites.

4.2.2 Comparison of Homebush Bay with External References

A comparison of the assemblages sampled by gill nets on mud flats in three bays indicated that during the study the fish assemblages of one habitat in Homebush Bay were similar to the assemblages occurring in the same habitat in other nearby bays.

Analyses of various species also indicated that abundances among bays tended to be statistically similar, although significant variation through time and at smaller spatial scales (e.g. between sites) occurred. For example, the abundance of yellowfin bream was significantly less in Survey 2 than at all other times, averaged across all bays (Figure 13a). In comparing sites within each bay, there was no significant difference between sites in Brays Bay or Majors Bay, but there was a large difference between Sites G5 and G4 in Homebush Bay (Figure 13b). In fact, G5 appeared to have much greater numbers of yellowfin bream, on average, than any of the other sites on mud flats that were sampled.

Total abundance of fish sampled on mud flats also varied through time inconsistently between sites. Overall, however, the total abundance of fish in Homebush Bay was quite similar to the external references and showed similar patterns of variation through time (Figure 14). The number of species of fish varied significantly through time, with fewer species collected per sample during Survey 1 (Figure 15).

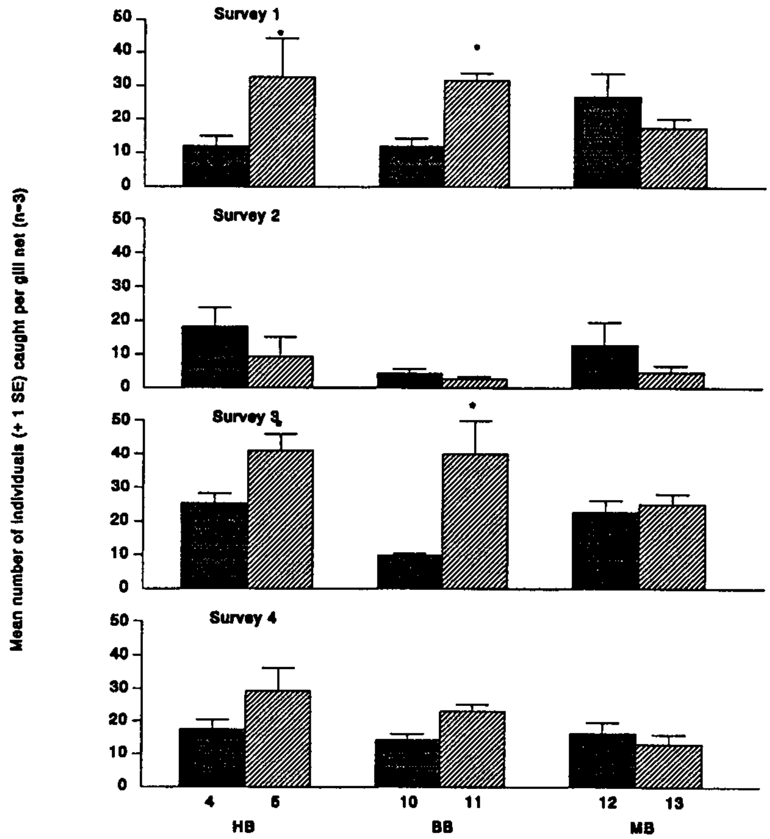

Figure 14. Total abundance of fish on mud flats collected by gill netting at sites within Homebush Bay (HB), Brays Bay (BB) and Majors Bay (MB). Asterisks indicate abundance per survey or site within location was greater than survey, or other site within the the bay without an asterisk. See Fig. 4 for position of sites.

The abundance of blue swimmer crabs and mud crabs varied between sites inconsistently through time. Comparing surveys at each site, no differences in abundance through time were detected in Homebush Bay or at sites G10 and G12, in Brays Bay and Majors Bay, respectively. At Site G11 (Brays Bay) more crabs were collected, on average, in Survey 4 than at other times and at G13 (Majors Bay), more were collected during Surveys 1 and 4 than Surveys 2 and 3. Comparing sites during each survey, G4 and G5 (Homebush Bay) were statistically equal throughout the study (Figure 16). In Brays Bay, Site G11 had significantly more crabs than G10 in Survey 4, while in Majors Bay G13 had more crabs than G12 during Surveys 1 and 4.

4.3 Beam Trawl Samples in Bay and Creek Habitat

4.3.1 Comparison of Habitats Within Homebush Bay

Assemblages of fish and crustaceans varied among locations within Homebush Bay during each survey. The relationship between assemblages from different locations was not constant, but varied among surveys. Also, several species of gobies were generally the most common discriminators of assemblages. In particular, the Swan River goby was an important discriminator in nearly all comparisons made, with other species, including several species of gobies and the king prawn, also frequent discriminators of assemblages

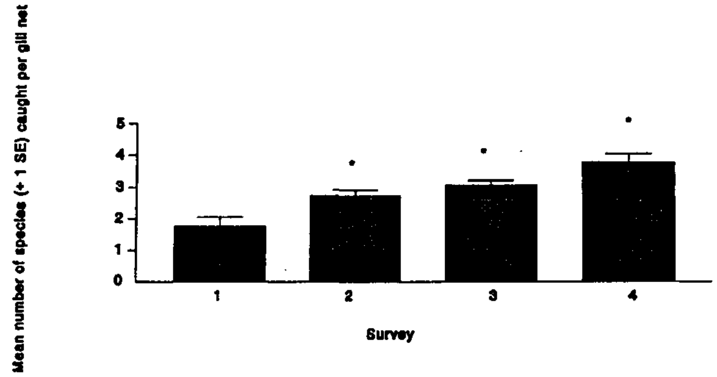

Figure 15. Total number of species of fish collected by gill netting on mud flats at sites within Homebush Bay (HB), Brays Bay (BB) and Majors Bay (MB) for the four surveys (bays and sites (bays) pooled, n=18). Asterisks indicate abundance per survey or site within location was greater than survey, or other site within that bay without an asterisk. See Fig. 4 for position of sites.

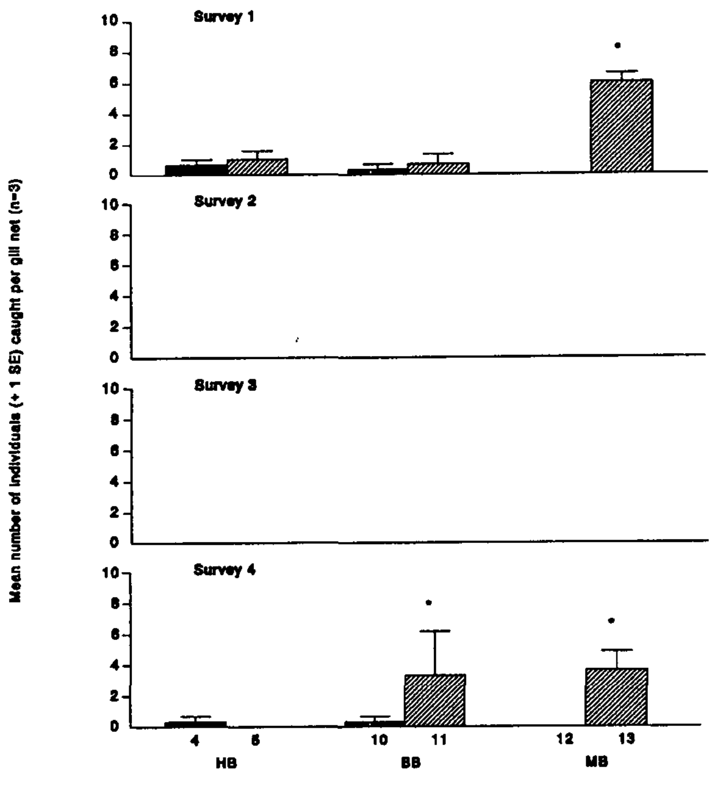

Figure 16. Total abundance of blue swimmer crabs and mud crabs collected by gill netting on mud flats at sites within Homebush Bay (HB), Brays Bay (BB) and Majors Bay (MB) for the four surveys (bays and sites (bays) pooled, n=18). Asterisks indicate abundance per survey or site within location was greater than survey, or other site within that bay without an asterisk. See Fig. 4 for position of sites.

An examination of the numbers of species of individuals sampled by the beam trawl indicated that variation for most of the variables occurred at relatively small spatial scales, rather than among locations, and that variation was often inconsistent between sites within locations through time.

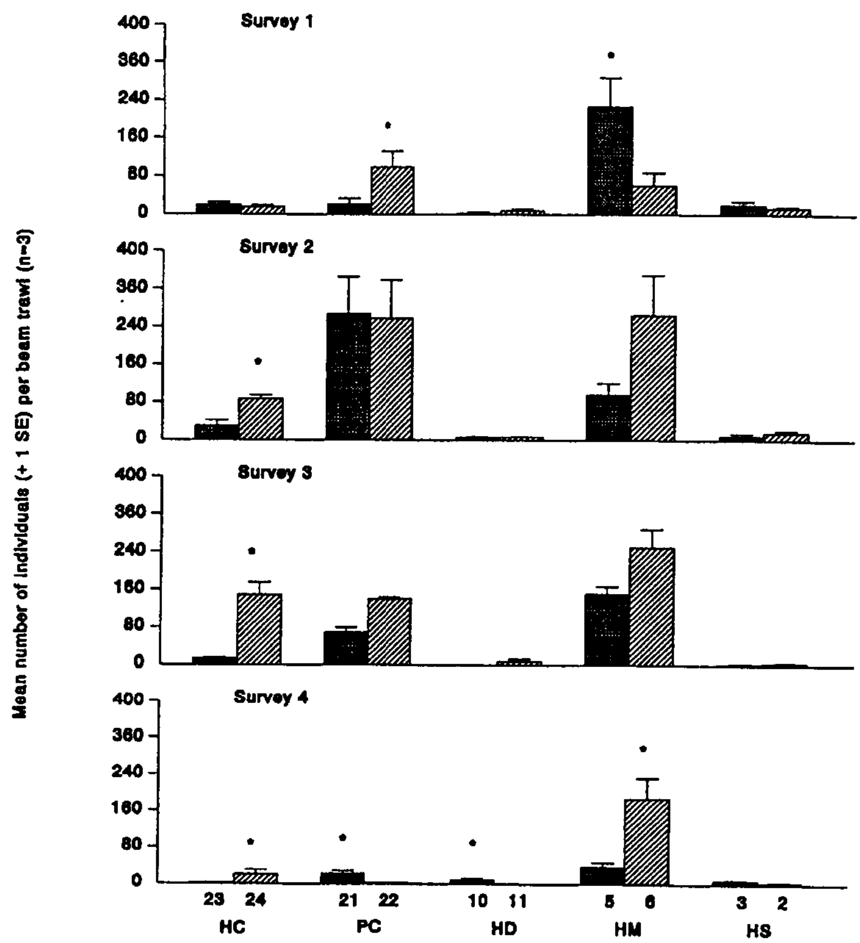

Figure 17. Abundance of Swan River goby collected by beam trawling at sites within Homebush Bay. HC= Haslams Creek, PC= Powells Creek, HD= navigation channel, HM= mud flat adjacent to mangroves, HS= mud flat adjacent to seawall. See Fig. 5 for position of sites. Asterisks indicate statistically significantly more fish at one site than the other within that location.

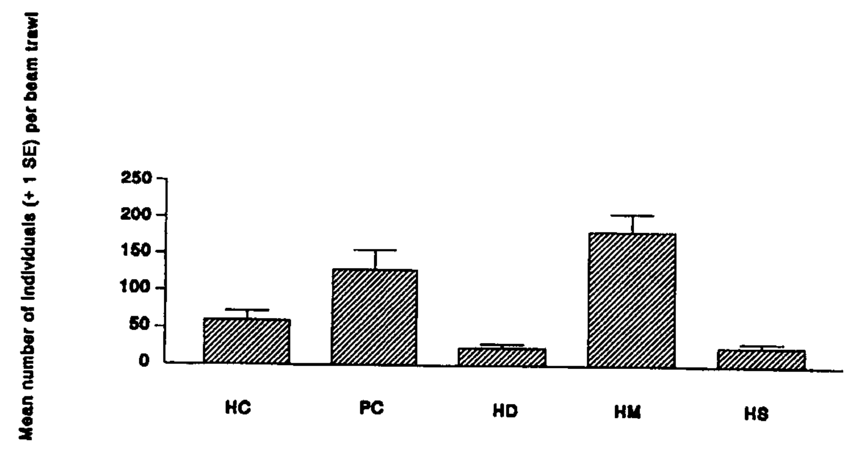

Figure 18. Total abundance of fish collected by beam trawling at locations within Homebush Bay (n=24). HC= Haslams Creek, PC= Powells Creek, HD= navigation channel, HM= mud flat adjacent to mangroves, HS= mud flat adjacent to seawall. See Fig. 5 for position of sites.

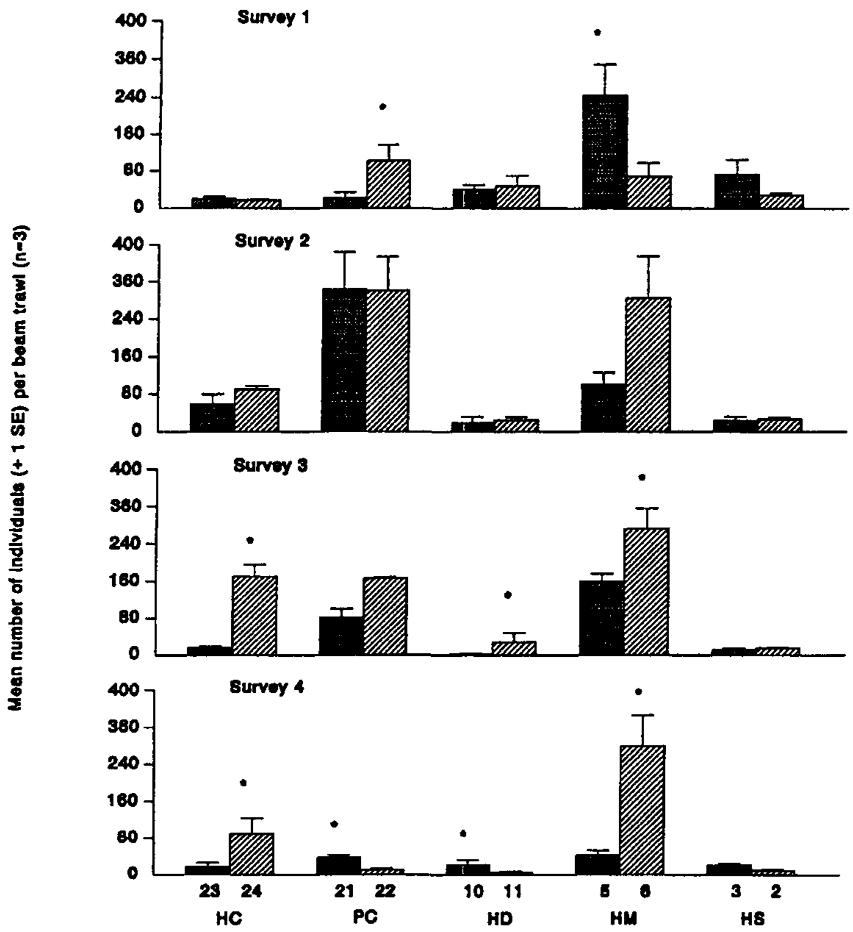

Figure 19. Total abundance of fish collected by beam trawling at sites within Homebush Bay. HC= Haslams Creek, PC= Powells Creek, HD= navigation channel, HM= mud flat adjacent to mangroves, HS= mud flat adjacent to seawall. See Fig. 5 for position of sites. Asterisks indicate statistically significantly more fish at one site than the other within that location.

One example is the Swan River goby, which showed consistent variation among locations, but varied inconsistently between sites within locations through time. Comparing locations over all times, this goby tended to be most abundant on mud flats adjacent to mangroves and in Powells Creek, least abundant in the channel and on mud flats adjacent to seawall, with Haslams Creek being intermediate between the two groups. There were significant differences in the abundance of Swan River goby between sites within locations during every survey (Figure 17). In Survey 1, there were differences between sites in Powells Creek and on the mud flats adjacent to mangroves. In Surveys 2 and 3 there were significant differences between sites in Haslams Creek and in Survey 4 there were differences between sites at all locations except on mud flats adjacent to seawalls (Figure 17).

The total abundance of fish sampled by beam trawl varied consistently among locations but inconsistently between sites within locations. There was trend for more fish to occur on mud flats adjacent to mangroves than in the navigation channel (Figure 18). At the smaller spatial scale, total abundance of fish varied at very site, except B2. Variation was inconsistent between sites, for example, on mud flats adjacent to mangroves there was a trend for more fish to be present during Survey 1 than Survey 4 (B5), at the other site (B6), there were fewer fish present in

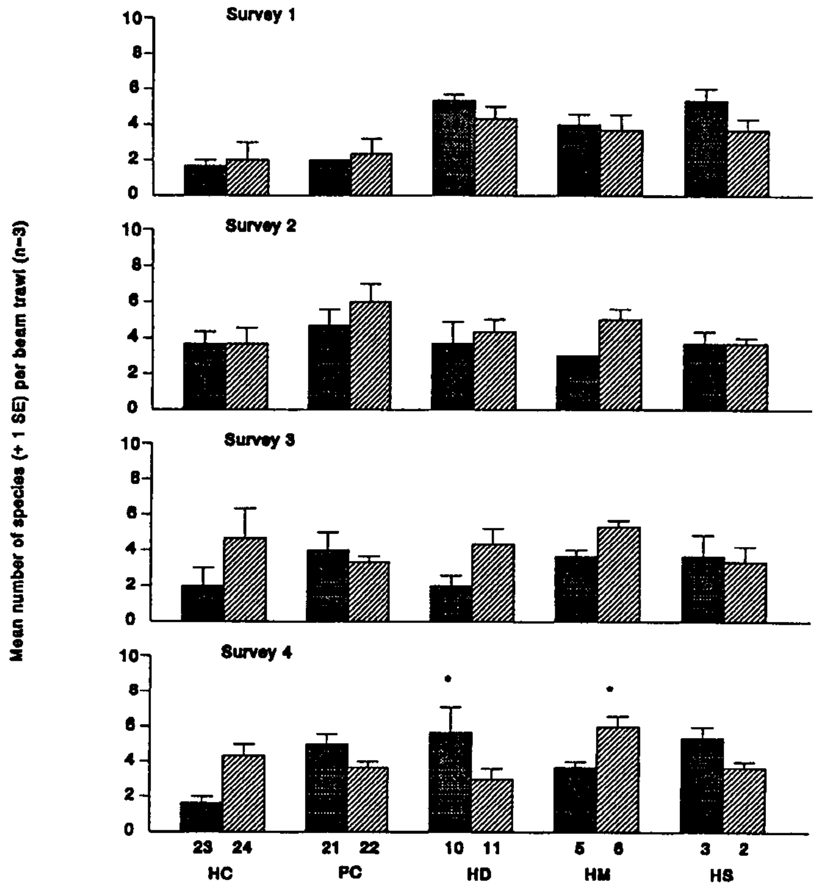

Figure 20. Total number of species of fish collected by beam trawling at sites within Homebush Bay. HC= Haslams Creek, PC= Powells Creek, HD= navigation channel, HM= mud flat adjacent to mangroves, HS= mud flat adjacent to seawall. See Fig. 5 for position of sites. Asterisks indicate statistically significantly more fish at one site than the other within that location.

Survey 1 than at all other times. Comparing sites during each survey, significant differences between some sites within locations occurred in Surveys 1, 3 and 4 (Figure 19). During Survey 1, more fish were collected from B22 than B21, in Powells Creek. During Survey 3, there were more at B24 than B23, in Haslams Creek and more fish occurred at B11 than B10, in the navigation channel (Figure 19).

The number of species of fish varied through time only at B21 (Powells Creek), where there was a trend for more species to occur in Surveys 2 and 4 than in Survey 1; and at B10 (navigation channel), where there was a trend for more species during Surveys 1 and 4 than in Survey 3. Comparing sites within locations at each time, more species were recorded at B10 than B11 (channel) and at B6 than B5 (mud flats adjacent to mangroves) during Survey 4 (Figure 20). No other comparisons were significant.

The abundance of king prawns varied significantly through time at three sites. At B5 (mud flat adjacent to mangroves) more king prawns were collected during Survey 4 than at other times. At B2 (mud flat adjacent to seawall), more were collected during Survey 1 than at other times. At B24 (Haslams Creek), more were collected in Survey 3 than at other times. Comparing sites within locations during each survey, significant variation was detected only in Surveys 3 and 4

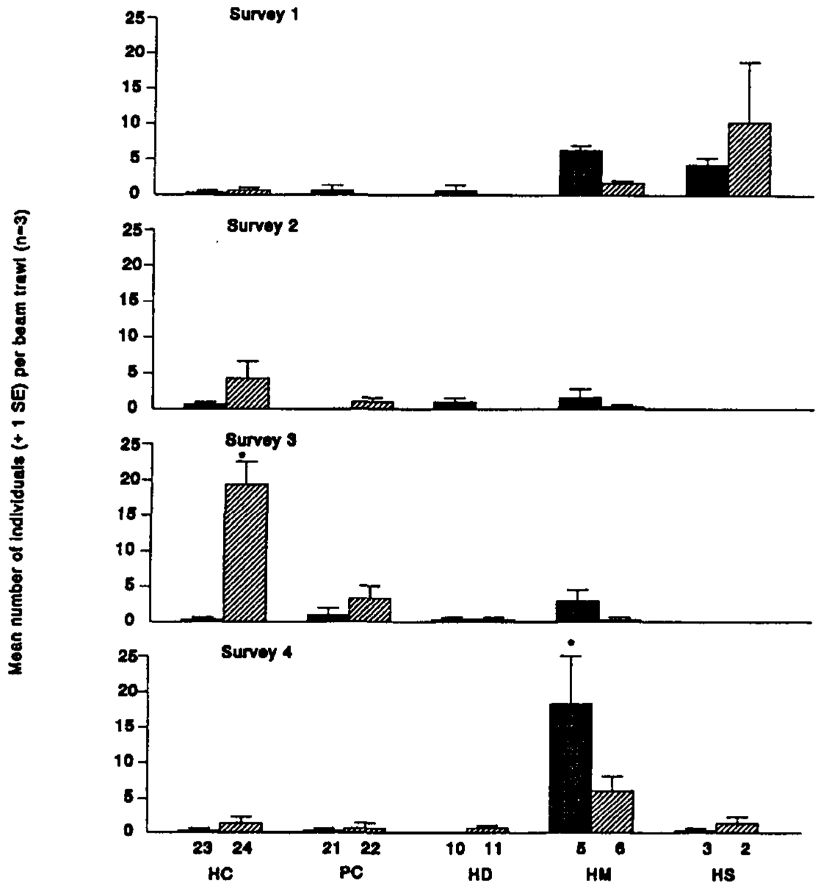

Figure 21. Abundance of eastern king prawns collected by beam trawling at sites within Homebush Bay. HC= Haslams Creek, PC= Powells Creek, HD= navigation channel, HM= mud flat adjacent to mangroves, HS= mud flat adjacent to seawall. See Fig. 5 for position of sites. Asterisks indicate statistically significantly more fish at one site than the other within that location.

(Figure 21). In Survey 3, more king prawns occurred at B24 than B23 (Haslams Creek) and in Survey 4, more occurred at B5 than B6 (mud flats adjacent to mangroves).

4.3.2 Comparison of Homebush Bay with External References

The assemblage of fish and crustaceans sampled on mud flats in Homebush Bay was, essentially, similar to those in the external references. During Survey 4 there was some indication that the assemblages on flats adjacent to mangroves in Homebush Bay were dissimilar to assemblages sampled elsewhere, due mainly to several species of gobies.

Analyses of species and individuals suggested little variation among bays; most variation occurred at the smaller spatial scales of locations within bays and sites within locations and bays. As an example, the Swan River goby varied among sites, but inconsistently through time. There were differences between sites within locations during Surveys 1, 2 and 4 (Figure 22). In Survey 1, differences occurred between sites on flats adjacent to mangroves in Homebush Bay and on flats adjacent to seawall in Majors Bay. In Survey 2 there were differences between sites adjacent

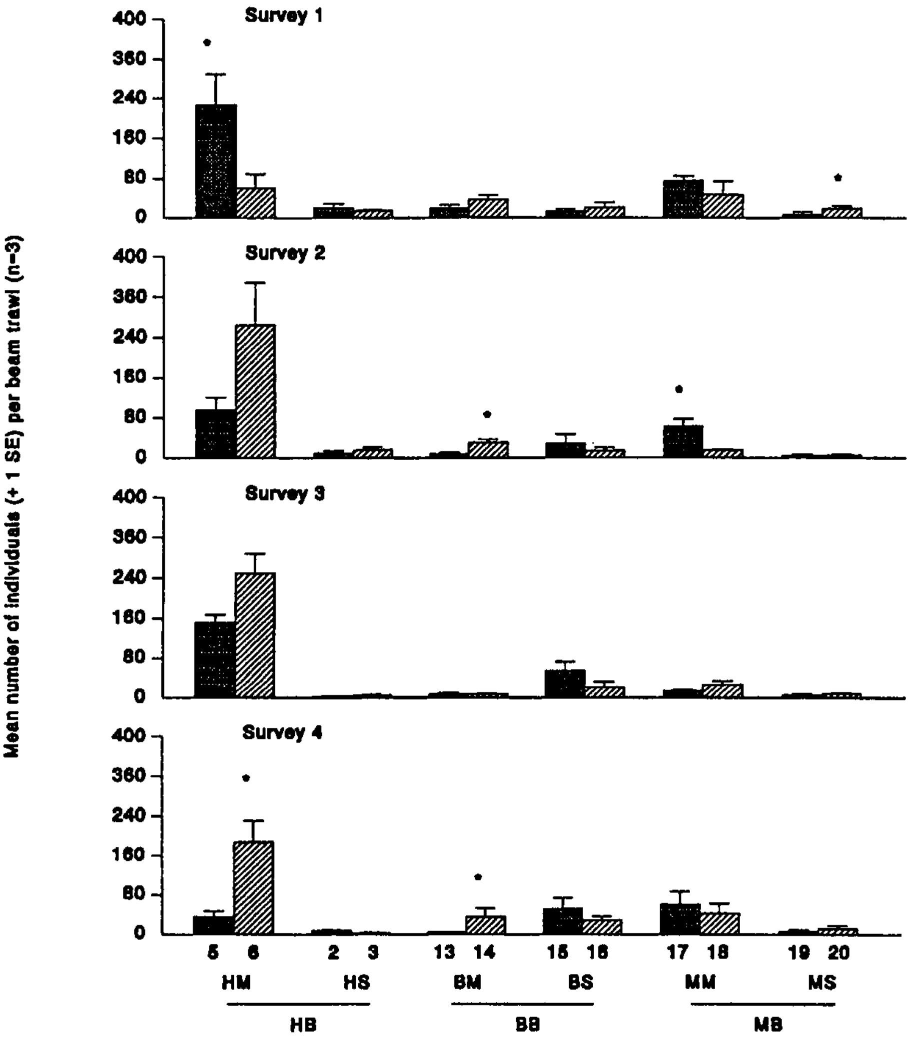

Figure 22. Abundance of Swan River goby collected by beam trawl on mudflats within Homebush Bay (HB), Brays Bay (BB) and Majors Bay (MB). Locations HM, BM and MM were adjacent to mangroves; HS, BS and MS were adjacent to seawalls. See Fig. 5 for position of sites. Asterisks indicate statistically significantly more fish at one site than the other within that location.

to mangroves in Brays Bay and in Majors Bay. In Survey 4, there were differences between sites adjacent to mangroves in Homebush Bay and Brays Bay.

Analysis of total abundance of fish showed significant differences among sites that were inconsistent through time. Examining variation through time at each site, there were only 2 sites, both on the mud flat adjacent to mangroves in Homebush Bay, that varied significantly through time. At Site B5, there was a trend to greater abundance in Survey 1 compared to Survey 4. At B6, however, there were fewer fish sampled in Survey 1 than at any other time. Comparing sites during each survey, there were significant differences between sites within at least one location during every survey (Figure 23). In Surveys 1 and 4 there was a significant difference between sites adjacent to mangroves in Homebush Bay. In Surveys 1 and 2 there was a significant difference between sites adjacent to seawalls in Brays Bay. In Survey 3, the difference between sites was at the location adjacent to seawalls in Majors Bay.

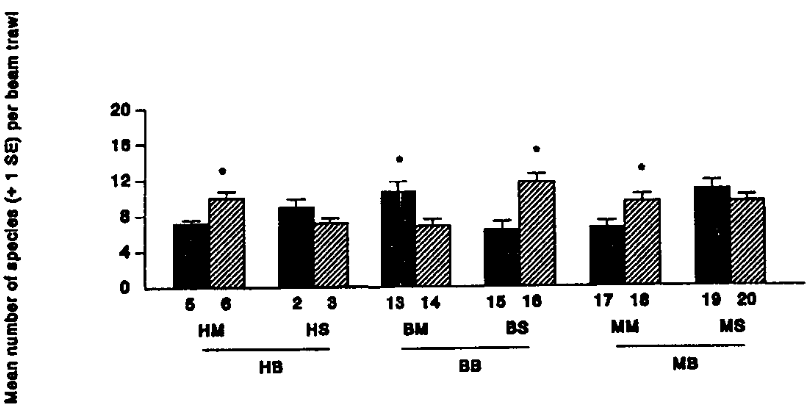

Figure 23. Number of fish collected by beam trawl on mudflats at sites within Homebush Bay (HB), Brays Bay (BB) and Majors Bay (MB) over all surveys (n=12). Locations HM, BM and MM were adjacent to mangroves; HS, BS and MS were adjacent to seawalls. See Fig. 5 for position of sites. Asterisks indicate statistically significantly more fish at one site than the other within that location.

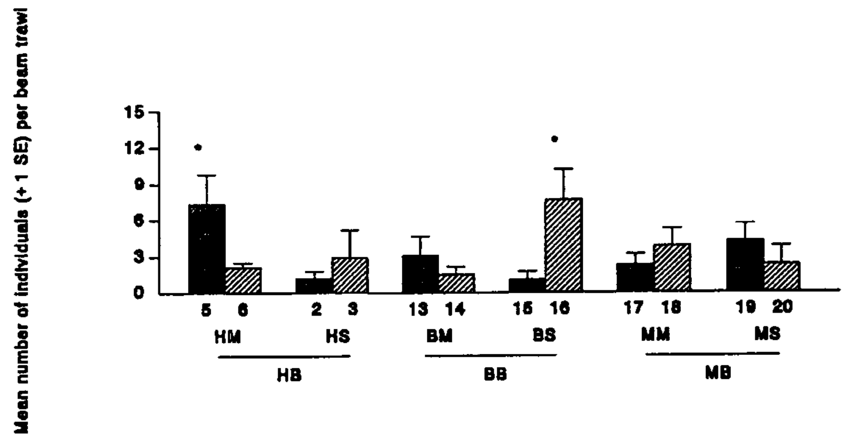

Figure 24. Abundance of Eastern King prawns collected by beam trawl on mudflats at each site Homebush Bay (HB), Brays Bay (BB) and Majors Bay (MB). Locations HM, BM and MM were adjacent to mangroves; HS, BS and MS were adjacent to seawalls. See Fig. 5 for position of sites. Asterisks indicate statistically significantly more fish at one site than the other within that location. Locations and bays for all surveys (n=12).

The number of species of fish sampled by beam trawl varied consistently between sites during the study. Significant differences between sites occurred on mud flats adjacent to mangroves in all bays and there was a significant difference in the number of species collected on flats adjacent to seawalls in Brays Bay (Figure 24).

The abundance of king prawns varied consistently between sites within locations and bays, but inconsistently through time at the larger spatial scale of between locations within bays. Significant differences in the abundance of king prawns occurred between sites at 2 locations, mud flats adjacent to mangroves in Homebush Bay and flats adjacent to seawall in Brays Bay (Figure 25).

Table 5 **Lengths(mm) of fish (LFC) and crabs (caraspace width) of economic value. Life history definition based on SPCC (1981b), SJ = small juvenile, LJ + large juvenile, AD = adult; n = number of fish or crabs measured throughout the study.**

Species	Common name	Life History definition (mm)			Homebush Bay Study					
					n	Length	Mean (se)	Percentage of total measured		
		SJ	LJ	AD		Range	Total Sample	SJ	LJ	AD
FISH										
Herklotsichthys castelenaui	Southern herring	–	–	>150	1	170	170	0	0	100
Engraulis australis	Anchovy	–	–	>155	2	68–88	78.00 (10.00)	0	0	100
Platycephalus fuscus	Dusky flathead	<125	125–324	>324	86	27–559	283.95(17.61)	30.2	16.3	53.5
Pseudocaranx dentex	Trevally	<145	145–284	>284	1	330	330	0	0	100
Sillago ciliata	Sand whiting	<145	145–244	>244	25	176–353	310.64(7.79)	0	8	92
Pomatomus saltatrix	Tailor	<105	105–244	>244	25	91–289	147.40(9.46)	12	80	8
Trachurus novaezelandiae	Yellowtail	–	–	>205	1	155	155	0	100**	0
Acanthopagrus australis	Yellowfin bream	<105	105–204	>204	543	11–350	216.91(1.75)	0.7	55.8	43.4
Gerres subfasciatus	Silver biddy	<65	65–124	>124	61	14–179	109.89(5.89	18	31.1	50.8
Girella tricuspidata	Luderick	<145	145–284	>284	4	201–337	261.75(33.66)	0	50	50
Mugil cephalus	Sea mullet	<230	230–300	>300	1049	152–418	301.46(0.98	2.3	43.5	54.1
Liza argentea	Flat-tail mullet	<164	164–204	>204	187	290.55	(1.69)	0	0.5)	99.5
Pseudorhombus jenynsii	Small-tooth flounder	–	–	>210*	3	31–164	116.00(73.82)	33.3**	66.6**	0
Pseudorhombus arsius	Large-tooth flounder	<105	105–205	>205*	5	52–89	72.80(15.58)	100	0	0
Monacanthus chinensis	Fan-belly leatherjacket	–	–	>150	1	40	40	100**		
CRABS										
Scylla serrata	Mud crab	–	–	–	10	70–210	119.90(45.60)	–	–	–
Portunus pelagicus	Blue swimmer crab	–	–	–	58	84–168	123.93(2.82)	–	–	–

** average of males and females*
*** approximate life history class*

4.4 Length Frequency Distributions of Fish and Crabs of Economic Value

Most of the fish sampled were either large juveniles or adults (Table 5). This finding should be interpreted cautiously, however, as the sampling procedures were probably biased towards the large size classes of many of the fish collected. Length frequency distributions were plotted for the most abundant species (Volume II); the yellowfin bream is used as an example here.

Yellowfin bream were sufficiently abundant to plot length frequency distributions for each survey (all locations and bays combined), for each habitat within Homebush Bay (surveys combined) and for the mud flat habitats in each bay (surveys combined). Overall, most of the fish sampled were considered to be large juveniles or adults, with a very small proportion of small juveniles, which were collected in the beam trawl (Table 5). An inspection of the length frequency plots suggested several trends in sizes. Comparing surveys, length frequency distributions in Surveys 1 and 4 tended to be relatively similar; a smaller number of much larger fish were sampled in Survey 2 and fish slightly larger than those taken in Survey 1 and 4 tended to occur in Survey 3 (Figure 26).

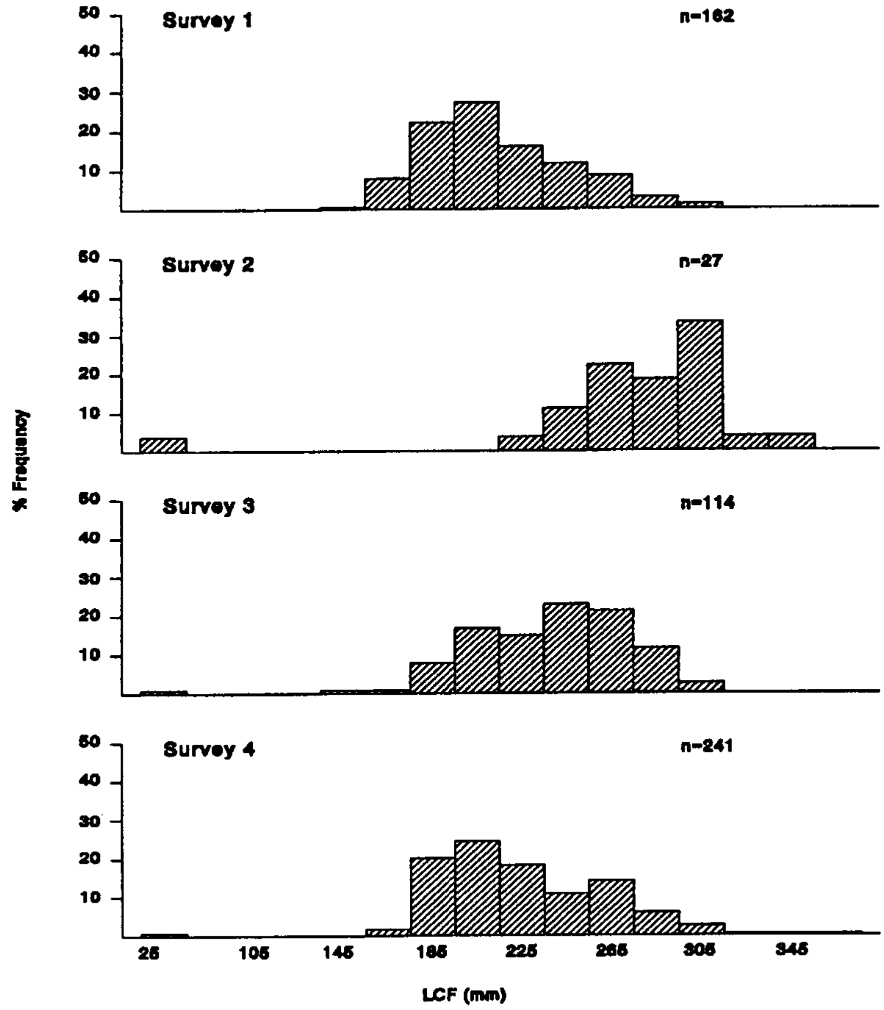

Figure 25. Length frequency distribution of yellowfin bream collected by gill netting and beam trawlling for each survey. All sites pooled.

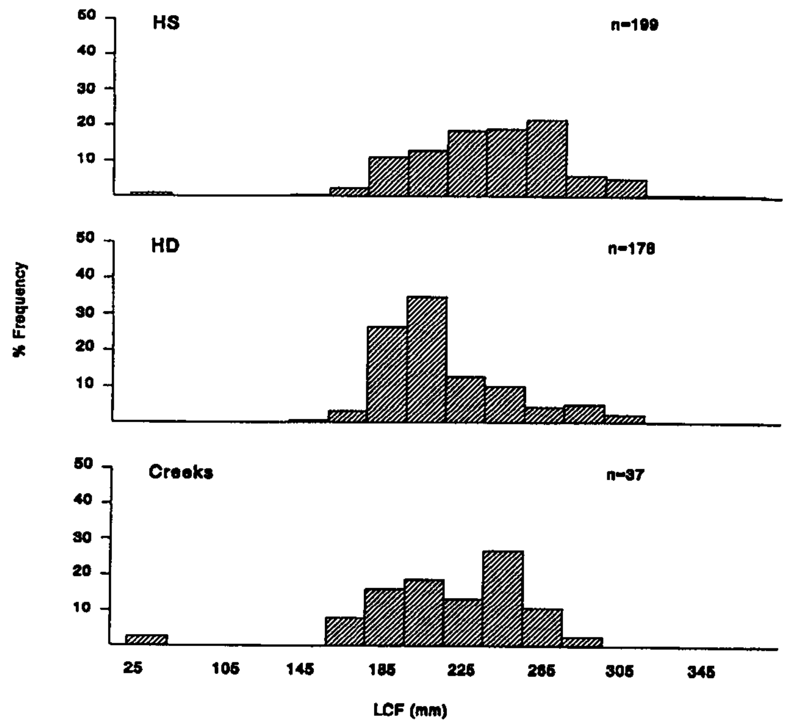

Figure 26. Length frequency distribution of yellowfin bream collected by gill netting and beam trawlling at sites within Homebush Bay. HS= mudflats, HD= navigation channel, Creeks= Haslams and Powells Creeks pooled. All surveys pooled.

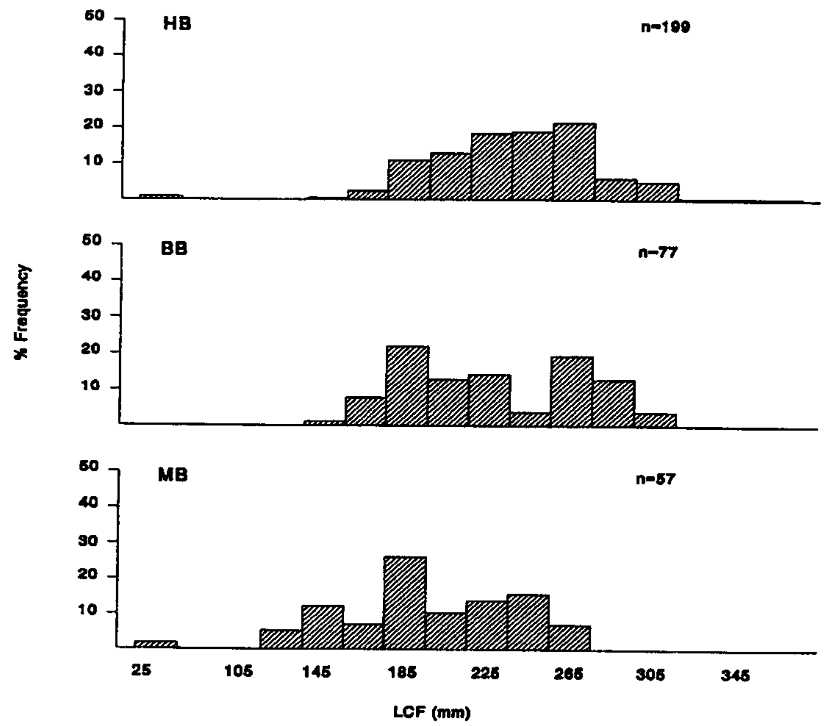

Figure 27. Length frequency distribution of yellowfin bream collected by gill netting and beam trawlling at sites at mudflats within Homebush Bay (HB), Brays Bay (BB) and Majors Bay (MB). All surveys pooled.

Table 6 Fish recorded in Homebush wetland.

Site[1]	Sampling method[2]	Species	Common name	Number recorded[3]	Size of species of economic value (LCF, mm)	
					range	mean
1	vis	–		0	–	–
2	gn	*Mugil cephalus*	Sea mullet	4	358–395	370.8(8.5)
	bs	*Pseudomugil signifer*	Blue eye	14	–	–
	bs	*Mugil cephalus (?)*	Sea mullet	6	<20	–
	bs	*Acanthogobius flavimanus*	Oriental goby	1	–	–
	bs	*Pseudogobius olorum*	Swan River goby	29	–	–
	bt	*Pseudogobius olorum*	Swan River goby	9	–	–
3	vis	–		0	–	–
4	vis	*Pseudomugil signifer/Gambusia affinis*	Blue eye/Mosquito fish	A	–	–
5	dn	*Pseudomugil signifer*	Blue eye	25	–	–
	vis	*Anguilla sp.*	Eel	3	–	–
6	dn	*Pseudomugil signifer*	Blue eye	15	–	–
	vs	Mugilidae	Mullet	A	–	–
7	vis	–		0	–	–
8	vis	*Pseudomugil signifer*	Blue eye	A	–	–
	vis	*Gambusia affinis*	Mosquito fish	A	–	–
9	vis	–		0	–	–
10	gn	*Mugil cephalus*	Sea mullet	34	256–394	339.8(5.5)
11	vis	–		0	–	–

[1] *See fig. 5 for site positions*
[2] *Vis = visual observation, gn = gill net, bs = beach seine, bt = beam trawl, dn = dip net.*
[3] A = *Abundant*

Comparing habitats within Homebush Bay, yellowfin bream of a relatively smaller size tended to occur in the navigation channel compared to the mud flats over the study (Figure 27). A few fish were collected from the creeks, but these tended to be of a similar size to those taken from the other habitats. A few small juveniles were collected in the creeks and over the mud flats; none occurred in the samples from the channel (Figure 27).

Comparing bays, small juveniles were collected from Homebush Bay and Majors Bay, but the numbers were too small to interpret meaningfully (Figure 28). The sizes of yellowfin bream collected in Homebush Bay and Brays Bay were relatively similar and these tended to be larger than those from Majors Bay.

4.5 WETLAND HABITATS

4.5.1 Homebush Bay Wetlands

Six species of fish were collected from the Homebush Bay wetlands from October to December 1993 (Table 6, Figure 6). A site-by-site description follows.

Site 1. Drainage Canal — 2SM pondage to Parramatta River.

This canal runs alongside Bennelong Road. Its efflux is a concrete pipe through an embankment into the Parramatta River. At this end the canal is quite narrow, the water being 1 m or less across and about 10–30 cm deep. The canal contains many mangrove seedlings and a few mature trees.

The canal broadens to the south. It is about 5–7 m wide, with water 2–3 m wide, approximately 200 m south of efflux, at the electricity substation. At this point it is lined by casuarinas. The canal continues at about this width until it reaches the 2SM tower, where it ends. From the electricity substation to this point there are very few mangroves, but bullrushes are common. This area was not considered to be a significant habitat for fish and no fish were observed there.

Site 2. Northern 2SM Radio tower

There is a large, tidal lagoon around the base of the radio tower. During sampling a thick algal growth covered approximately 5% of the water surface. Mangroves surrounding the lagoon included both large, mature *Avicennia marina* and seedlings. Water depth in the lagoon seemed to be quite shallow (<1 m), although soft sediments prevented wading to middle of the lagoon to confirm this. Sediments were anoxic, being black and having a hydrogen sulphide odour.

Tracks to the radio mast divide the lagoon into two basins. Channels and pipes through the radio mast access roads allow the movement of water between the two sections. Most water movement appears to be via the channels in the western track. Tidal flow is via a small canal (15–20 m wide) linked with Haslams Creek. This canal has a strong tidal flow, particularly where it narrows. A second culvert to Haslams Creek was found, but its end was blocked by a hinged cap at the end closest to Haslams Creek and it appeared that little, if any, water flowed through this pipe.

Fish were observed around the radio mast, including small unidentified species of mullet, blue-eye, gobies and schools of very small (5 mm long), unidentified fish. Gill netting yielded 4 sea mullet, while beam trawling and seining yielded blue eye, Swan River goby and oriental goby.

Apparently good tidal exchange, a dense surrounding growth of mangroves and the large number of fish seen suggest that this lagoon provides suitable habitat for fish.

Site 3. 2KY Lagoon

Further south, alongside the 2KY radio mast, is a small (30 m), shallow (about 30 cm deep) lagoon surrounded by mangroves. This lagoon appears to be fed by flow from Haslams Creek through a grove of mangroves to the east. Some small unidentified fish (possibly mosquito fish and/or blue eye) were seen near the culvert to Haslams Creek. There is virtually no permanent water within the mangrove stand and it is likely that saltwater only enters the lagoon at extreme high tides. As the lagoon is small and the mangrove forest becomes almost dry, habitat for fish is very limited.

Site 4. Pond near PWD Stone Works, Bennelong Road

This appears to be freshwater, with no visible link to tidal areas. Banks are vegetated by willows, an unidentified species of trees and bullrushes. The northern end has a very dense growth of rushes. Many small fish and several freshwater eels (50 cm to 1 m long) were seen. Blue eye were collected by dip net from this site (Table 6). This pond appears to provide suitable habitat for freshwater and brackish water fish.

Site 5. Bicentennial Park Lake

This is an artificial freshwater lake. It has dense beds of bullrushes along much of its shoreline. The lake is fed by a creek which has undergone major works during construction works. A small artificial pondage has been created below some playing fields; above this the creek is very small, had black water during our visit and, thus, appeared to be very polluted. Dip-netting around the bullrushes in the pond yielded only a few aquatic insects but no fish.

The overflow from Bicentennial Park Lake enters Powells Creek via a tidal creek. About 200 m from the lake an elevated pipe under a road prevents tidal penetration. Powells Creek is about 400 m from this point. For a distance of approximately 100 m downstream the creek is lined by casuarinas and becomes dry at low tide. Schools of blue eye and mullet were observed in a pool below the pipe, isolated by the falling tide. A footbridge marks the beginning of the mangroves in the creek and permanent water which joins Powells Creek. The tidal section of the creek provides suitable habitat for juveniles of estuarine species, such as mullet.

Site 6. Waterbird Refuge

This large shallow water body appears to have very poor, if any, tidal exchange with Powells Creek. The refuge receives stormwater runoff from Bennelong Road. Few mangroves grow around the margins and several dead trees are present. The water depth ranges from 30-50 cm. The substratum is composed of very soft, anoxic sediments, in places greater than 1 m deep. Algal mats cover the surface of the water. No fish were observed and the area appeared to be poor fish habitat.

Site 7. Western Lagoon, Bicentennial Park

This lagoon appears to be mostly freshwater. It is separated from the main forest of mangroves by a raised pathway along its eastern margin. No culverts were found to connect it with estuarine areas. Stormwater from Bennelong Road appears to drain to this area.

The lagoon is quite shallow, about 30 cm deep, and has algal mats on the water surface. Mangroves are dotted throughout the lagoon and small fish, probably including blue eye and mosquito fish, were numerous. This area provides habitat suitable for fish.

Site 8. Eastern Lagoon, Bicentennial Park

This is a shallow (approximately 30 cm deep) body of water with thick algal growth on surface. The lagoon has many dead tree stumps standing within it and the bottom is littered with fallen branches, which could provide shelter for fish. Water exchange is via a culvert which seems to be well above the low tide level, thus water may only enter near top of tide. Tidal flow to this area may be insufficient to make this suitable habitat for fish. No fish were observed.

Site 9. Embayment off Homebush Bay

This area is connected to Homebush Bay by a short channel about 15 m wide. The area provides suitable habitat for fish; as it appears to have good tidal exchange and mangroves dotted across the mudflats. Many fish, probably mullet, were observed. Depth could not to be measured, but it appears that it would be sufficient to allow boat access, at least at high tide. Sampling by gill nets yielded sea mullet (Table 6). These were of a similar size range to the mullet sampled in the bay and creek habitats of Homebush Bay (*cf.* Table 5)

Site 10. Mason Park

This area consisted mostly of saltmarsh and contained very little standing water. We observed no channels or relatively permanent pools that could provide habitat for fish.

In conclusion, the most significant wetlands, in terms of estuarine fish habitat, were sites 2 and 9. Sites 6 (Waterbird Refuge) and 8 may be improved as habitat for fish by increasing tidal exchange. Sites 4 and 7 both provide suitable freshwater habitat for fish, however, without sampling similar areas outside Homebush Bay, their relative importance is unknown.

4.5.2 Newington Wetland

Sampling in the Newington wetland yielded only mosquito fish. These were collected by dip net from freshwater drainage channels leading into the wetland and from a large pond in the north eastern end of the wetland, where there are numerous dead mangroves interspersed with live trees. During the site inspections, the only exchange of estuarine water with the Parramatta River was via small pipes at the main tidal floodgate (Figure 6). This is likely to limit severely the amount of water entering the wetland and the movement of fish in and out of the wetland. We thus concluded that at the time of sampling the wetland provided a very poor fish habitat.

5 Discussion

5.1 Fish Habitats and Fish of Homebush Bay

The present study is one of three major studies done on the fish of Sydney Harbour. The other two were generally restricted to the main channel of the estuary (Henry 1984, Paxton *et al.* in prep.) thus, the information available on bays in the upper estuary prior to this study was very limited. The assemblage of fish occurring in Homebush Bay and the external references used compares quite favourably with other studies done in similar habitats in the Sydney region. For example, SPCC (1981a) surveyed a mangrove creek (using rotenone poison) and two shallow mud habitats (using a beam trawl and gill nets) every two months for two years. In that survey, a total of 55 species of fish was recorded, with just over 14 000 individual fishes. Considering the three sites sampled alone, 19 species of fish and 1901 individuals came from Cooks River; 33 species and 1489 individuals came from Woollooware Bay; and 40 species and 10 652 individuals came from the mangrove creek (SPCC 1981a). In comparison, the present study recorded 39 species of fish in all (33 from Homebush Bay alone) and over 19 000 individuals from one year's sampling.

Moreover, many of the species common in the present study were also prevalent in the work reported in SPCC (1981a) for Botany Bay and in work done by The Ecology Lab in similar habitats in the Hawkesbury River (The Ecology Lab 1989a). One notable exception to this was *Pseudogobius olorum*, the most abundant species taken in our study. Only four individuals of this species were collected in Botany Bay during the entire study (SPCC 1981a). There is no obvious model to explain this difference, but note that The Ecology Lab has collected this species from numerous estuaries in recent years, including the lower reaches of Sydney Harbour (The Ecology Lab unpubl. data).

One interesting finding from the studies done in Botany Bay is that analyses of assemblages indicated that, of the many habitats sampled in the bay (e.g., mangrove creek, shallow mud, *Zostera* and *Posidonia* seagrass beds, shallow sand, deep sand and deep mud), the fish assemblages of the shallow mud and mangrove creek habitats were most similar to each other (SPCC 1981a). This similarity becomes more striking when it is considered that the mangrove creek in Botany Bay was adjacent to seagrass beds and was kilometres away from the shallow mud habitats sampled. It was speculated that the muddy substratum of the mangrove and shallow mud habitats was more a determinant of fish assemblages than the vegetative nature of the mangrove forest (i.e. mangrove roots and trunks) (SPCC 1981a).

In Homebush Bay, the mangrove creeks sampled were adjacent to the muddy habitats and it is therefore not surprising that many of the species of fish occurred both in the creeks and the bay habitats. Nevertheless, the multivariate analyses indicated that the assemblages of the creeks - sampled both by gill nets and beam trawl - were often distinctive compared to the bay habitats. Also, the univariate analyses indicated that the creeks often had fewer species of fish and fewer individuals. Without the use of external references for the creeks, it is not possible to determine whether the creeks entering Homebush Bay had fewer fish than we might expect for similar creeks in Sydney Harbour or the region. Perhaps comparable sampling in other parts of the harbour, such as the Lane Cove River or Middle Harbour (Figure 2) would provide suitable references.

During the study it was noted that the creeks, particularly Haslams Creek, showed the following evidence of pollution that would be likely to affect fish assemblages. The floor of the creeks had a large amount of gross pollution, as we found while sampling with the beam trawl. Large amounts of litter — cans, styrene foam, timber, glass, plastics, etc, were nearly always recovered in the beam trawl. In contrast, beam trawling adjacent to mangroves in the external references and outside the creeks in Homebush Bay generally yielded mostly mangrove detritus, such as leaves. Differences in the substratum due to gross pollutants may be an important determinant of the structure of fish assemblages within the creeks entering Homebush Bay.

Of the bay habitats, the mud flats generally had relatively large numbers of species of fish and individuals, throughout the study. It was also found that the sites sampled on mud flats near the entrance to Powells Creek often had large numbers of fish compared to other sites in Homebush Bay and compared to the reference bays. This was particularly evident for yellowfin bream.

The use of external references, although limited to the mud flat habitat, was valuable in providing a context against which the Homebush Bay data could be compared. Neither the gill net nor the beam trawl samples indicated differences at the spatial scale of bays; most variability occurred at smaller spatial scales, either between locations within bays (which were hundreds to thousands of metres apart) or sites within locations within bays (which were tens to hundreds of metres apart). Thus, on the basis of both the multivariate and univariate analyses, it is concluded that, for one habitat, the fish assemblages of Homebush Bay are similar to those in other bays in the upper part of the estuary.

Whilst the external references were useful in providing a geographical context for Homebush Bay, they will also be critical if fish assemblages are to be monitored following any modifications of Homebush Bay as part of the redevelopment of the area.

The investigations of the Homebush Bay and Newington wetlands indicated that fish assemblages in these areas were depauperate. In the Homebush Bay wetland a number of water bodies were sampled ranging from narrow tidal channels, to small lagoons (e.g. beneath the 2SM radio tower) to brackish and freshwater ponds. Only six species of fish were collected. Further sampling may have yielded a few more species, but, it is considered that many of the water bodies in the wetland are inadequately flushed and this severely limits their value as fish habitat, in terms of allowing access by fish and maintaining water quality and a supply of food.

The Newington wetland supported even fewer fish than the Homebush Bay wetlands. In fact, only one species of fish was collected, mosquito fish. Given that blue eye were collected in the Homebush Bay wetlands, it is possible that populations of this species also occur in the Newington wetland.

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The Ecology and Management of Shorebirds

The Ecology and Management of Shorebirds (Aves: Charadrii)

Dr Iain Taylor and edited by Dr Pat Hutchings
incorporating comments received by Drs Penny Berents, Richard Major, Graham Pyke
Harry Recher and Jeremy Thompson
The Australian Museum:
December 1994

SUMMARY

1. This study concerntrated on the ecology and management of shorebirds (*Aves: Charadrii*) in the wetlands of Homebush Bay. Eleven shorebird species were recorded. The study concentrated on the most abundant of these; black-winged stilt *Himantopus (himantopus) leuchocephalus*, curlew sandpiper *Charadrius ferruginea*, and bar-tailed godwit *Limosa (lapponica) baueri*. The distribution, abundance and diet of each species was determined. The abundance of invertebrate prey species was estimated. Relationships were examined between bird densities, food abundance and physical attributes of habitat, such as water depths and tidal exposure periods. Recommendations for the management of the area for shore birds are given.
2. Two main shorebird habitat types occurred in the study area; shallow, saline lagoons at Bicentennial Park, Mason Park and the Newington Naval Depot (RANAD), and intertidal mudflats at the southern end of Homebush Bay. The lagoons supported the greatest diversity and highest densities of shorebirds.
3. Three types of potential shorebird prey occurred in the lagoons: the larvae of midges (Chironomidae) and mosquitoes (Culicidae) and oligochaete worms. Midge larvae were found on submerged substrates in all lagoons, mosquito larvae occurred in the water column around lagoon edges and oligochaetes occurred in high densities in the substrate of only the Waterbird Refuge at Bicentennial Park. The densities of midge larvae, estimated by sampling along transects, varied from lagoon to lagoon and temporally within individual lagoons.
4. Black-winged stilts foraging on the lagoons appeared to feed mostly upon midge larvae. The birds' capture rates of these larvae were correlated with variations in the densities of larvae.
5. Densities of foraging black-winged stilts varied between lagoons and temporally at individual lagoons. These variations were correlated with variations in the densities of midge larvae recorded along sample transects. The Waterbird Refuge at Bicentennial Park had higher densities of midge larvae and higher densities of stilts than had the lagoons at Newington or Mason Park.
6. Water depth within lagoons was a major habitat variable for shorebirds. Adult black-winged stilts foraged in water up to 18 cm deep but preferred depths between 10–15 cm. Black-winged stilt chicks and juveniles preferred to feed in shallow water around lagoon edges. This was related to their need for cover in saltmarsh to avoid predators and to their inability to capture midge larvae as proficiently as the adults in open lagoon areas. The young stilts probably fed more upon mosquito larvae than did adult stilts.
7. All other species of shorebird showed preferences for particular water depths when feeding in lagoons. Curlew sandpipers preferred to feed in depths from 3–6 cm. Sharp-tailed sandpipers preferred to feed along the water's edge and black-fronted plovers preferred moist, freshly exposed substrates.
8. The lagoon system has the potential to support a considerably higher diversity and abundance of shorebirds than presently occurs. To achieve this, water depths must be regulated so that there is the maximum extent of water at the depths preferred by each species, and densities of prey items must be maximised.
9. The intertidal areas of Homebush Bay supported a small population of bar-tailed godwits comprising about 5% of the total number in the upper Parramatta estuary. No other shorebirds occurred regularly in these intertidal areas. The main area for godwits was in Hen

and Chicken Bay which had densities around 4.2 times those in Homebush Bay. At both Homebush and Hen and Chicken Bays the godwits fed entirely upon polychaete worms. However, prey capture rates were lower at Homebush Bay and the prey items caught were smaller. Polychaete worm densities were lower in the substrates of Homebush Bay than in Hen and Chicken Bay. At Homebush Bay substrates were exposed for less time at low tide than Hen and Chicken Bay so that the godwits had shorter foraging periods. Thus, Homebush Bay was a poor quality area for the godwits in contrast to Hen and Chicken Bay.

Management of the Lagoon Habitats at Homebush for Shorebirds

Management Objectives

The Homebush Bay Lagoon habitats do not at present support populations of any shorebird species that is seriously threatened or endangered at state or national level and there is thus no requirement to target management specifically for any priority species, although many of the species are protected by various international agreements (see Table 1), and NSW NPWS (National Parks and Wildlife Service) will ensure that these legal obligations are adhered to. The wetlands are a valuable local resource for education and recreation and can also contribute to the local conservation of several shorebird species. Thus, the most appropriate overall management objective would be to aim to achieve without compromising other environmental values, the highest diversity and densities of shorebirds possible, and yet encouraging public access to and use of the resource. However this must be done with consideration of the management requirements of other components of the biota in Homebush Bay. The management objectives and actions presented herein are for shorebirds only.

Main Issues

This research programme has identified a number of key issues that must be addressed in order to achieve the above management objective. These are relevant to all lagoons but their significance and precise details vary from lagoon to lagoon. The individual management issues are specified below and their application to each lagoon complex is detailed in the following section.

Management of prey populations

The most important prey species for shorebirds in the lagoons appear to be the larval stages of midges (Chironomidae) and mosquitoes (Culicidae). Management should aim to maximise the densities of these prey species on all lagoons. However oligochaetes are present sometimes in substantial numbers and additional studies should be undertaken to determine whether they are also important as prey items for the birds.

Use of insecticide to reduce mosquito populations

The use of insecticide to reduce mosquito populations will reduce the availability of mosquito and chironomid larvae to shorebirds and should be avoided. The impact of other mosquito control programs on these prey items and hence to shorebirds must be assessed carefully before implementation.

Management of water levels

Each shorebird species has been shown to have specific preferences for particular water depths or substrate types. Water levels must be managed precisely at all times to provide the maximum extent and range of conditions needed by each species. A number of species have conflicting requirements of water depths and compromises will be needed to achieve the maximum diversity of species. Also, the maximum potential of the entire lagoon system will be achieved only if the management of water levels is coordinated and integrated over all lagoons.

Improvement of water quality

All of the lagoons are eutrophic and some extremely so (Cheng 1993, this study). This results in extensive growth of filamentous green algae which on some lagoons restricts the extent of suitable shorebird and wildfowl foraging habitat, and the algae is also aesthetically unpleasant. Attempts should be made to reduce nutrient levels in the lagoons to minimise this growth. However this must be done in conjunction with evaluating the water quality and sediment requirements of chironomids and oligochaetes. A monitoring program should be implemented to study the effects of improving water quality on populations of chironomids and oligochaetes which are currently the major food source for some shorebirds. The program should also evaluate if any replacement invertebrate speces which colonise the area provide suitable food for the shorebirds. If the improved water quality reduces the amount of food available to the birds, then some level of comprimise wil need to be found to ensure that adequate food supplies are available for the birds. A recent study by Rehfisch (1994) is relevant to these studies and also more detailed information on chironomids should be obtained from the relevant experts.

Management of edge habitats

The precise nature of the edge habitats around lagoons is important in two respects: it provides roosting areas for shorebirds and cover for young stilts, and also provides cover for the predators of shorebirds. The presence of a broad zone of saltmarsh around lagoons should be encouraged and the extreme close proximity of tall dense tree cover of mangroves should be discouraged.

Provision of nesting sites

Natural nesting places for black-winged stilts do not exist on most lagoons and the provision of artificial nesting places should be undertaken to encourage a larger breeding population of stilts, if this is considered desirable.

Management of public access and activity

The conservation of shorebirds is incompatible with unrestricted public access. The fullest conservation potential and hence the best educational and recreational quality of the area will be achieved only by the careful regulation of human activity. Consideration must be given to ways in which the best compromises between the two can be reached.

MANAGEMENT OF SPECIFIC LAGOON COMPLEXES

At present each of the three lagoon complexes at Bicentennial Park, Mason Park and Newington are under separate administration. The management requirements for each are therefore presented separately, below. It must however be remembered that the birds do not treat these as separate ecological units, they move freely and frequently among them. The fullest potential of the wetlands will be achieved only by adopting an integrated management programme over all components.

Bicentennial Park Lagoons

The Waterbird Refuge

Present Situation

1. The lagoon has high densities of invertebrate prey for shorebirds, adequate to meet daily foraging requirements.

2. Bottom profiles over the northern third of the lagoon slope gently providing graded water depths.
3. As a consequence of 1 and 2, the lagoon has the potential to provide high quality foraging habitat for high densities of black-winged stilts, curlew sandpipers, sharp-tailed sandpipers and several species of wildfowl.
4. The lagoon has the potential to provide a high quality educational and recreational resource. This is particularly important given the location of the wetlands in a densely populated area of Sydney.
5. There currently exists no mechanism for the regulation of water levels.
6. Water inputs are irregular, and uncontrolled resulting in variable water depths which may not be suitable for a variety of wading birds.
7. Levels of dissolved plant nutrients are excessively high, resulting in excessive growth of filamentous green algae which limits the extent of habitat available to waterbirds, including shorebirds.
8. Edge areas lack diversity of contour.
9. There are inadequate areas of high quality edge habitat in the form of saltmarsh.
10. The number of potential nesting places for black-winged stilts is inadequate.
11. There is excessive human disturbance along the entire eastern shore of the lagoon limiting the use made of this area by waterbirds.

Management Objectives

1. Provide feeding conditions for the maximum diversity of waterbird species, including shorebirds, at the maximum possible densities.
2. Provide suitable conditions for a small breeding population of black-winged stilts.
3. Provide better quality edge habitats for some shorebirds.
4. Eliminate excessive growth of filamentous green algae.
5. Minimise negative impacts of visitors to the lagoon.
6. Encourage increased human use of the natural resources of the lagoon for educational and recreational purposes.

Back Pool

Present Situation

1. Ecological conditions at its southern end are unusual for the area as it receives periodic freshwater input.
2. The potential exists to provide suitable foraging conditions for black-winged stilt, black-fronted plover, red-kneed dotterel, Japanese snipe and a variety of other bird species.
3. Water levels are too deep to allow use by shorebirds for most of the year.
4. There is excessive human disturbance around the lagoon which limits the quality of habitat for shorebirds.
5. There is excessive invasion of mangroves over much of the lagoon, reducing the area of habitat suitable for shorebirds.

Management Objectives

1. Provide suitable foraging conditions especially for black-winged stilt, black-fronted plover and red-kneed dotterel.
2. Minimise human disturbance around lagoon.
3. Reduce mangrove cover by at least 50% and prevent subsequent reinvasion.

4. Improve human use of lagoon for educational and recreational purposes.

Mason Park Lagoon

Present situation

1. The potential to provide excellent quality habitat for a wide diversity of shorebirds is high.
2. The lagoon provides a roosting place for scarce lesser golden plovers.
3. The lagoon has frequently fluctuating water levels and often dries out completely. Average water depths are below the optimum levels for maximum diversity of shorebirds.
4. Densities of invertebrate prey suitable for shorebirds are low, perhaps as a consequence of drying out.
5. Arrangements for water entry are inadequate and no mechanism exists to regulate water levels.
6. Recent tree planting along western shore may soon reduce the suitability of the lagoon to shorebirds that avoid close proximity to dense tall cover that can harbour predators.
7. High levels of human activity occur at close proximity around whole perimeter of lagoon.

Management Objectives

1. Provide high quality feeding habitat for black-winged stilt, curlew sandpiper, sharp-tailed sandpiper and black-fronted plover.
2. Maintain a secure roost site for lesser golden plovers.
3. Provide suitable conditions for breeding black-winged stilts.
4. Prevent any further increase in human activity around lagoon.
5. Increase public awareness of value and sensitive nature of the lagoon and its wildlife.

Newington Lagoons

Present Situation

1. There are limited and inadequate water inputs to all lagoons and no means of regulating water levels on any of them.
2. Public access is restricted and most of wetlands suffer little human disturbance.
3. The entire area is fenced off and there seems little or no problem from terrestrial predators such as feral cats.
4. The Wharf Pool has mainly a freshwater run-off input and in this respect is unique among the existing complex. It has steep edges and a uniform bottom profile and thus cannot offer suitable conditions for a diversity of shorebird species simultaneously. Water levels fluctuate from too deep for any shorebird to totally dry.
5. The Main Lagoon has lower densities of invertebrate prey for shorebirds than does the Waterbird Refuge. It has relatively uniform water depths, suitable over most of its extent only for black-winged stilts. Water levels are relatively stable. There is limited potential to offer suitable feeding habitat for a comprehensive range of species simultaneously because of uniform water depths. Edge habitats of saltmarsh are highly favourable for breeding black-winged stilts and offer secure roosting areas on the eastern shore for stilts, other shorebirds and wildfowl.
6. The Corner Marsh and 33-Marsh Lagoons have no water inputs other than rainfall and ground water. Consequently, water levels are normally inadequate and the lagoons support few shorebirds. Invertebrate prey abundances for shorebirds are low. At 33-Marsh levels of disturbance from activities at adjacent buildings are high which limits the use made of this

lagoon by shorebirds, otherwise there is a high potential to provide a large area of good quality foraging habitat for several shorebird species. Edge habitat in the form of saltmarsh is of high quality for shorebirds. The Corner Marsh lagoon has excessive colonisation of mangroves but has potential to provide better quality shorebird habitat.

Management Objectives

1. To provide a high quality conservation area for the maximum possible number of breeding and feeding black-winged stilts from October to March.
2. To provide the maximum area of suitable habitat for black-fronted plovers from March to August.
3. To maintain exclusion of feral cats and dogs and foxes.
4. To maintain low levels of human disturbance and encourage only limited, escorted visitor facilities.

Management Recommendations for Intertidal Areas

1. The intertidal zone of Refuge Bay is not an important area for shorebirds and requires little specific management for these birds. There is only one immediate management objective. A small area of mudflat at the extreme south-eastern corner of Refuge Bay (Fig. 32) is the only area that can be used by bar-tailed godwits on neap tides when the main mudflats do not become uncovered. The area is being colonised by mangroves
2. The intertidal area was used for feeding by a wide range of other waterbirds many of which move into Bicentennial Park at high tide (see list given by Straw, 1993). The juxtaposition of these intertidal mudflats and the mangrove ecosystem in Bicentennial Park provides the opportunity for a holistic approach to the teaching of estuarine ecology emphasising the importance of these natural systems in fisheries management and wildlife conservation. This opportunity should be developed.
3. Consider the control of further spreading of mangroves at the southern end of Hen and Chicken Bay.

1 INTRODUCTION

1.1 BACKGROUND TO STUDY

This study is concerned with the shorebirds that make use of the complex of wetland habitats within the Homebush Bay area at the head of the Parramatta estuary, New South Wales. At the time of white settlement the upper reaches of the estuary supported extensive communities of saltmarsh, mangroves and mudflats. From the end of the 19th century the area has been subject to successive reclamation, infilling and development which removed or severely modified most of these natural habitats. Nevertheless, the remnants and the recently colonised habitats that survive are important and valuable representatives of their habitat types (Clarke and Benson 1988).

Eleven shorebird species use the Homebush area regularly (Straw 1993, this study). These can be divided into two groups; those species that breed in the arctic and subarctic regions of Siberia and Alaska and spend the southern summer in Australia, and those that are permanent Australian residents (Table 1).

Table 1 Species of shorebird that occur in the wetlands of Homebush Bay, showing estimated NSW population numbers (Smith 1993), breeding and migratory status in NSW and appropriate international agreements covering their conservation. Status: NB - non-breeding, BR - breeding, SR - Australian summer resident, N - nomadic or migrant within Australia, S - sedentary, WF - first year birds spend northern summer in Australia.

Common name	Scientific name	Status in NSW	Breeding area	NSW pop. est.	Relevant conservation agreement
Lesser Golden Plover	*Pluvialis fulva*	NB/SR	Arctic tundra, Siberia & Alaska	1 800	CAMBA, JAMBA, RAMSAR
Red-Kneed Dotterel	*Erythrogonys cinctus*	BR/N	Australia	5 000	RAMSAR
Black-fronted Plover	*Elseyornis melanops*	BR/N	Australia/ New Zealand	6 000	RAMSAR
Black-winged Stilt	*Himantopus (himantopus) leucocephalus*	BR/N	Australia/ New Zealand	45 000	RAMSAR
Japanese (or Latham's) Snipe	*Gallingo hardwickii*	NB/SR	Japan	12 000	RAMSAR, JAMBA, CAMBA
Bar-tailed Godwit	*Limosa (lapponica) baueri*	NB/SR/ WF	Arctic tundra, Siberia & Alaska	8 000	CAMBA, RAMSAR, JAMBA
Sharp-tailed Sandpiper	*Calidris acuminata*	NB/SR	Arctic tundra, Siberia	40 000	CAMBA, JAMBA, RAMSAR
Curlew Sandpiper	*Calidris ferruginea*	NB/SR	Arctic tundra, Siberia	6 000	CAMBA, JAMBA, RAMSAR
Masked Lapwing	*Vanellus novae hollandiae*	BR/S	Australia/ New Zealand	55 000	RAMSAR
Greenshank	*Toinga nebularia*	NB/SR	Sub-arctic Siberia	2 000	CAMBA, JAMBA, RAMSAR

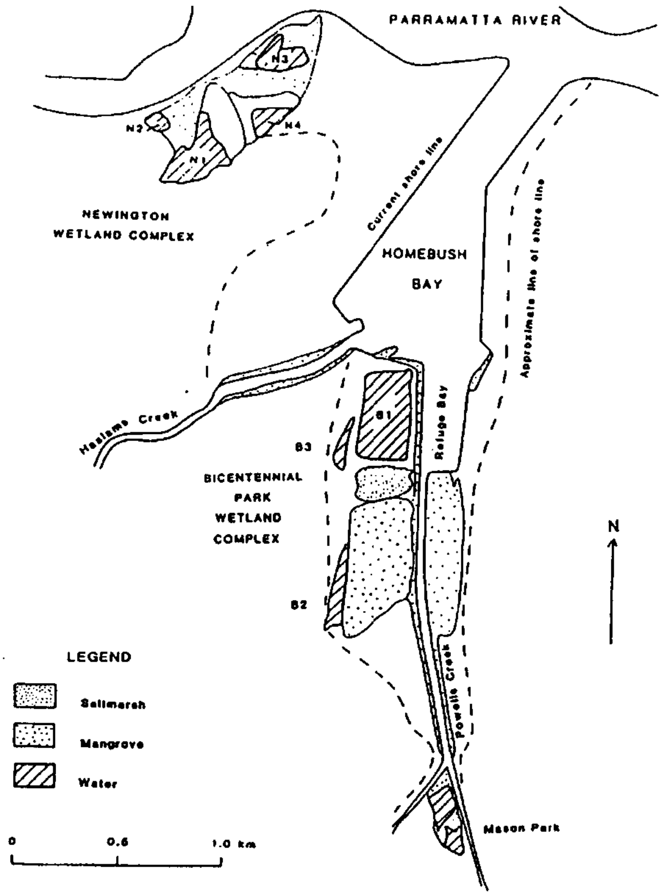


Figure 1. Locations of wetland units in Homebush bay area. Lagoon habitats occur at Newington (N1 to N4, see Fig. 5), Bicentennial Park (B1 = Waterbird Refuge; B2 = Brickworks Pond; B3 = Back Pond) and at Mason Park. Intertidal mudflats occur at Refuge Bay at the southern end of Homebush Bay. The dashed line shows the line of the original shoreline prior to reclamation of most of the area.

The northern migratory species depend upon suitable habitats being maintained in their breeding areas, along their migration routes and in their wintering areas. They are the subject of a number of international conservation agreements to which Australia is a signatory, including the Convention on Wetlands of International Importance Especially as Waterfowl Habitat (RAMSAR); the Japan-Australia Migratory Bird Agreement (JAMBA); the China-Australia Migratory Bird Agreement (CAMBA), and the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention).

The Royal Australian Ornithologist Union has prepared a national plan for shorebird conservation in Australia, presenting guidelines by which Australia can fulfil these international obligations (Watkins 1993). For NSW an assessment of the conservation needs for shorebirds has been prepared by the National Parks and Wildlife Service (Smith 1991). Both reports identified sites within Australia and NSW that merit special protection on the basis of their exceptionally high numbers of shorebirds. Additionally, the RAOU recommended that '*shorebird conservation in areas outside conservation reserves (be) adequately addressed in land use and management decisions,*' and that, '*management of all areas takes into consideration the needs of shorebirds.*'

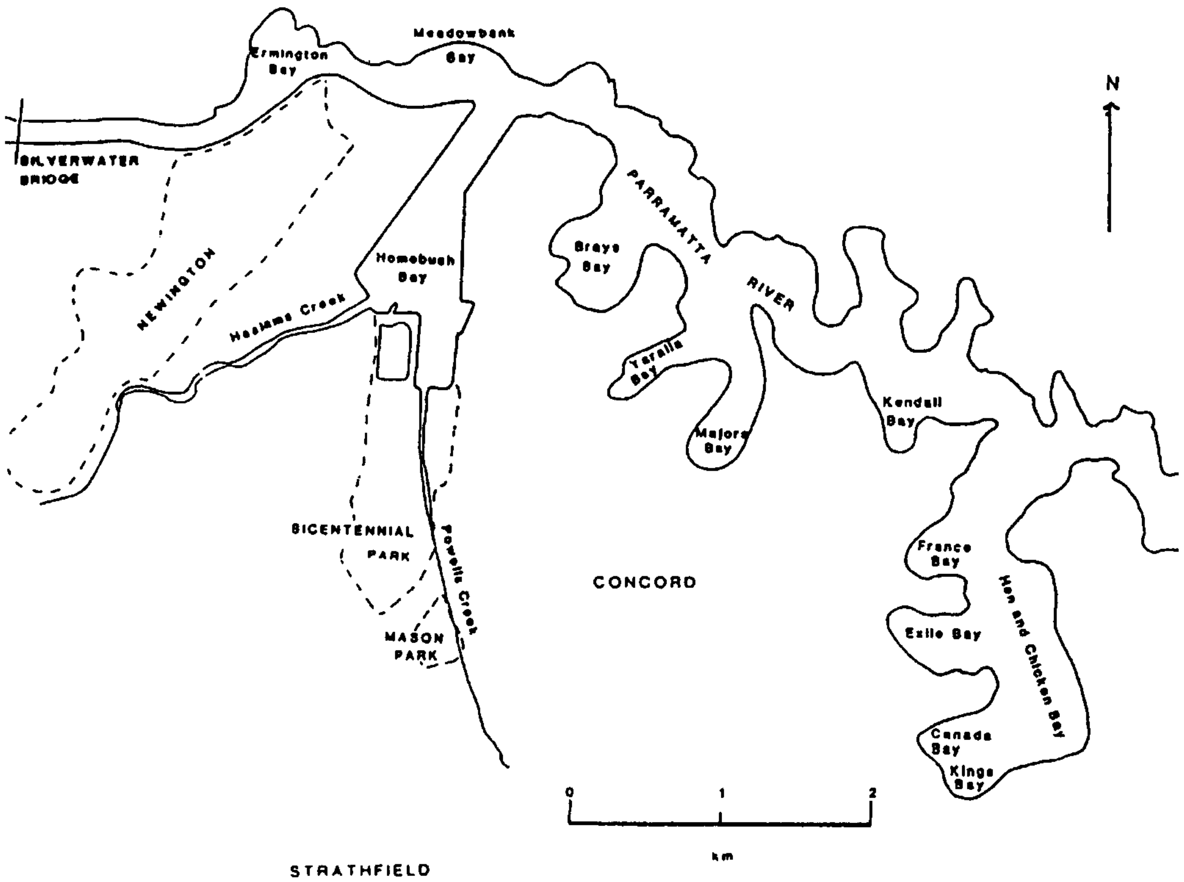


Figure 2. The total extent of potential intertidal habitat for shorebirds examined in this project. The study extended from Hen and Chicken Bay to Silverwater Bridge and included all of the bays shown.

The aim of the work described here was to quantify the ways in which shorebirds make use of the Homebush wetlands, to identify the importance of the various components in the existing habitats and to provide information on management options. For those species that breed in arctic and subarctic areas and spend the southern summer in Australia the provision and maintenance of suitable foraging and roosting areas are the main issues. For species that are Australian residents and which breed at Homebush, the study included investigation of their specific habitat requirements for successful breeding in addition to those for foraging.

The study was primarily concerned with the wetlands within the Royal Australian Navy Armament Depot (RANAD) at Newington, within Bicentennial Park and at Mason Park, as well as the intertidal mudflats of Homebush Bay (Fig. 1). Previous studies of shorebirds elsewhere have shown that it can be misleading to consider individual sections of estuarine systems in isolation from adjacent areas. Harris (1988) undertook a cursory study of the habitat use by wading birds along the Parramatta River as part of an Honours Project. Many shorebirds move among neighbouring sections according to tide or to other factors, such as human disturbance (Summers 1977, Bergur *et al.* 1977, Conners *et al.* 1981). To place Homebush Bay in context, the study of intertidal areas was extended to encompass all suitable shorebird habitat from Hen and Chicken Bay to Silverwater (Fig. 2).

The wetlands encompassed within the study area can be subdivided into three types: shallow, brackish to hypersaline lagoons at Newington, Bicentennial Park and Mason Park; intertidal mudflats, along the Parramatta estuary and cumbungi swampland at Newington. In addition to being ecologically distinct these areas also proved to be functionally distinct in the use made of them by most shorebirds. This study concentrated on the lagoon and intertidal habitats and the results for each are presented separately.

1.2 OBJECTIVES

1. To evaluate the significance of the Homebush wetlands for shorebirds by assessing the numbers of each species using the area.
2. To investigate the ways in which shorebirds utilise the wetland habitats, in particular to conduct detailed studies of the foraging ecology of the most numerous species, including investigations of their diet, the distribution and abundance of their prey, the factors that affect their ability to capture prey and the factors that determine the densities of foraging birds.
3. To study the breeding ecology of those species that breed in the wetlands.
4. To produce guidelines for the future management of the wetlands for shorebird conservation based upon the findings of this study.

1.3 SHOREBIRD ECOLOGY

The habitat requirements and foraging behaviour of shorebirds have been little studied in Australia but have been investigated in depth in Europe, north America and southern Africa. It is useful to consider some of the basic findings from these studies to establish the general principles that are applicable to the present study.

The quality of foraging areas for shorebirds is determined by abiotic and biotic factors. The most important abiotic factors include tidal regimes, salinity, substrate types and weather patterns (Bergur 1984). Biotic factors include those related to the birds' food supply (mostly benthic invertebrates) which in turn are determined mainly by the abiotic factors, such as the presence of predators and the activity of intra- and interspecific competitors (Puttick 1984, Goss-Custard 1984, Myers 1984).

The birds' requirements vary according to climatic factors and also show marked seasonal changes. Outside the breeding and migrating seasons they need only satisfy their daily maintenance needs, but species that nest in arctic and subarctic areas must exceed normal maintenance intake levels for up to 6 weeks before migration in order to accumulate sufficient reserves of energy to fuel their long distance flights. For example, the bar-tailed godwit, *Limosa lapponica*, one of the species investigated in this study, increases its body mass by about 42% before leaving Australia to fly to China on the first leg of its return to the breeding areas (Barter 1989). Similar weight gains occur in European populations of the same species (Piersma and Brederode 1990, Piersma and Jukema 1990). The level of reserves achieved by the birds before departure affects their survival during migration and may affect breeding success.

To achieve this increased body mass the birds have either to forage at a faster rate or for longer each day for about 4 to 6 weeks before departure (Piersma and Brederode 1990). Prey densities and the daily duration of suitable foraging conditions may be critical during this period. Species such as the bar-tailed godwit that feed only over intertidal mudflats can only do so when these are uncovered or when water depths are shallow enough, so exposure periods which are determined by tidal regimes and altered by reclamation schemes which affect beach profiles are important considerations. Other factors such as human disturbance that interrupt foraging could also be of greater significance during this premigratory period. Sections of an estuary that may meet the birds' requirements from October to February could be inadequate during the premigration period in March and April. Habitat quality and suitability must therefore be assessed in a way that takes such considerations into account.

Several studies have shown positive correlations between the densities of foraging shorebirds and the densities of their preferred prey (e.g. Goss-Custard 1970, Prater 1972, Goss-Custard *et al.* 1977, Bryant 1979, Evans and Duggan 1984, Goss-Custard *et al.* 1991). In areas of high prey densities the birds achieve higher rates of prey capture and energy intake (e.g. Goss-Custard 1970, Goss-Custard *et al.* 1977, Sutherland 1987). This relationship between bird density and prey density could be the result of long term population processes such as survival and productivity, or it could be the consequence of short-term processes of density regulation based on variations in the birds' aggressive behaviour to each other. Aggression, involving threat calls and attacks, is commonly observed in flocks of foraging shorebirds and there are numerous examples of aggressiveness increasing with increasing density of birds (Hamilton 1959, Recher 1966, Recher and Recher 1969, Goss-Custard 1977, Silliman *et al.* 1977, Bergur *et al.* 1979, Vines 1980, Fleischer 1983, Stawarczyk 1984, Metcalf and Furness 1987). High densities could result in increased interference during foraging leading to a decrease in prey capture rates (e.g. Goss-Custard 1976, Goss-Custard *et al.* 1977, Zwarts 1978, Zwarts and Drent 1981).

Food supply is one of the main factors determining the relative importance of shorebird habitats. There are three main sources of variability in food supply — the absolute abundance of prey species, the behaviour of prey and physical factors such as water turbidity and light intensity that affect the birds ability to detect the prey (Bergur 1984, Puttick 1984, Goss-Custard 1984).

In addition to a rich food supply the other main habitat requirement for non-breeding shorebirds is access to a suitable roosting site. Roost sites are generally selected to offer safety from predators and human disturbance and tend to be in open areas on islands or headlands. Good feeding areas may be unsuitable if there are no roosting places available close by.

This study thus concentrated on the foraging ecology of the species that occur at Homebush to quantify any relationships between the abundance and density of the birds and variations in the abundance of their food supply as well as relationships with the physical characteristics of the habitat such as water depths and substrate types.

2 LAGOON HABITAT

2.1 INTRODUCTION

Saline lagoon habitats occurred at three sites; Bicentennial Park, Newington (RANAD) and Mason Park, spread over a distance of almost 4 km. At Bicentennial Park there were two main lagoons, the Waterbird Refuge and the Back Pond, that offered shorebird habitat. The most extensive complex was at Newington consisting of five lagoons adjacent to the Parramatta River, four of which were potential shorebird habitat (Straw 1993). Mason Park had a single lagoon adjacent to Powells and Saleyard Creeks.

These lagoon habitats have been affected by reclamation and infilling projects and have not been specifically managed for shorebirds. Present conditions are largely accidental and may not be optimal. Nevertheless, 11 species have been recorded to feed or roost in the lagoons (Straw 1993, this study). Overall, the lagoons are the most important component of the wetland system for shorebirds and offer the greatest potential for future management to maintain and enhance their value.

The black-winged stilt and curlew sandpiper were the most numerous species using the lagoon habitat, and research concentrated on these. The numbers and distribution of each species were determined and where possible details of diet were obtained. The abundance of invertebrate prey was investigated. Relationships between bird density, prey abundance and water depths were examined. Some observations were also made of the black fronted plover, the sharp-tailed sandpiper, the red-kneed dotterel, the lesser golden plover and the masked lapwing.

2.2 DESCRIPTION OF LAGOON HABITATS

2.2.1 Methods

General descriptions were made of each lagoon by ground survey and by the examination of aerial photographs. To determine the extent of each of the main lagoons that had water depths suitable for shorebirds, water depth profiles were made by walking along transects and measuring depths at regular intervals. At each visit to a particular lagoon a record was made of the positions of waterlines so that changes in total water area could be calculated. Depth gauges were installed at the Waterbird Refuge and at the Wharf Pool, Newington from which temporal changes in water depth during the study were obtained. Much of the Waterbird Refuge was too deep for stilt foraging and changes in the total water area with suitable depths were calculated from a map of water depths in combination with readings from the water gauge. Other lagoons were shallow enough for stilt foraging over their entire extent so changes in total water area were taken as changes in the area of suitable stilt habitat.

The physical and biochemical characteristics of the Waterbird Refuge have been described by Cheng (1993). The results of that work are summarised and incorporated into the following site description. Similar details are not available for the other lagoons.

Sediment samples were collected by cores in Newington Main Lagoon, Newington Corner Lagoon, Newington Wharf Lagoon, Newington 33-Marsh Lagoon, Mason Park and Waterbird Refuge and textural analyses undertaken to determine % of mud, sand and gravel at each site (textural classification after Folk 1968) as well as % of organic carbon and sulphur by weight. For results of sediment analysis, and sample locations, please see original report.

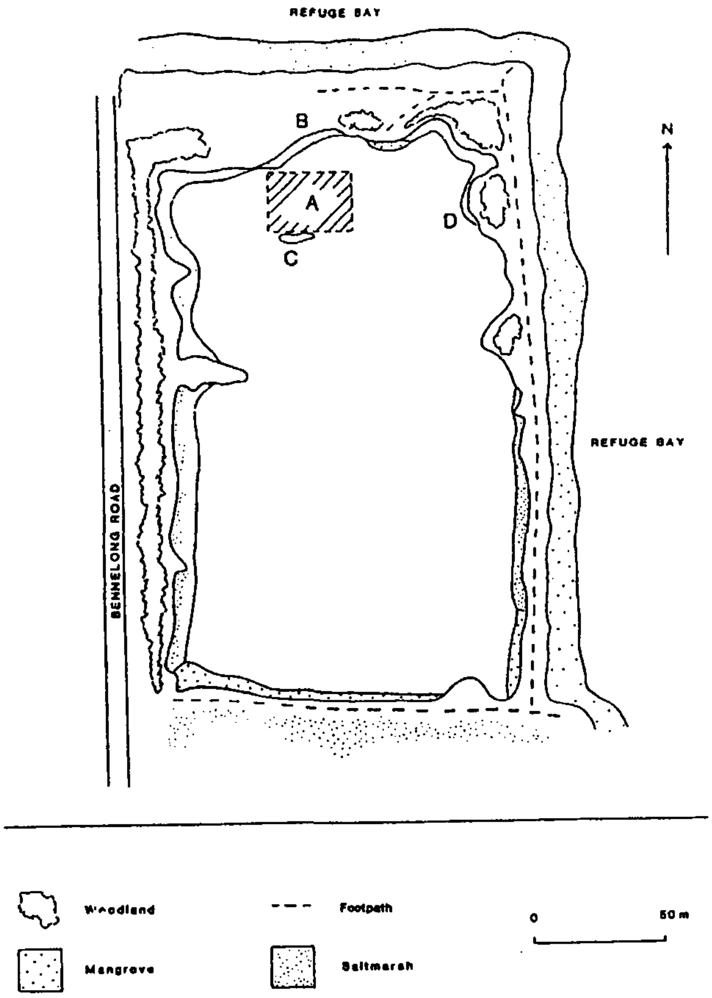


Figure 3. The Waterbird Refuge, Bicentennial Park. Suitable habitat for shorebird foraging occurred in the northern section of the lagoon beyond the point on the western shore, and also along most of the western shore. Cross-hatching (A) shows the intensive study area for stilt foraging behaviour and B shows the raised observation position for this study. C and D are the locations of shorebird roosting sites on the lagoon.

2.3 RESULTS AND DISCUSSION

2.3.1 Bicentennial Park

2.3.1.1 Waterbird Refuge

The Waterbird Refuge was the largest single lagoon of the area, measuring about 250 m x 400 m (Fig. 3). The site is artificial having been reclaimed from Homebush Bay by the formation of bund walls. During the late 1950s and early 1960s it was partially infilled (Clarke and Benson 1988). The Lagoon received water from three sources: as rainfall, as overflow that entered from an adjacent pond through a culvert under the Bennelong Road at the south west corner of the lagoon, and from the Parramatta River through two 20 cm diameter steel pipes which pass through the eastern bund wall of the lagoon. The latter input was saline, limited in volume and restricted to high spring tides. The Bennelong Road culvert input was fresher water and flowed only after periods of heavy rainfall. The main loss of water from the lagoon was through

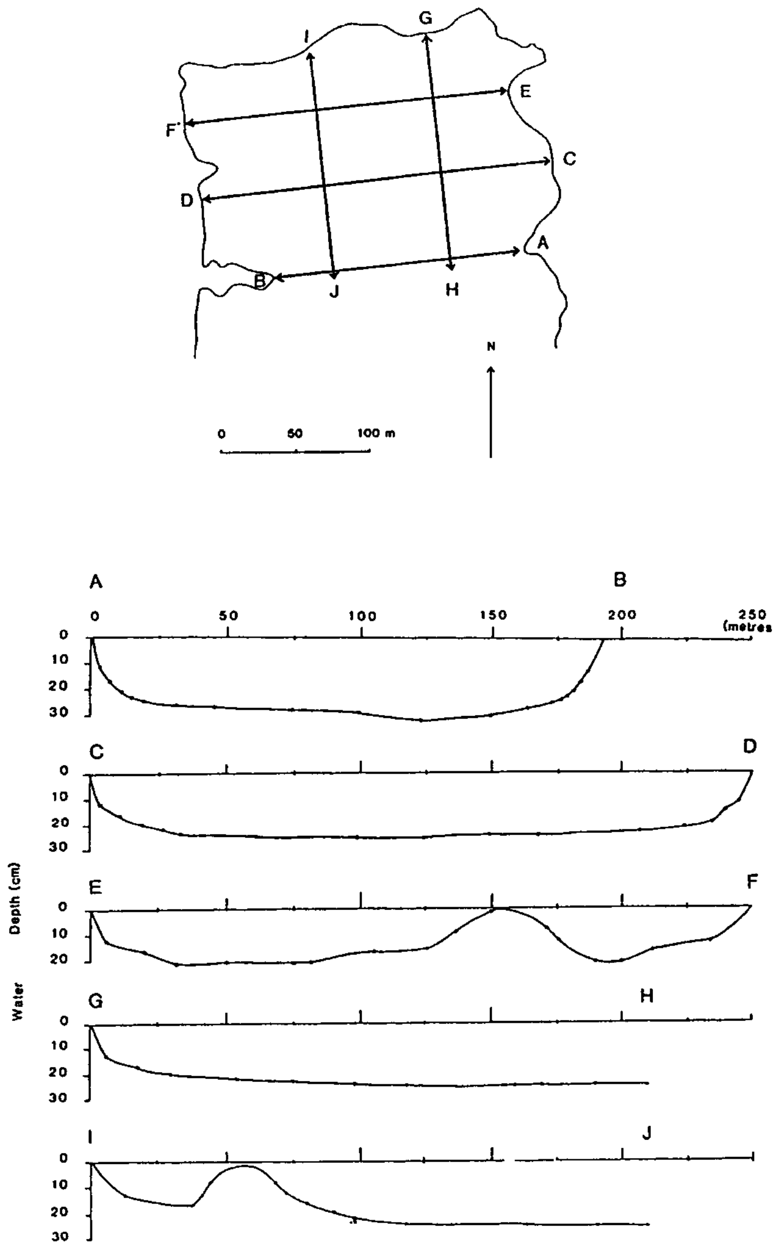


Figure 4. Profiles of water depths across the northern section of the Waterbird Refuge, March 1994. Positions of transects are shown above, water depths are shown on the following page. This was the main shorebird foraging area of the lagoon. Depths slope slowly from the northern shore towards the centre of the lagoon.

evaporation. No quantification has been made of rates of water input and output to the system nor of its periodicity or seasonality. The quality of incoming water has also not been assessed.

Exact details of water depths for the entire lagoon are not available but at periods of highest water levels almost all of its area was less than 1 m deep. The southern section was generally deeper than the northern section. The northern part had gently grading bottom profiles giving extensive areas of shallow water (Fig. 4). Data on temporal changes in water depth were obtained for the

Table 2 **Changes in water depths and extent of foraging area within depth limits used by black-winged stilts at the Waterbird Refuge between November 1993 and May 1994. Water depths were recorded against a measuring pole inserted at the northern end of the lagoon. The extent of suitable foraging area was calculated from a contour map of depths prepared for the lagoon supplemented by observations of foraging birds. Maximum depth of water utilisable by black-winged stilts was 18 cm.**

Date period	Water depth (cm)	Extent of suitable foraging area (thousand m^2)
24-29/11/93	13.0	8.50
06-10/12/93	13.5	7.75
17-22/12/93	11.5	10.81
04-07/01/94	11.0	11.83
17-22/01/94	8.5	16.50
26/01-01/02/94	5.5	21.18
08-10/02/94	4.0	30.00
14-18/02/94	2.5	35.23
01/03/94	2.0	36.00
5-7/03/94	8.0	17.03
16-18/03/94	12.0	10.05
22-23/03/94	9.5	14.75
28-30/03/94	14.5	7.35
09-13/04/94	12.5	9.60
22-24/05/94	17.0	3.43
26/06/94	18.5	2.3
18/07/94	21.0	0.7

northern section from December 1993 to June 1994. At the lowest water levels recorded, in February 1994, the deepest point was only 0.04–0.025 m. During the 7 month period levels fluctuated over a range of about 15 cm, correlated with rainfall and ambient temperatures (Tables 2 and 3). Thus the area of the lagoon with water depths suitable for foraging stilts (1–18 cm, see Figure 21) also changed during the study period, reaching its maximum extent during February and decreasing again through March to June (Table 2, Fig. 5)

The shallowness and restricted flows through the lagoon resulted in variable dissolved oxygen levels, variable salinities which have been recorded as high as 41.1 ppt (hypersaline) following dry periods down to 18 ppt (hyposaline) following rainfall, and variable temperatures which can reach high levels close to ambient air temperatures (Cheng 1993). The water was alkaline (pH 7.5–9.0) and had high nutrient levels. Phosphorous concentrations ranged from mean values of 132.9 μg per litre to 369.4 μg per litre between September 1992 and February 1993. A high proportion (often exceeding 50%) of this was ortho-phosphate, the form most readily utilisable for algal growth (Cheng 1993). On the basis of these phosphate levels the lagoon would be classified as highly eutrophic (Vollenweider 1971). Inorganic nitrogen levels recorded over the same period ranged from means of 89.5 μg N/L to 160.3 μg N/L, thus falling within a mesotrophic classification. The high nutrient levels and temperatures resulted in high productivity and the

Table 3 Total rainfall and mean maximum daily temperatures recorded at Riverview (7 km east of Bicentennial Park) at 10 day intervals from November 1993 to May 1994.

Month	Dates	Total rain (mm)	Mean maximum daily temperatures (°C)
November	01-10	17	23.9
	11-20	47.8	26.1
	21-30	23.2	23.9
December	01-10	47.8	26.1
	11-20	6.2	28.9
	21-31	5	27.1
January	01-10	6.2	28.9
	11-20	21	27.5
	21-31	4	26.1
February	01-10	21	27.5
	11-20	56.9	26.2
	21-28	9.0	26.3
March	01-10	56.9	26.2
	11-20	20.0	21.3
	21-31	66.6	22.4
April	01-10	10.0	24.6
	11-20	95.4	20.7
	21-30	0.4	24.1
May	01-10	9.6	21.1
	11-20	15.0	18.8
	21-31	0.4	21.2
June	01-10	15.0	18.4
	11-20	0.0	21.1
	21-30	49.0	16.8

development of extensive floating mats of filamentous green algae which restricted the area of the lagoon that could be used by waterbirds.

Water turbidity was found to be low during Cheng's study (1993) and was also low throughout this study. The bottom sediment was clearly visible through the water column at all times.

Sediments were mostly fine mud and were highly anoxic with dense black layers immediately below the surface. The blackness was the result of high hydrogen sulphide levels arising from low oxygen concentration and high nutrient concentrations in the sediment (Cheng 1993). During the present study there was a brown oxidised layer extending for about 1–3 mm below the surface. The sediment had high levels of phosphorous, nitrogen and organic carbon (Cheng 1993) indicating that it was a potentially important source of nutrients to the lagoon water column.

To complement the studies undertaken by Cheng (1993), additional sediment samples were collected during this study. A synopsis of the results of these sediment analyses indicated that mud dominated both when organics were included and also when they were excluded. There was some variation in composition of sediments over time but this probably represents slight variation between sites in the Waterbird Refuge. The % of organic carbon by weight varied from 4.6%–6.4%.

The lagoon was constructed as a rectangular shape and has regular straight edges. The southern and eastern sides slope steeply with little or no adjacent saltmarsh or exposed sediment. By contrast, the western side and northern sections slope more gently and have narrow zones of exposed substrate, except when water levels are highest, and fragmented patches of saltmarsh.

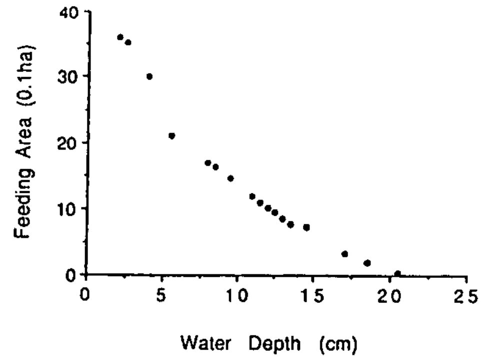


Figure 5. Relationship between water depth at the Waterbird Refuge, measured from a gauge at the northern end, and the area available within the depths utilised by foraging black-winged stilts. $r = -0.87$, $p < 0.001$.

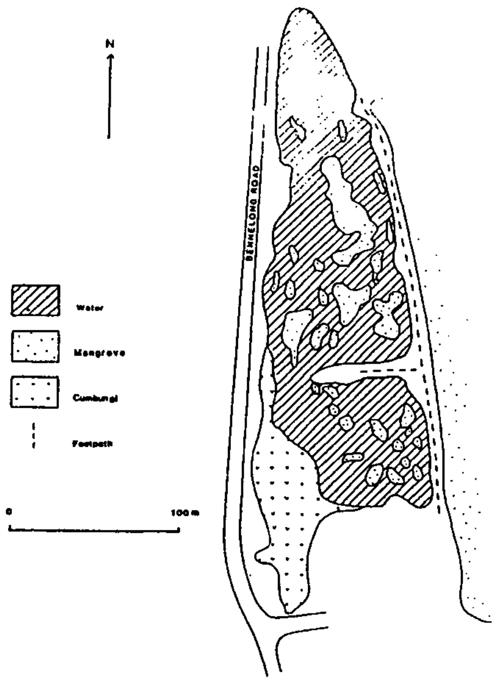


Figure 6. The Back Pond, Bicentennial Park. A flow of freshwater developed at the southernmost point of the lagoon following rainfall. The lagoon was being invaded by mangroves. Only the southern part of the lagoon became shallow enough for shorebird foraging after prolonged dry periods.

2.3.1.2 Back Pond

The Back Pond was the only other lagoon at Bicentennial Park that offered suitable shorebird habitat, albeit intermittently (Fig. 6). This was a brackish pool of about 300 m length and average breadth of 80 m. Over most of its area it was being invaded by mangroves and was usually too deep for shorebirds. A small section measuring 100 m x 100 m at the extreme southern end became shallow enough during February 1994 to be used by a number of species. The pool had a fresh water run-off input via a culvert under the Bennelong Road and an area of freshwater marshland at its southern end. Water and sediment qualities of the lagoon have not been studied.

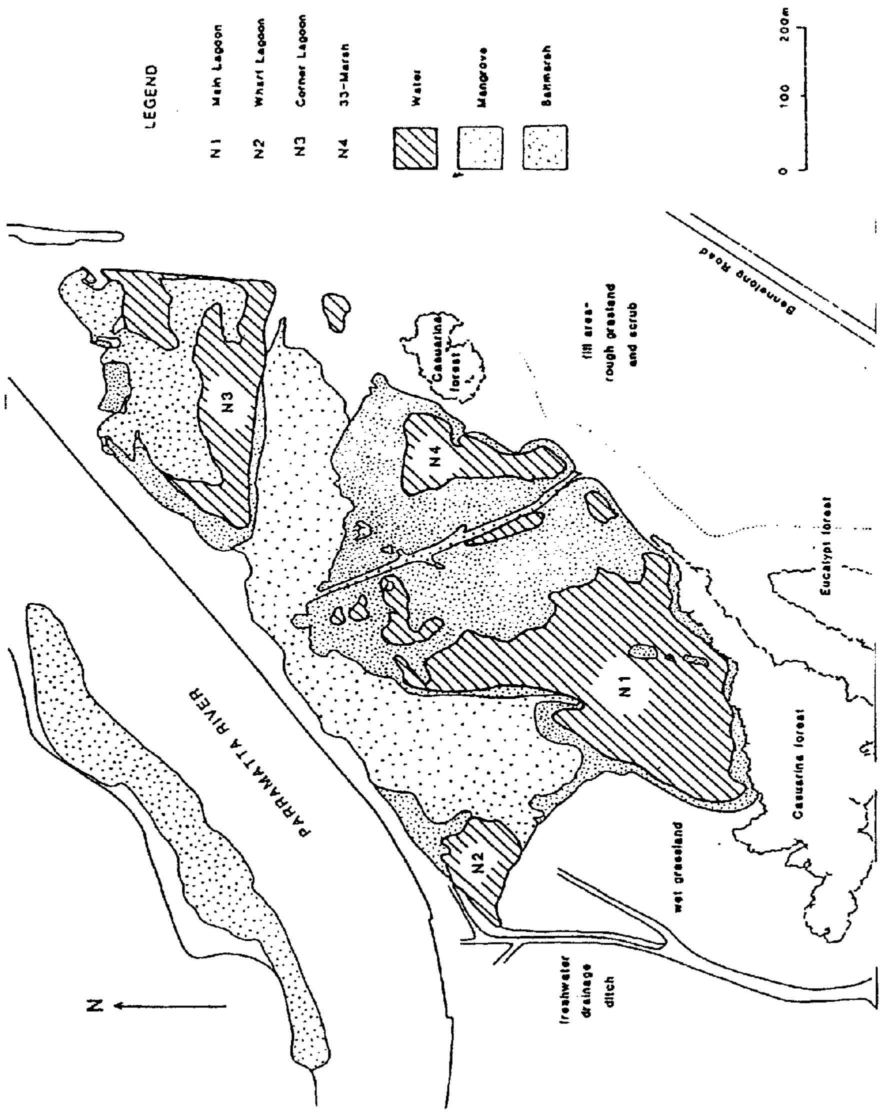


Figure 7. Wetland complex within RANAD, Newington. N1-Main Lagoon; N2-Wharf Pool; N3-Corner Marsh Lagoon; N4-33-Marsh Lagoon.

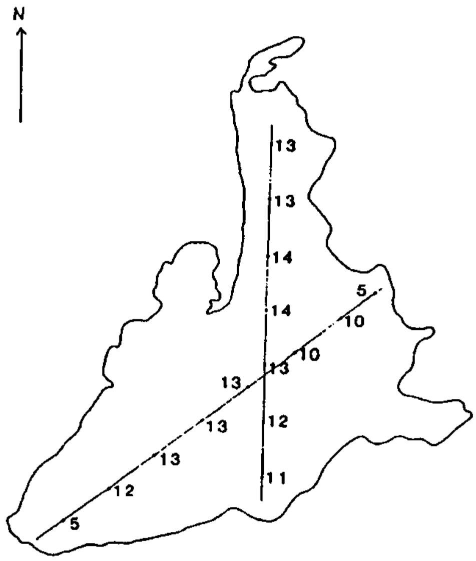


Figure 8. Water depths at the Main Lagoon, Newington, March 1994. Figures give the depth, in cm, at the locations shown.

2.3.2 ***Newington Lagoon Complex***

The Newington Lagoon complex was the most varied and most extensive in the Homebush area, consisting of a series of 5 lagoon areas separated by low bunds with substantial areas of saltmarsh and mangroves (Fig. 7). The survival of such a large area of wetlands results from its location within the Naval Depot. The entire complex had only a single point at which water from the Parramatta River could enter or leave — a 90 cm floodgate which allowed a limited flow at the top of high tides. Some tidal flushing was apparent in the mangroves immediately adjacent to the floodgate (referred to as two small pipes in the Fish Study by the Ecology Lab. 1994) but under normal tidal and weather conditions little of this extended to the main lagoon areas. Presumably, occasional flooding events occur which result in larger amounts of saline estuarine water entering the system but these have not been documented. The main regular inputs must have been in the form of direct rainfall and run-off from the surrounding land. Water loss presumably occurred mostly through evaporation.

2.3.2.1 The Main Lagoon (N1)

This was the largest area of open water (4.7 Ha, Fig. 7). It had a varied shoreline most of which was bordered by saltmarsh, especially along its eastern side where the marsh was extensive. Within this section of marsh there were several small areas of open standing water which were used by shorebirds and which for the purposes of this study were included within the Main Lagoon. Almost all of the lagoon had depths of from 12–18 cm for most of this study. Its edges sloped quite rapidly to these depths, mostly within 5 m of edge (Fig. 8). Water depths did not alter considerably with tide and varied within a range of only about 7 cm over the course of the study correlating with periods of heavy rainfall and evaporation. Thus the total area of this lagoon with water depths suitable for stilt foraging changed little over the course of the study (Table 4).

There has been no detailed study of water quality in the Main Lagoon. A single measure of salinity taken in May 1992 gave a value of 41.0 ppt (Hayles 1993). Presumably values vary from hypersaline to hyposaline according to periods of freshwater input in much the same way as those at the

Table 4 Changes in the area of water (thousand m^2) at suitable depths for stilt foraging at the Newington and Mason Park Lagoons. * Pool too deep for stilt foraging, † Pool dry.

	Newington				Mason Park
Time period	Main Lagoon	Corner Marsh Lagoon	Wharf Pool	33-Marsh Lagoon	Mason Park Lagoon
10-12/11/93	46.0	5.0	1.13	† 0	4.6
17-18/11/93	46.0	10.5	1.13	3.5	18.0
24-29/11/93	46.5	11.3	1.13	2.4	18.1
06-10/12/93	47.0	6.9	1.13	† 0	3.2
17-22/12/93	47.1	15.2	1.13	† 0	16.3
04-07/01/94	46.3	1.5	0.1	† 0	7.5
17-22/01/94	46.7	0.8	† 0.0	† 0	18.1
26-30/01/94	46.0	0.2	† 0.0	† 0	7.5
14-18/02/94	46.0	0.2	† 0.0	† 0	6.4
07-10/03/94	47.0	11.7	*0.0	6.5	18.1
16-18/03/94	47.0	15.5	*0.0	8.6	18.1
22-23/03/94	47.1	15.5	*0.0	8.6	16.3
28-30/03/94	47.1	15.5	*0.0	8.0	16.3
07-11/04/94	47.1	13.6	*0.0	7.5	13.6
22-24/05/94	47.1	15.5	*0.0	2.9	19.1

Waterbird Refuge (see above). During the present study there was a thick mat of filamentous green algae extending over an area of about 30 m x 50 m at the western end, indicating that the system was maybe eutrophic. The substrate was fine mud with a 1-3 mm deep oxidised microzone below which the remainder was darker and anoxic. Water turbidity was low with the substrate clearly visible through the water column at all visits. The sediment characteristics indicate the high % of mud that was present, and an even higher % of mud was present when organics were excluded. The % of organic carbon by weight varied from 5.6%– 9.7%, some of the highest levels recorded during the study. For details of sediment analysis, and sample locations, see original report

2.3.2.2 The Wharf Pool (N2)

This lagoon differed from all other lagoons at Newington. There seemed to be no major input of saline water from the Parramatta River and the pool received mainly fresh water from a ditch which entered at the north-western corner and which drained the land to the west and south. The flow was intermittent depending upon rainfall. Salinity measured on 21st May 1992 was only 4.0 ppt (Hayles 1993). The entering water carried a high load of fine ochre-coloured clay sediment held in a semi-colloidal suspension. As a result water turbidity was high throughout the period of this study and the substrate was not visible through the water column. Water depths

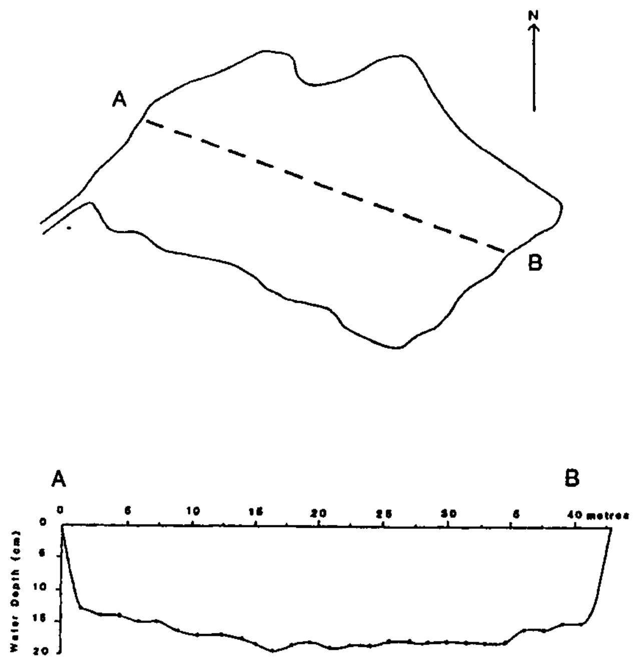


Figure 9. Water depth profiles across the Wharf Pool, Newington, March 1994. Spot checks either side of the transect gave similar depths, this lagoon has an extremely uniform bottom with little gradation of depths at any point.

varied little over the area of the pool (Fig. 9) but showed substantial seasonal variations. At the start of the study, during November 1993, average depth was 13–15 cm but this fell progressively until the pool dried up completely by late December. It remained dry until early March 1994 when it filled to an average depth of 16-18 cm following heavy rainfall. The chemical qualities of the water column and substrate were not assessed but there was no indication of algal growth and the substrate was ochre in colour for several centimetres and not obviously anoxic. The surrounding vegetation was mostly *Typha* sp. and *Juncus* sp. The sediment characteristics indicate the high % of mud present, both when organics and non organics were considered. The % of organic carbon by weight varied from 1.7%–3.7%.

2.3.2.3 *Corner Marsh Lagoon (N3)*

Situated on the north-eastern corner of the wetlands, this lagoon was uniformly shallow and had no apparent input from the Parramatta river or drainage from ditches. At the highest water levels recorded in this study, depths were mostly less than 10 cm. Water levels fluctuated frequently between November 1993 and June 1994 from only 2–3 cm to 10 cm correlated with rainfall. Thus, the area of water available as habitat for foraging stilts and other shorebirds varied throughout the study period (Table 4). Salinity on 21st May 1992 was 36.9 ppt, but this probably varied with water levels (Hayles 1993). No other aspect of water or substrate quality was measured but extensive and dense algal growth suggested eutrophication. The substrate was fine mud, black and anoxic with no evidence of a surface oxidised layer. The western end of the pool had an extensive area of saltmarsh. Otherwise the open water was mostly flanked by mangroves. There were many mangrove stumps throughout the pool.

The sediment characteristics indicate the high % of mud present, both when organics and non organics were considered, there were no differences between sampling periods. The % of organic carbon by weight varied from 3.9%–9.1%.

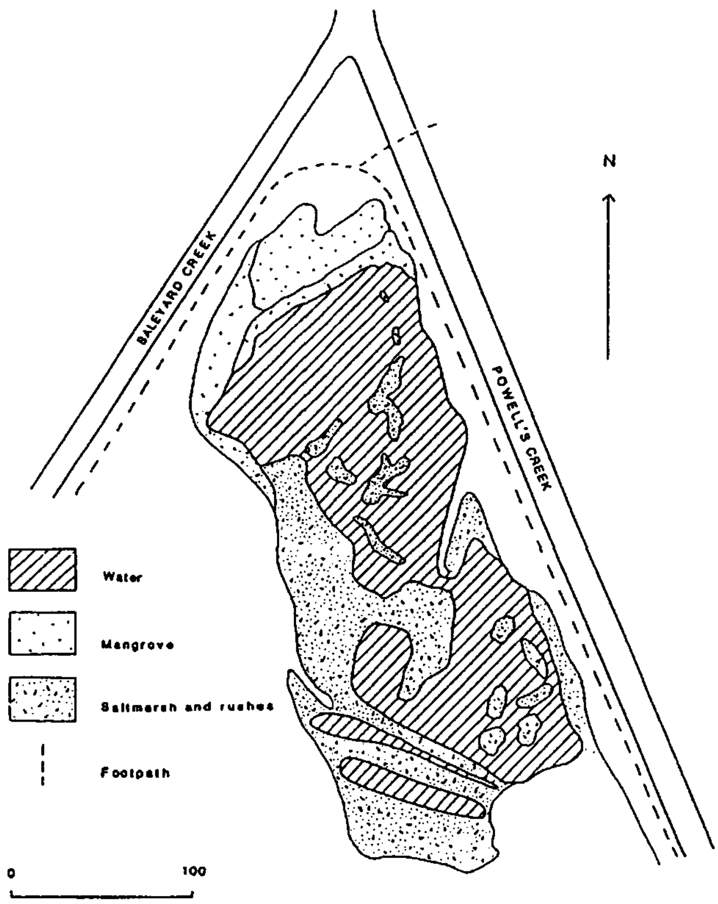


Figure 10. The lagoon at Mason Park. This is the last surviving remnant of once more extensive wetlands at the head of Homebush Bay. The lagoon has extensive fragmented saltmarsh used by shorebirds for roosting and nesting.

2.3.2.4 33-Marsh Lagoon (N4)

This was uniformly shallow with no obvious inputs of tidal water. For most of this study the pool was completely dry and filled only partially and temporarily following heavy rainfall (Table 4). Water and sediment qualities were not assessed. The lagoon was flanked on its northern and western edges by an extensive area of saltmarsh. Immediately adjacent, on its southern edge, was an area of buildings (referred to as the 33-Building) around which there was usually considerable human activity.

The sediment characteristics indicate the high % of mud present, both when organics and non organics were considered, and there were differences between sampling periods. The % of organic carbon by weight varied from 4.3%– 4.6%.

2.3.3 Mason Park Lagoon

This was an isolated remnant of wetland which until the 1940s lay at the southern end of an extensive area of saltmarsh close to the upper tidal limit of the Homebush system (Clarke and Benson 1988). It now lies between Powells and Saleyard Creeks, which have been canalised and concreted close to their point of confluence (Fig. 10). The only remaining connection with tidal

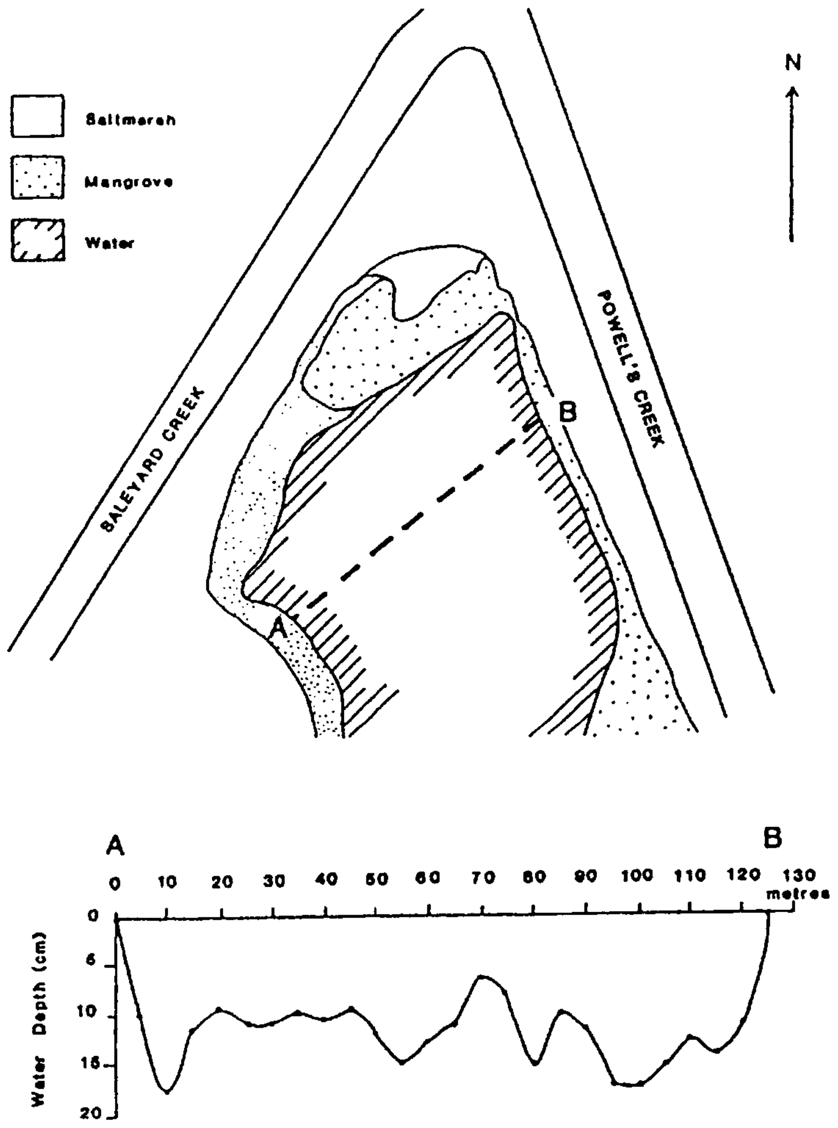


Figure 11. Profile of water depths across the northern section of Mason Park Lagoon March 1994. The lagoon had steep sloping sides and some variability in depths. However spot checks on depths within 50 m either side of the transect gave similar depths to the transect. However, depths declined steadily towards the southern end of the lagoon.

waters was artificial, through two 60 cm pipes placed behind a drop-log weir at the north-eastern corner. This arrangement was ineffective due to blockages and substantial water flow into the lagoon occurred only infrequently at the top of high spring tides. Consequently, water levels fluctuated frequently, mainly in relation to rainfall. The area of water available to shorebirds also fluctuated (Table 4). The main area of open water was in the northern section of the lagoon. Water depths, measured on 15th March 1994 when levels were about the highest of this study, were from 10 cm to 15 cm over most of the lagoon (Fig. 11). No assessments were made of water or substrate qualities. However, the water was obviously saline and there was little algal growth suggesting that conditions might not be eutrophic. Water turbidity was low with the substrate clearly visible. The sediment characteristics indicate the high % of sand present. The % of organic carbon by weight varied from 1.9%–6.8%.

Much of the vegetation in and around the lagoon was saltmarsh but this was fragmented and clumped. There was a small area of mangroves at the northern end and an area of reed swamp at the southern end. Recent plantings of eucalypts and *Casuarina* all along the western edge of the lagoon may soon become highly deleterious to the system. There was considerable human activity around the lagoon.

During this study Powells Creek and Saleyard Creek, both within a few metres of the lagoon, had accumulated deposits of silt over which shorebirds from the lagoon fed at low tide. These creeks were probably an important component of the system, but were bulldozed clear of sediment near the start of the study and their significance could not be established.

3 Black-winged Stilt

3.1 Methods

Black-winged stilts were studied at all of the lagoon habitats within the Homebush area. Their abundance patterns, diet, prey capture behaviour and prey capture rates, time and activity budgets, aggressive interactions and breeding ecology were examined. The abundance of prey species within lagoons was estimated.

3.1.1 Numbers and Densities

Counts of black-winged stilts over all of the wetlands were made at approximately 10 day intervals, always between 0900 and 1100 (EST). Observations were done simultaneously by observers at each site on 15 of 18 occasions. On the three occasions when this was not possible the two largest lagoons holding together on those dates around 90% of the total number of birds, were surveyed back to back there being about 10 mins between such surveys. Counts at three lagoons totalling 64 hrs indicated that there were generally less than 10 arrivals and departures combined per hour. Over the course of an entire day though, large numbers of birds did move between lagoons. Separate records were kept of foraging and non-foraging birds so that totals for each lagoon could be calculated. The locations of roost sites were recorded.

Numbers were converted to densities by dividing by the total area of water available in each lagoon that was within the depth range useable by the stilts. The birds foraged in water from about 1–2 cm deep to water about 17–18 cm deep which reached their bellies, approximately 17–18 cm deep. Most of the lagoons at Newington and at Mason Park were within this depth range throughout the study and for these the total area covered by water was taken as the area of suitable habitat. The Wharf Pool at Newington was of uniform water depth and was sometimes close to or above the maximum level useable by stilts. Depths recorded from the water gauge installed at its deepest point were used to assess whether or not the lagoon was suitable for stilts. At the Waterbird Refuge the area available within the required range was calculated for each occasion from water depths recorded at the measuring pole in combination with a map of depths over the lagoon assessed on 10 February 1994.

3.1.2 Diet

The diet of shorebirds can be established by the analysis of gut contents, from oral pellets which some species regurgitate, from faecal pellets and from direct observation. The first option was not appropriate and the birds were not observed to produce oral pellets and the items caught by them were too small to be identified by observation, so that the analyses of faecal pellets was the only option available to determine the prey items eaten. Preliminary samples collected during late December 1993 and early January 1994 contained undigested prey remains including those from chironomid larvae and adult dipterans. Samples of faecal pellets were then collected from the Waterbird Refuge, the Main Lagoon and Mason Park Lagoon from January to April 1994. Each pellet was examined microscopically and the presence or absence of major prey types was scored. The reliability of this method may sometimes be questionable especially if it is used to make a precise quantification of the relative importance of a range of prey items in particular diets (Davies 1977, Major 1990). Some soft bodied prey items may be digested completely leaving no evidence in the faeces and others may be digested to differing extents such that the proportions recorded in faeces do not accurately reflect proportions consumed. In the present case, the sampling of macrofauna in the lagoon substrates identified an extremely restricted range of prey in the areas where the birds were foraging so the potential for error was limited. The analysis was used only to identify the most important prey and no attempt was made to estimate the amount of prey consumed from faecal analyses.

3.1.3 Densities of Invertebrate Prey

Preliminary sampling of the substrate in the open areas of lagoon used by adult stilts revealed that only chironomid larvae and small oligochaete worms were present, and occasionally emerging adult chironomids and therefore the only potential prey items which were available to the birds. Subsequently, the densities of chironomid larvae and oligochaetes were estimated in 6 lagoons during the study period. At the Waterbird Refuge, oligochaetes were present in dectable densities only at the start of the study. The sampling procedure caused considerable disruption to the substrate, liberating a fine suspension of anoxic mud and leaving deep footstep imprints. A random sampling procedure over entire lagoons would have caused severe damage to the habitat thereby invalidating the results of further studies. Thus a sampling procedure was employed in which on each sampling occasion 15 cores were randomly selected along a transect perpendicular to the shore. The location of each transect was selected randomly. A corer of 7 cm diameter was used, inserted to a depth of 2 cm thus taking in all of the oxygenated layer containing invertebrates. Core samples were placed in a 0.5 mm mesh bag immediately after collection, sealed and placed into a container of 7% formalin. In the laboratory, the samples were washed to remove the fine sediment, the remaining sediment and fauna transfered to alcohol and all invertebrates removed, identified and counted under a binocular microscope. This collecting method using mesh bags ensures that all small organisms are retained and extracted under the microscope rather than sorted on a sieve in the field where small animals are easily damaged or missed.

Samples were taken only on submerged substrates. Sampling periods could not be organised to a strictly regular timetable for a number of reasons. Security clearance to sample at Newington was granted only at the end of January, and at some of the lagoons with highly variable water levels sampling was done only when they were flooded. Samples were taken more frequently on lagoons that were used most by the stilts and timed to coincide with estimates of stilt densities and prey capture rates. For this reason all lagoons could not be sampled on the same day. Sampling of invertebrate prey was always undertaken after estimates of stilt density and prey capture rates were made to ensure that the sampling procedure did not disturb the birds or their feeding.

Differences in the densities of larvae among transects were tested using analyses of variance, data were tested for normality and homogeneity of variances using the F max test.

3.1.4 Prey Capture Rates

The rates at which the stilts caught prey items were quantified at the Waterbird Refuge, Mason Park and the Main Lagoon, Newington at about 10 day intervals to coincide with counts of foraging birds, water levels and prey abundance estimates. Estimates of prey capture rates were made more frequently at the Waterbird Refuge in association with other work there. Some estimates were made for the Wharf Pool Lagoon, Newington before it dried up in December 1993.

The birds could be observed undisturbed at close range on all lagoons (except the Corner Marsh), but the items caught were small (less than 1 cm) and telescopes at 25x magnification were used.

Thirty-second sample periods were used during which all capture attempts and successes were recorded. Separate records were kept of items caught from the water column and those taken from the submerged substrate. Birds were selected over each lagoon at each sample period so that the whole area was represented. Only one 30–second sample was taken for each bird so that as many as possible of the population were included. For most estimates this involved at least 30 individuals.

Attempts were made to quantify prey capture rates at the Corner Marsh, Newington but the birds were nervous and unapproachable when foraging on this lagoon and the mangrove stumps made it impossible to observe individuals continuously for more then a few seconds. Consequently no data could be obtained.

3.1.5 Time and Activity Budgets

The amount of time shorebirds devote to foraging each day can be influenced, among other factors, by the density of food available to them. The assessment of time budgets can therefore be a useful indication of the quality and adequacy of particular foraging sites for the birds.

The quantification of time budgets is labour intensive. For this reason complete assessment was made at the Waterbird Refuge only, replicated over 2 days, in mid-February when the maximum numbers of birds were foraging there, giving statistically valid sample sizes. Observations were made from dawn to dusk on each day. During each hour, at 20 mins intervals, the number of stilts foraging, preening, resting and flying were counted over the entire lagoon. From these data, average figures were calculated for each hour. Assuming that each bird had roughly the same food requirements and prey capture success, the percentage of birds involved in each activity averaged across all hours should be equivalent to the percentage of time the average bird devotes to these activities.

The birds' prey capture rates were also estimated during mid-February to coincide with the time budget analysis. By combining these two figures, the daily food intake at the Waterbird refuge could be calculated.

3.1.6 Aggressive Interactions

Initial observations showed that the stilts were aggressive towards each other during foraging. This took the form of threat calls and attacks which sometimes resulted in contact. The aim of this part of the work was to assess whether or not this aggressiveness was density dependent such that it might limit the densities of foraging birds.

An intensive study area for this was established at the northern end of the Waterbird Refuge (Fig. 3). Here, during December, only a small and discrete section was within the depth range accessible to stilts, giving the opportunity for a controlled set of observations. A grid was established of colour coded 10 mm diameter stakes set at 5 m intervals over an area of 55 x 40 m. The total number of birds within this sample area and their exact positions with respect to each other could be assessed by reference to the grid. A period of 3 weeks was allowed between installation of the grid in late November 1993 and taking the first observations to allow the substrate to recover and the birds to habituate to the stakes. A series of observations was then made over a 5-week period from mid December 1993 to the third week of January 1994. The study period was restricted in order to minimise any possible additional influences arising from seasonal changes in prey abundance so that aggression could be examined in relation to bird density independently of variations in food supply. Samples of prey density at the start and end of the period suggested that there was little overall variation in prey abundance over the period.

On each observation day approximately eight, 5–mins samples were taken, spaced at 20 mins intervals. During this time, the total number of threat calls and attacks given by all birds within the gridded area were recorded. The numbers of stilts feeding were counted five times at 1–mins intervals and summed to give the average number feeding during the 5–mins sample. The numbers of birds within the grid changed during each day's recording as birds joined or left a roosting area immediately adjacent, thus providing variations in density against which variations in aggressiveness could be compared. Similar recording of threat and attack rates in relation to density were made at the Wharf Pool, Newington during December 1993. In this case the entire lagoon could be observed from one point at close range so observations were made on all birds present.

Relationships between bird density and threat call and attack rates were examined using regression analyses.

3.1.7 Breeding ecology

Black-winged stilts were the only shorebirds to breed on the lagoons in substantial numbers. Attempts were therefore made to quantify the main aspects of their habitat requirements for breeding. During visits to each lagoon, records were kept of the number of stilts involved in any aspect of breeding — courtship, nest building, incubation, etc. Laying dates (the date of laying of the last egg) were determined to the nearest 10 days either from direct observation of eggs or by recording hatching times and back-dating using an incubation period of 24 days (Pringle 1987). Clutch sizes were determined for as many pairs as possible by direct inspection of nests. At Newington nests could not be visited because of the softness of the substrate and they were therefore inspected by observation from raised positions on the shore. Attempts were made to locate and count all broods at each visit but this proved difficult as not all areas were visible from concealed observation points, and the birds reacted to human intrusions by seeking cover in saltmarsh where they could not be seen. By about 35 days of age all of the chicks fed and rested in open areas around the lagoon edges so accurate counts could be made and overall productivity quantified. Observations were made of the habitat selection of chicks throughout their development. On each visit, the positions with respect to the shoreline and the wading depths were recorded of all chicks that were visible during a single scan of the lagoon. The number of pairs was not great and most broods could be followed individually during their development. Several were first observed within a day or so of hatching so their ages and growth could be monitored. Such birds were used to gauge the ages of other birds in addition to the use of data on tarsus growth from Pierce (1982).

The development of the chicks' foraging methods and success was quantified in relation to their ages. Individual chicks were selected randomly at each visit and their rates of prey capture, their success and the methods used were quantified during 30 second sample periods. Samples were also taken of adults foraging simultaneously in the same locations, for comparison.

Differences in the foraging locations of adult and juvenile stilts were tested using a chi-square test. Differences in the foraging depths of adults and juveniles were tested using a Mann-Whitney U-test.

3.2 Results

3.2.1 Numbers and Densities

Between November 1993 and June 1994, 18 counts were made over all lagoon habitats. The total number of stilts in all lagoons, varied from 62–227. The variation was seasonal; numbers rose from 60–110 in November/December to around 200 for most of January and February, falling again to 70–80 by June (Table 5).

The changes in numbers at each lagoon tended to be less consistent than the total numbers. Only two lagoons, the Waterbird Refuge and the Main Lagoon at Newington, had foraging stilts at every visit during the study. At the Waterbird Refuge numbers rose from around 20 to 30 in November/December to between 100 and 130 during February and falling to less than 20 in May. Numbers at the Main Lagoon at Newington were generally greater than those at the Waterbird Refuge. They fluctuated around 30–50 during November and December, rose to between 70 and 120 during January, fell slightly during February, rose again during March and then declined during April and May (Figs 12,13).

Large numbers (up to 25) of stilts fed on the Wharf Pool and the Corner Marsh at Newington only during November and December. At both sites, numbers varied considerably from day to day during these months. Stilts were recorded foraging on 33-Marsh, Newington on one occasion, in June. It may be important that this was also the only occasion when there was no human activity around the edge of this lagoon (Figs 13,14).

At Mason Park, stilts were recorded throughout the study but numbers fluctuated greatly. Short periods with higher numbers (up to 22/23) were interspersed with longer periods with either very low numbers (less than 5) or none (Fig. 15).

The Back Pool at Bicentennial Park supported few or no stilts for most of this study with the exception of a brief period during February when numbers reached a maximum of 28 (Fig. 12).

These data give an idea of the distribution of stilts within the wetland complex and of temporal changes in their abundance. However, they could not be used for comparisons between sites as

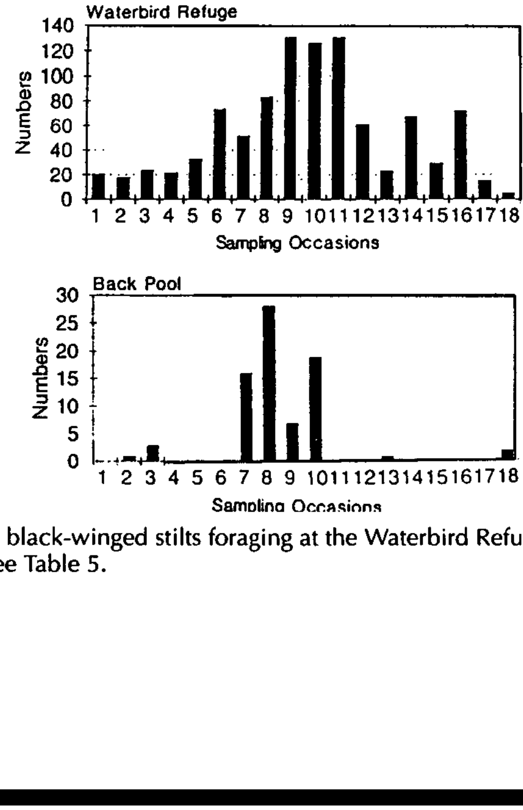


Figure 12. The number of adult black-winged stilts foraging at the Waterbird Refuge and the Back Pool. For the dates of sampling see Table 5.

the surface area of these sites differ, and therefore the figures were converted to densities. There were consistent differences among lagoons in the densities of stilts they supported (Table 6). At the Wharf Pool, Newington, during November and December 1993 they fed at densities exceeding those found at any other site throughout the entire study period with the exception of the Back Pool, Bicentennial Park, which had similarly high densities during February 1994. Average density at the Wharf Pool over the two months was 9.6 birds per 1000 m^2, almost 3x greater than average densities at the Waterbird Refuge, 6x greater than those at the Main Lagoon and about 18x greater than those at Mason Park. Over the whole period of study, average density at the Waterbird Refuge was 3.3 birds per 1000 m^2, more than twice that of 1.54/1000 m^2 for the Main Lagoon at Newington and about six times that of 0.55/1000 m^2 recorded for Mason Park.

Densities recorded at the Waterbird Refuge showed only limited temporal variation in comparison with those at the other sites, from a minimum of 2.25 to a maximum of 4.86 birds/ 1000 m^2. There was no evidence of any consistent seasonal pattern in these variations and densities at the Refuge were not significantly correlated with numbers ($r = 0.07$, $p = 0.80$). This means that the changes in the numbers of birds feeding at the Refuge, especially during January and February could not be explained by changes in the densities of birds.

Table 5 **Numbers of adult black-winged stilts foraging on seven lagoons in the Homebush wetlands from November 1993 to June 1994.**

Date	Sampling Occasions	Waterbird Refuge	Back Pool	Main Lagoon	Wharf Pool	Corner Marsh Lagoon	33-Marsh Lagoon	Mason Park Lagoon	Total
12/11/93	1	21	0	31	14	14	0	0	80
18/11/93	2	18	1	20	4	6	0	13	62
25/11/93	3	24	3	50	8	0	0	21	106
09/12/93	4	22	0	32	19	25	0	0	98
22/12/93	5	33	0	43	9	17	0	10	112
05/01/94	6	74	0	85	0	0	0	4	163
19/01/94	7	52	16	123	0	2	0	23	216
01/02/94	8	84	28	78	0	0	0	2	192
08/02/94	9	131	7	44	0	0	0	2	184
18/02/94	10	127	19	54	0	0	0	2	202
01/03/94	11	131	0	61	0	0	0	4	196
08/03/94	12	61	0	131	0	0	0	17	209
17/03/94	13	23	1	186	0	0	0	17	227
23/03/94	14	68	0	81	0	0	0	13	162
28/03/94	15	29	0	134	0	0	0	11	174
11/04/94	16	73	0	91	0	0	0	5	169
24/05/94	17	15	0	56	0	0	0	9	80
21/06/94	18	5	2	48	0	0	8	15	78

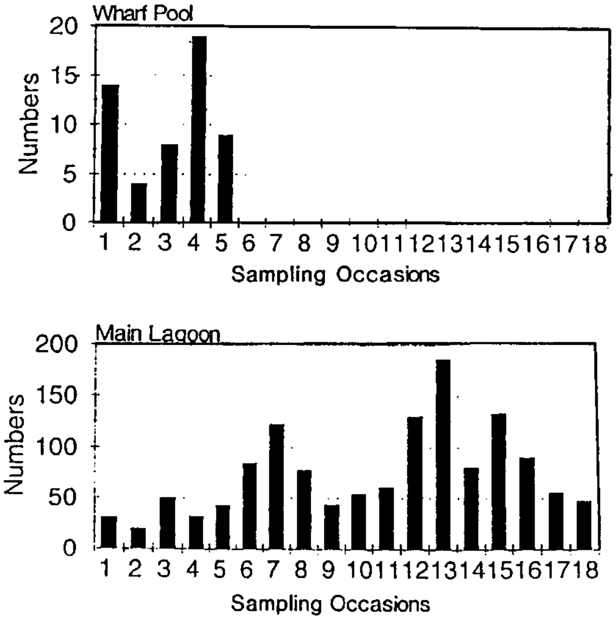


Figure 13. The number of adult black-winged stilts foraging at the Wharf Pool and the Main Lagoon. For the dates of sampling see Table 5.

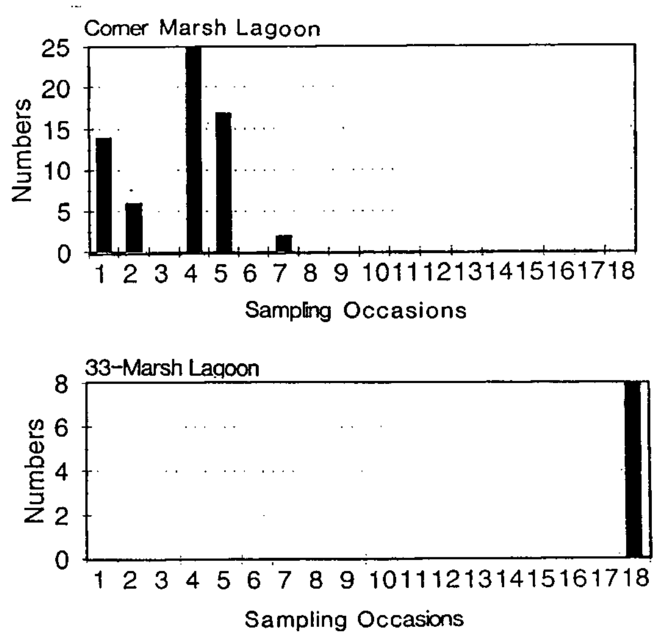


Figure 14. The number of adult black-winged stilts foraging at the Corner Marsh Lagoon and the 33-Marsh Lagoon. For the dates of sampling see Table 5.

At the Main Lagoon at Newington, densities varied from 0.66–4.04 birds/1000 m^2 over the period of study. However, in this case, in marked contrast to the Waterbird Refuge, variations in densities were correlated with variations in numbers of birds ($r = 0.99$, $p < 0.001$), ie the area did not change.

Table 6 **Densities of foraging adult black-winged stilts recorded at seven lagoons in the Homebush wetlands between November 1993 and June 1994 (numbers per 1000 m² of water surface at suitable water depths – see text). * lagoon dry + lagoon above maximum depth for stilt foraging, - no counts undertaken.**

Date	Waterbird Refuge	Back Pool	Main Lagoon	Wharf Pool	Corner Marsh Lagoon	33-Marsh Lagoon	Mason Park Lagoon
12/11/93	2.7	-	0.69	12.44	0.45	*	+
18/11/93	2.9	-	0.44	3.56	0.39	0.0	0.72
25/11/93	3.1	-	1.11	7.12	0.0	0.0	0.83
09/12/93	2.9	0.0	0.68	16.89	3.63	*	0.0
22/12/93	3.02	0.0	1.13	8.00	0.73	*	0.61
05/01/93	2.48	0.0	1.84	*	0.0	*	0.53
19/01/94	3.15	6.40	2.62	*	0.43	*	1.27
01/02/94	3.95	9.49	1.70	*	0.0	*	0.27
08/02/94	4.37	2.80	1.00	*	*	*	0.27
18/02/94	3.58	7.60	1.18	*	*	*	0.27
01/03/94	3.63	0.0	1.36	*	0.0	0.0	0.94
08/03/94	2.25	0.0	2.78	+	0.0	0.0	1.05
17/03/94	2.32	0.0	1.32	+	0.0	0.0	0.80
23/03/94	3.46	0.0	1.72	+	0.0	0.0	0.67
28/03/94	3.66	0.0	2.85	+	0.0	0.0	0.37
11/04/94	4.86	0.0	1.93	+	0.0	0.0	0.45
24/05/94	4.37	0.0	1.19	+	0.0	0.0	0.75
21/06/94	2.63	-	1.02	+	0.0	0.93	-

Densities recorded at the Corner Marsh Lagoon and at the 33-Marsh Lagoon were low throughout the study.

3.2.2 Prey Searching, Diet and Prey Capture Rates

3.2.2.1 Prey Searching Methods

Black-winged stilts have been observed to pick items from the surface of exposed substrates, but more commonly they forage while wading through water. They use a variety of capture techniques involving both visual and tactile cues (Hamilton 1975, Pierce 1985).

At Homebush, adult stilts were not observed to forage on exposed substrates even though such substrates were available. They fed while wading, utilising water depths from just over their feet to about the level of their bellies, equivalent to a range of 2-18 cm. It was evident that most birds fed in water depths spanning a much narrower range than this. To determine whether or not a definite preference existed for particular water depths, a comparison was made of recorded foraging depths with those expected by chance calculated on the basis of the areas available of

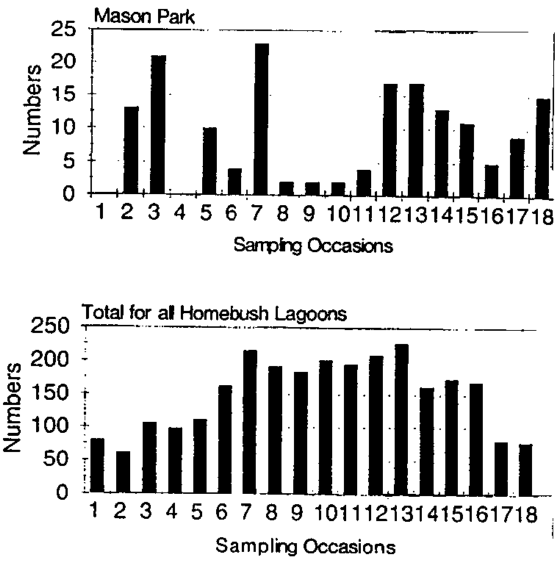


Figure 15. The number of adult black-winged stilts foraging at Mason Park Lagoon and the total for all the Homebush Bay Lagoons. For the dates of sampling see Table 5.

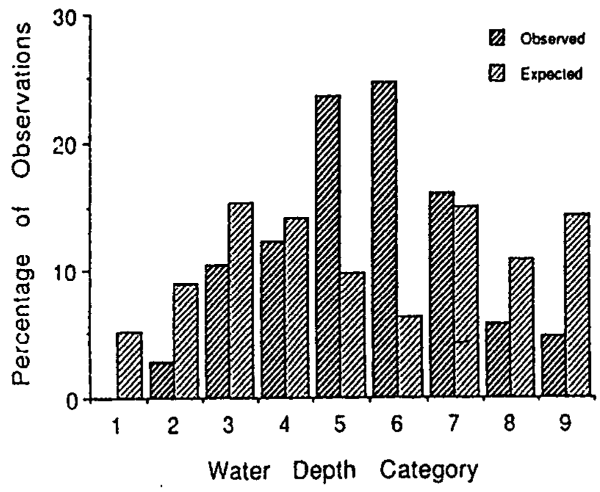


Figure 16. Foraging depths of adult black-winged stilts at the Waterbird Refuge on 8 and 10 February 1994. From 2 complete scans of all birds foraging on Refuge. Average number of birds observed per scan = 106. Expected values calculated from the area of water available in each depth category. Depth categories: 1 = 0-1.4 cm; 2 = 1.5-4.2 cm; 3 = 4.3-7.0 cm; 4 = 7.1-9.8 cm; 5 = 9.9-12.2 cm; 6 = 12.3-14.2 cm; 7 = 14.3-16.2 cm; 8 = 16.3-18.2 cm; 9 = 18.3-19.2 cm. Chi-square test of average values from 2 scans: $X^2 = 98.5$, $p < 0.001$.

different water depths at the Waterbird Refuge on 8 and 10 February 1994. A statistically significant preference was shown for depths between 10-15 cm (equivalent to about the birds' 'ankle' joint to 4 cm above it). The birds fed in depths below 10 cm and above 15 cm much less than expected by chance (Fig. 16).

Both tactile and visual prey capture methods were observed. Tactile methods consisted of plunging the bill under the water and at an angle into the substrate then moving it rapidly from side to side in a 'scything' motion or walking forwards with the bill still in contact with the substrate but with no sideways movement. These methods were observed only at the Wharf Pool, Newington and at the Back Pool, Bicentennial Park, where all birds foraged using these tactile techniques. This is consistent with the observation that the water in these lagoon was always highly turbid. The substrate could not be seen through the water column and the birds would not have been able to use visual cues. Tactile prey capture methods were not observed at any of the other lagoons where visual techniques were used exclusively. When foraging by visual cues the birds walked slowly through the water with the bill oriented downwards, looking intently into the water column. Capture attempts were made by precise pecks or probes with no lateral movements of the bill. The great majority of items were taken by probes onto the surface of the substrate through the water column, but some were also pecked from the water surface or from just below. On a few occasions at Mason Park a small number of items were pecked from partially submerged saltmarsh plants.

3.2.2.2 Diet

All of the faecal samples examined from each of the three lagoons contained remains of chironomid larvae and the remains of adult dipterans were found in 41.9%, 56.8% and 34.6% of faeces from the Waterbird Refuge, the Main Lagoon and Mason Park Lagoon repectively (Table 7). Adult chironomids were identified among the remains of the adult diterans. All samples also contained small fragments of insect exoskeleton that could not be identified.

High densities of oligochaetes were found in the core samples taken from the Waterbird Refuge during January but not subsequently, and not at any of the other lagoons. None of the faecal pellets examined recognisable fragments of oligochaetes. It is therefore reasonable to conclude that they were not important food items as they were not abundant in the lagoons, however it is possible that they were eaten at the Waterbird Refuge in January when high numbers were present in the core. If this occurred then oligochaetes must be completely digested as to leave no detectable remains in the faecal pellets. Another reason why it is unlikely that oligochaetes were prey items even at the Waterbird Refuge is that stilts forage using visual methods of prey detection and it is unlikely that they were able to locate oligochaetes within the substrate.

For most of the study period on all lagoons chironomid larvae were the only macrofauna available to the stilts on the surface of the substrate. The birds captured most of the prey by pecking on the surface of the substrate (82%, 80% and 54% of all prey taken on the Waterbird Refuge, Mason Park Lagoon and Main Lagoon respectively). It is thus reasonable to conclude from this and from the identification of chironomid larvae in all faecal pellets that chironomid larvae were important prey and probably also the main prey items taken. Items taken from nearer the water surface could also have been chironomid larvae disturbed from the bottom by the birds feeding activity but they

Table 7 Frequency of occurrence of identifiable prey remains in samples of faecal pellet material of black-winged stilts collected at the Waterbird Refuge, the Main Lagoon, Newington and the Mason Park Lagoon, between January and April 1994. n = nos of faecal pellets examined.

	n	Numbers containing chironomid larvae	Numbers containing adult dipterans
Waterbird Refuge	43	43 (100%)	18 (41.9%)
Main Lagoon at Newington	37	37 (100%)	21 (56.8%)
Mason Park Lagoon	26	26 (100%)	9 (34.6%)

may have been emerging or emerged adult chironomids trapped on the surface or other adult dipterans that could have blown into the lagoon from adjacent areas.

3.2.2.3 *Prey Capture Rates*

Records were kept separately of items taken from the submerged substrate and those taken from the water surface. Capture of the former items, although small (approximately 0.5–1.0 cm in length), was always accompanied by a distinct swallowing movement, so successful captures were obvious. These items must have been chironomid larvae as those were the only prey available to the birds on the substrate surface and the only benthic items identified in the faeces. Items picked

Table 8 **Mean prey capture rates (number of items per 30 secs, ± SE) of adult black-winged stilts foraging on the Waterbird Refuge, the Main Lagoon at Newington and Mason Park Lagoon, and Wharf Pool, from November 1993 to April 1994. Data are divided into items taken from the substrate (bottom items) and from the water surface (surface). The blank section within Wharf Pool refers to when the pool was either completely dry or too deep for foraging by the birds.**

Time period	Waterbird Refuge				Mason Park Lagoon			
	Bottom		Surface		Bottom		Surface	
	± SE	n	±SE	n	±SE	n	± SE	n
24 to 29/11/93	7.6 ± 0.3	150	0	150	2.9 ± 0.3	54	0	54
06 to 10/11/93	7.8 ± 0.6	38	0	38	No birds foraging			
17 to 22/12/93	7.1 ± 0.6	73	0	73	3.9 ± 0.3	60	0	60
04 to 07/01/94	12.3 ± 0.6	70	0	70	5.7 ± 0.5	25	0	25
17 to 19/01/94	10.6 ± 1.4	25	0	25	5.8 ± 0.5	41	0	41
26/1 to 1/2/94	13.6 ± 0.9	47	7.8 ± 0.7	47	3.8 ± 0.5	25	10.4 ± 2.0	25
14 to 18/02/94	13.1 ± 0.7	78	5.2 ± 0.5	78	No birds foraging			
02 to 07/03/94	13.2 ± 0.7	31	0.4 ± 0.2	31	7.5 ± 0.8	32	0.6 ± 0.2	32
16 to 18/03/94	14.1 ± 0.5	60	2.7± 0.4	60	8.3 ± 0.1	30	1.8 ± 0.4	30
21 to 22/03/94	14.3 ± 0.4	83	1.8 ± 0.4	83	8.7 ± 0.5	40	0.8 ± 0.2	40
09 to 13/04/94	13.8 ± 0.4	81	1.7 ± 0.3	81	5.5 ± 0.7	52	0.2 ± 0.1	52
	Main Lagoon, Newington				Wharf Pool, Newington			
24 to 29/11/93	12.3 ± 0.9	30	0	30	6.9 ± 0.5	61	0	61
06 to 10/11/93	10.1 ± 0.6	30	0	30	10.7 ± 0.7	59	0	59
17 to 22/12/93	11.0 ± 0.8	25	0	25				
04 to 07/01/94	10.3 ± 0.4	31	0	31				
17 to 19/01/94	7.7 ± 0.8	25	0	25				
26/1 to 18/2/94	10.0 ± 0.5	42	14.4 ± 0.8	42				
14 to 18/02/94	No data		No data					
02 to 07/03/94	4.5 ± 0.4	30	1.3 ± 0.3	30				
16 to 18/03/94	5.8 ± 0.6	50	4.7 ± 0.7	50				
21 to 22/03/94	5.0 ± 0.6	41	8.6 ± 0.7	41				
09 to 13/04/94	6.2 ± 0.6	50	1.5 ± 0.3	50				

from the water surface were always minute and only just discernible by telescope at close range and no obvious swallowing motion was associated with them. It is likely that such items were adult chironomids or the adults of other small dipterans. No comparison was possible in this study of the relative calorific value to birds of these various types of prey but simply on the basis of size, the larvae should have greater nutritional value than the adult insects.

With only a few exceptions prey taken from the substrate greatly out-numbered those taken from the water surface. There was a seasonal trend in the proportion of surface items taken, from zero during November to mid January, reaching a peak in late January and February then declining again during March to June. This change correlates with ambient temperatures and probably was a result of seasonal emergence patterns of adult dipterans. Even at their maximum occurrence, surface items were less important numerically than the chironomid larvae taken from the substrate. Thus, although a precise quantification in terms of the relative calorific intake rates cannot be given, chironomid larvae were the most important food source for the stilts.

Considering only the capture rates achieved by the stilts when feeding on larvae, there were differences among lagoons and some indication of temporal changes (Table 8). During November and December, capture rates were slightly higher at the Main Lagoon at Newington than at the Waterbird Refuge but from January onwards this was reversed with capture rates at the Refuge exceeding those at the Main Lagoon. By March and April the birds were able to achieve an intake rate at the Refuge of some two to three times greater than that achieved at the Main Lagoon. In this respect the Waterbird Refuge was a higher quality feeding area than the Main Lagoon for most of the study period.

At Mason Park, the rates at which the stilts captured larvae increased steadily from just under 3 per 30 sec in November to over 8 per 30 sec at the end of March. Nevertheless these rates were consistently lower than those achieved at the Waterbird Refuge. Compared with capture rates at the Main Lagoon at Newington, those at Mason Park were lower from November to January, but higher during March and April.

3.2.3 Density of invertebrate prey

Chironomid Larvae

Densities of chironomid larvae recorded along the sample transects varied significantly with time over the study period at the Waterbird Refuge, the Main Lagoon and Mason Park (Tables 9,10). There was a tendency for densities to be low on all transects from mid February to early March. This period covered the time of minimum water levels followed by rapid rises as a result of heavy rainfall. However, the data were insufficient to determine what, if any, relationships existed between these variables.

Comparisons of the densities of larvae were made among transects at these three lagoons for four occasions on which samples were taken on all of them within five- day time periods: 27 January to 1 February; 2–7 March; 22–24 March; 11–15 April. For all periods, densities varied significantly among sites (Table 9). The Waterbird Refuge consistently had higher densities of chironomid larvae than the other two lagoons. The Main Lagoon had higher densities than Mason Park on two occasions, on one occasion there was no significant difference between them and on the other occasion densities at Mason Park were higher than those at the Main Lagoon.

Converting the mean number of larvae per core to densities per square metre, the Waterbird Refuge had densities ranging from $1073/m^2$ to $9473/m^2$ and an average for the period of $5172/m^2$,

Table 9 **Mean densities (mean no./core with S.E.) of chironomid larvae recorded in 6 lagoon sites at Homebush throughout the study period. In all cases the number of sample cores taken was 15. Densities varied significantly over time at the Waterbird Refuge (ANOVA, $F^{5\ 84} = 18.23$, $p < 0.001$), at the Main Lagoon, Newington (ANOVA, $F^{4\ 70} = 16.56$, $p < 0.001$) and at Mason Park (ANOVA, $F^{4\ 70} = 16.56$, $p < 0.001$). From late January to mid April samples were taken within 5 days of each other at the Waterbird Refuge, Main Lagoon, Newington and Mason Park on 4 occasions. On all, densities of larvae varied significantly among sites. (27 Jan-1 Feb, ANOVA, $F^{2\ 42} = 17.05$, $p < 0.001$; 2-7 March, ANOVA, $F^{2\ 42} = 24.19$, $p < 0.001$; 22-24 March, ANOVA, $F^{2\ 42} = 25.53$, $p < 0.001$; 11-15 April, ANOVA, $F^{2\ 42} = 266.4$, $p < 0.001$). - no samples collected.**

Date sampled	Waterbird Refuge		Main Lagoon		Mason Park		Wharf Pool		Corner Marsh		33-Marsh	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
23/12/93	12.7	3.8	-		-		-		-		-	
12/01/94	18.7	1.9	-		-		-		-		-	
27/01/94	-		10.6	1.4	-		-		-		-	
28/01/94	18.5	2.5	-		-		-		-		-	
01/02/94	-		-		4.5	0.8	-		0.9	0.3	-	
18/02/94	-		0.2	-	0.1	-	-		-		-	
02/03/94	-		-		0.7	-	-		-		-	
04/03/94	-		0.0	-	-		-		-		3.4	0.6
07/03/94	4.1	0.7	-		-		3.1	0.5	-		-	
22/03/94	29.1	4.0	-		4.7	0.6	-		-		-	
24/03/94	-		11.7	1.5	-		-		-		8.3	1.3
25/03/94	-		-		-		11.3	1.7	0.4	-	-	
11/04/94	36.5	1.8	-		2.8	0.5	-		-		-	
15/04/94	-		4.5	0.7	-		-		-		8.4	1.5

almost four times the average for the Main Lagoon and almost eight times that for Mason Park. For the stilts, the Waterbird Refuge thus had by far the highest densities of prey, although prey abundance varied 8.8 fold over the study period (Table 9).

The Wharf Pool and 33-Marsh had densities of chironomid larvae equivalent to those found on the Main Lagoon but the Corner Marsh Lagoon had markedly lower densities.

Oligochaetes

Oligochaetes measuring 4–6 mm long were recorded in the core samples from all lagoons except the Wharf Pool. Highest densities were recorded at the Waterbird Refuge up until the end of January, subsequently few individuals were found (Table 11). The Main Lagoon was the only other lagoon to be sampled during January but densities here were only $18.2/m^2$ compared with the value of $5564/m^2$ at the Waterbird Refuge. All other lagoons had similarly low densities during February to April.

Table 10 Densities of chironomid larvae in 6 lagoons at Homebush, expressed as numbers per m^2. In all cases the number of sample cores taken was 15. - no samples collected.

Sampling date	Waterbird Refuge	Main Lagoon	Mason Park	Wharf Pool	Corner Marsh	33-Marsh
23/12/93	3290.9	-	-	-	-	-
12/01/94	4849.3	-	-	-	-	-
27/01/94	-	2753.2	-	-	-	-
28/01/94	4797.4	-	-	-	-	-
01/02/94	-	-	1176.6	-	241.6	-
18/02/94	-	52.0	18.2	-	-	-
02/03/94	-	-	189.6	-	-	-
04/03/94	-	0.0	-	-	-	883.1
07/03/94	1072.7	-	-	813.0	-	-
22/03/94	7550.6	-	1228.6	-	-	-
24/03/94	-	3044.2	-	-	-	2155.8
25/03/94	-	-	-	2927.3	103.9	-
11/04/94	9472.7	-	727.3	-	-	-
15/04/94	-	1176.6	-	-	-	

Table 11 Densities of oligochaetes (mean no. per core) recorded in 6 lagoons at Homebush. In all cases the number of sample cores taken was 15. - no samples collected.

Sampling Date	Waterbird Refuge		Main Lagoon		Mason Park Lagoon		Wharf Pool		Corner Marsh Lagoon		33-Marsh Lagoon	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
23/12/93	21.3	6.96	-		-		-		-		-	
12/01/94	55.7	13.1	-		-		-		-		-	
27/01/94	-		0.07	0.13	-		-		-		-	
28/01/94	21.4	3.5	-		-		-		-		-	
01/02/94	-		-		0.07	0.13	-		0.27	0.23	-	
18/02/94	-		0		0		-		-		-	
02/03/94	-		-		0		-		-		-	
04/03/94	-		0		-		-		-		0.07	0.73
07/03/94	0		-		-		0		-		-	
22/03/94	0.27	0.23	-		0		-		-		-	
24/03/94	-		0		-		-		-		0	
25/03/94	-		-		-		0		0.13	0.75	-	
11/04/94	0		-		0		-		-		-	
15/04/94	-		0.2	0.19	-		-		-		-	

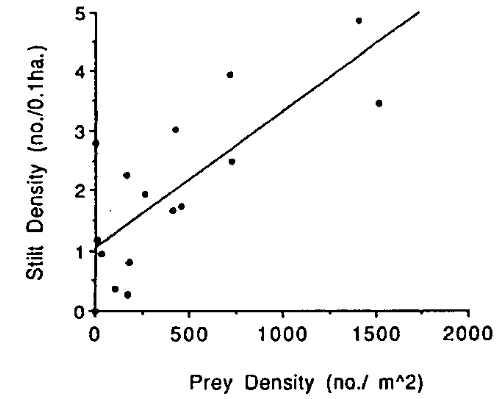


Figure 17. Relationship between the density of chironomid larvae and the density of foraging black-winged stilts in lagoon habitats at Homebush, December 1993 to April 1994. Data for Waterbird Refuge (6 days), Main Lagoon, Newington (5 days) and Mason Park Lagoon (5 days) combined. $r = 0.77$, $p < 0.001$.

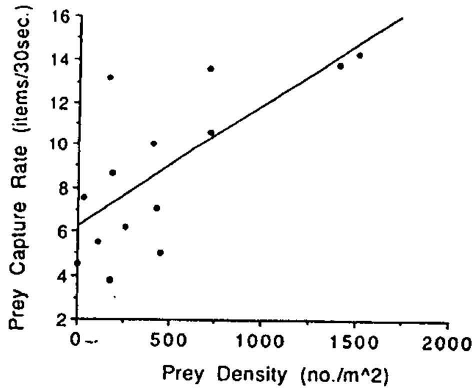


Figure 18. Relationship between the prey capture rates (bottom items only) achieved by black-winged stilts and the density of chironomid larvae in lagoon habitats at Homebush, December 1993 to April 1994. Data for the Waterbird Refuge, the Main Lagoon, Newington and Mason Park Lagoon combined. $r = 0.71$, $P < 0.01$.

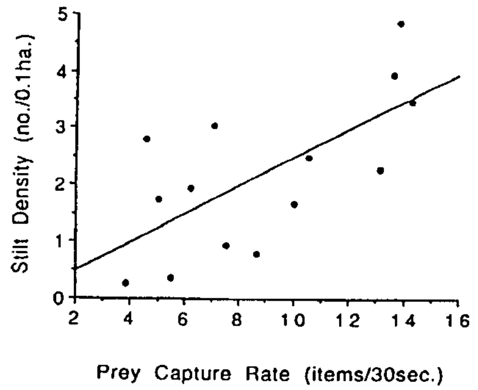


Figure 19. Relationship between the density of black-winged stilts and their prey capture rate in lagoon habitats at Homebush, December 1993 to April 1994. $r = 0.68$, $p < 0.01$.

3.2.4 Relationships between prey abundance, prey capture rates and densities of stilts

Estimates were made of prey densities (chironomid larvae density) and corresponding stilt densities on six separate occasions at the Waterbird Refuge, five occasions at the Main Lagoon at Newington and five at Mason Park between December 1993 and March 1994. Prey densities were higher at the Refuge than at the Main Lagoon which in turn had higher average densities than those at Mason Park (see Table 8). Stilt densities were also consistently highest at the Refuge and lowest at Mason Park, thus suggesting a relationship between the density of the birds and their food supply. Combining data for all sites, a significant correlation was found between the two variables (Fig. 17). At the Waterbird Refuge, the relationship between these variables was also significant ($p < 0.01$) but on the other two lagoons the relationships were not significant (Main Lagoon $r = 0.81$, $p = 0.09$; Mason Park $r = 0.06$. $p = 0.9$).

Prey capture rate data were obtained for each site within one to three days before each estimate of prey density and a significant correlation was found between variations in prey capture rate and correlated with variations in their prey capture rates (Fig. 19). These two figures just include the 14 simultaneous samples of prey density, prey capture rates and stilt density.

Thus there is evidence that the densities at which the stilts fed were adjusted in some way by the rate at which they were able to catch prey which in turn was related to the abundance of their prey.

3.2.5 Regulation of density among foraging stilts

The most probable explanation limiting bird density is the result of changes in the aggressiveness of the birds in relation to food supply. If this was the case, one would predict that under specific prey densities the birds would exhibit increasing aggressiveness towards each other as their density increased and the distances between individuals decreased. Such aggressive behaviour would limit the density of foraging birds only if individuals attempting to feed were excluded from doing so. There would exist a surplus of such excluded birds within the general area that would feed on any lagoon if the opportunity arose. An appropriate test of density limitation operating through aggressive behaviour would be to demonstrate the existence of such a surplus of birds.

The main factor that influenced the size of suitable foraging areas for stilts at the Waterbird Refuge was changes in water depths. Water depths could not be manipulated experimentally, but the rapid changes in water levels that occurred in relation to variations in rainfall and evaporation resulted in equivalent changes in the extent of the suitable foraging area. If there were birds that had been excluded from foraging on the Refuge, there should have been an increase in the numbers that fed there when the size of the foraging area increased and *vice versa* and a correlation between the numbers feeding and the size of the foraging area. From initial observations it was clear that the stilts were frequently aggressive towards each other during foraging. This was observed on all lagoons and also even when they were feeding at the lowest densities recorded. Aggressive interactions took the form of threat calls, attacks and occasionally physical combat. Threat calls were harsh, nasal, yapping-like vocalisations that varied in loudness, pitch and frequency. Immediately preceding attacks the volume and frequency of such calling increased and was high throughout attacks. Attacks were made either by running through the water or by flying towards the other individual. They were hardly ever contested and the attacked individual almost always responded by moving off to distances varying from a few metres to about 60 m. Birds that had just been attacked were often attacked again by other birds if they landed back within the flock area but rarely so if they moved to the edge of the flock. The frequency of threat calls and attacks were recorded in relation to variations in the density of foraging birds at the Waterbird Refuge, in the gridded sample area at the northern end, and at the Wharf Pool, Newington. The reason for selecting these two lagoons for study was to provide a comparison of aggression levels at a lagoon where the birds feed by sight and a lagoon where they fed by tactile methods. Earlier it was shown that visual methods were used in the clear water of the Waterbird Refuge whereas tactile methods were used in the highly turbid water of the Wharf Pool. Studies of other shorebirds have sometimes shown that aggression levels vary according to the foraging methods used (e.g. Goss-Custard, 1980) and as a consequence birds may feed at differing densities. In this study, the stilts fed at higher densities at the Wharf Pool and Back Pool, both with highly turbid water, compared with other lagoons with clear water. Differing aggression levels may have been the explanation for these differing feeding densities.

Within observation periods variations in the density of birds feeding in the sample area of the Waterbird Refuge occurred mainly as individuals moved to and from the roosting area which was

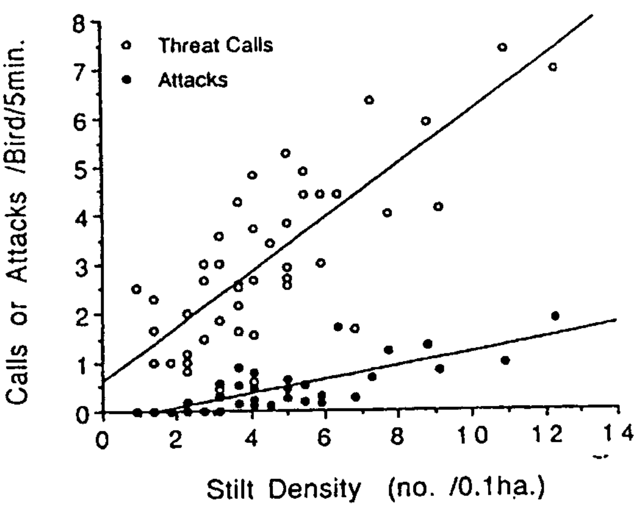


Figure 20a. Relationship between the frequency of threat calling and attack initiation per bird and overall density of foraging stilts at the Waterbird Refuge study grid, December 1993-January 1994. For call rate, $r = 0.72$, $n = 49$, $p < 0.001$; for attack initiation rate, $r = 0.75$, $n = 49$, $p < 0.001$. Stilts at this lagoon foraged by visual methods in clear water conditions.

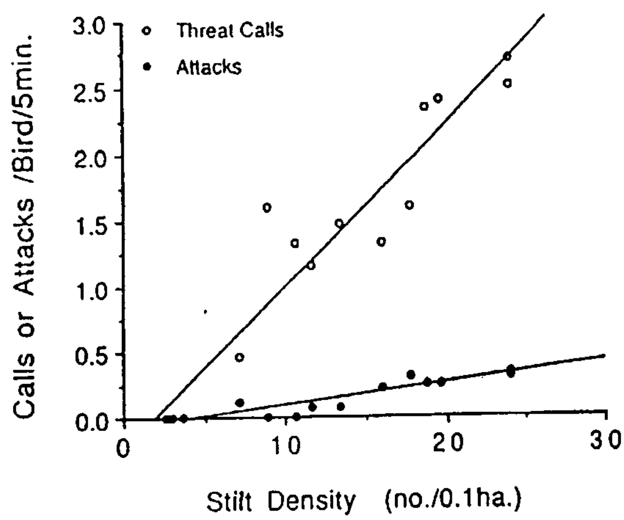


Figure 20b. Relationship between the frequency of threat calling and attack initiation per bird and overall density of foraging stilts at the Wharf Pool, Newington, December 1993. For call rate, $r = 0.96$, $n = 15$, $p < 0.001$; for attack initiation rate, $r = 0.91$, $n = 15$, $p < 0.001$. Stilts at this lagoon foraged by tactile methods in highly turbid water conditions.

within 10 m of the edge of the feeding area. An additional amount of variation arose from the birds moving around within the total foraging area at the northern end of the lagoon. At the Wharf Pool variation occurred as individuals moved to and from a roosting area at the edge of the lagoon and as birds moved in and out from adjacent lagoons. Thus during an observation period lasting only 2–3hrs, a six to eight fold variation in the density of birds was usually recorded.

Total threat call rates and the rates per bird increased significantly with increasing bird density at both the Waterbird Refuge and the Wharf Pool (Fig. 20a and Fig. 20b). At the Refuge, threat call rates increased from 1.0 per bird to 7.0 per bird per 5 mins when densities increased from one to 11 birds per 1000 m^2. At the Wharf Pool they increased from 0 to about one over the same range of bird densities. Attack rates per bird also increased significantly with increasing bird density at both sites and rates were higher at the Waterbird Refuge than at the Wharf Pool (Fig. 20a, 20b). The first part of our prediction, that the birds' aggressiveness increases with increasing density of foraging birds and decreasing distances between individuals is proved. Furthermore, aggression levels were higher when the birds fed by visual than by tactile methods. The birds' prey capture rates were similar in both situations (see Table 8) so it is unlikely that differences in aggression

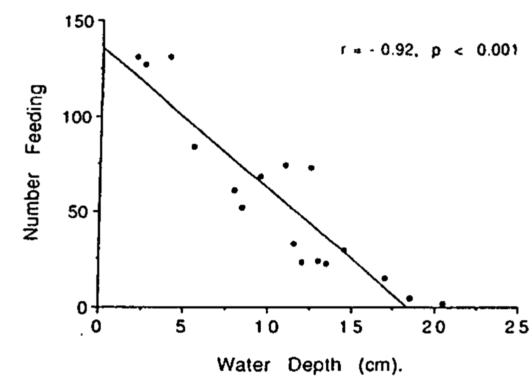


Figure 21. The number of black-winged stilts foraging at the Waterbird Refuge in relation to water depths recorded at a depth gauge at the northern end of the lagoon, November 1993 to June 1994. Thirteen of the points are averages of counts on 3 consecutive days, the remaining 4 are from single counts on single days. $r = -0.92$, $p < 0.001$.

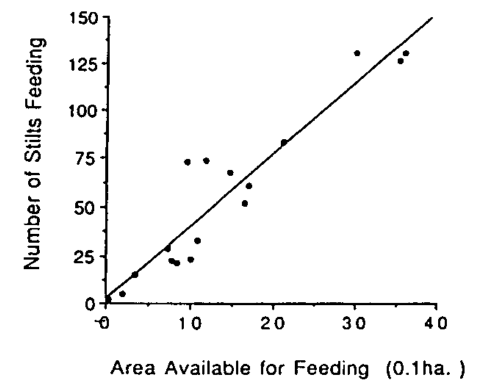


Figure 22. Relationship between the area of water within the depth range used by black-winged stilts at the Waterbird Refuge estimated on 17 occasions between November 1993 and June 1994 and the number of stilts foraging on the lagoon on each occasion. $r = 0.79$, $p < 0.001$.

were caused by differences in food intake rate. It is thus possible that variations in aggressiveness could have limited densities, but at different levels according to water turbidity and the birds' foraging methods. The second prediction was that the total numbers of stilts feeding is correlated with the size of a suitable foraging area. This was tested at the Waterbird Refuge as the Wharf Pool was dry for the main part of the study period. Compared with early December, water levels at the Refuge fell by 11.5 cm by late February and the size of the foraging area increased 4.7 fold (see Table 2). The reverse occurred as levels rose again by mid April. Over the course of these changes, the number of stilts feeding on the Refuge was correlated with water depths (Fig. 21) and with the extent of the foraging area (Fig. 22), confirming the second prediction.

3.2.6 Daily Activity Budgets

For neither adults nor juveniles was there any evidence of consistent or marked diurnal patterns in the percentage of time spent foraging. There was a tendency in both age groups for most birds to forage more in the morning than in the afternoon (Fig. 23). The aim was to simply assess the % of daylight hours available to the birds for feeding, as a simple measure of the adequacy of the lagoon as a feeding site.

Overall, adults spent on average 58.0% and 63.7% of their time foraging on the 2 days and juveniles spent 60.7% and 61.0%. Values were thus consistent between days and there were no major differences between age groups. There were no significant tidal influences in the Waterbird Refuge and the birds did not appear to respond to tide in any way.

The important point of these results is that they suggest that adult and juvenile stilts were able to secure their daily food requirements relatively easily and hence that prey densities at the

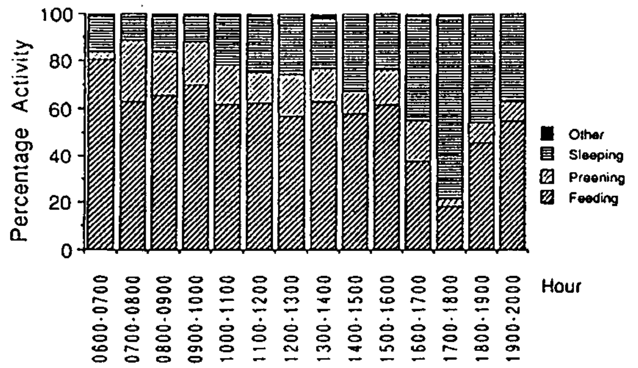
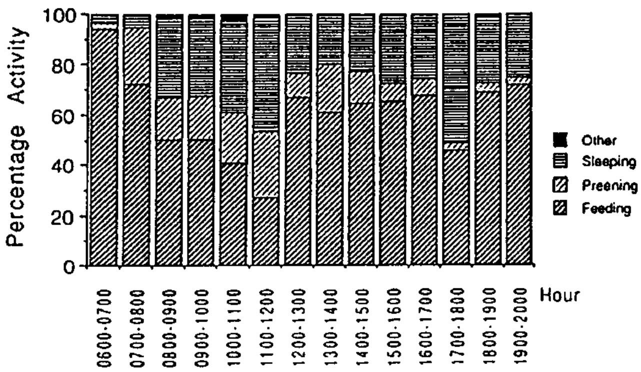


Figure 23. Daily activity budgets of adult (top) and juvenile (bottom) black-winged stilts foraging on the Waterbird Refuge, February 1994. Data are from 3 scans each hour, including all birds at the Refuge, averaged for each hour. Two days were sampled, 15th and 16th February, and data shown are mean values for the two days. Total adult stilt numbers ranged from 19-141 and juveniles from 37-54.



Waterbird Refuge were adequate. This assumption is on the basis that as the birds were only foraging for 60% of the day they must have secured adequate food during this time as presumably they feed until they have eaten sufficient food. Several hours of day light were still available for feeding but were not used by the birds again indicating that they had obtained adequate food resources.

It is not known to what extent, if any, these birds might have foraged at night. Many were still foraging at 2000 hrs, after dusk, when light levels were falling rapidly but most had ceased feeding 20 mins later. As their foraging method was visual, one would not expect night time foraging except perhaps on nights with bright moonlight, alternatively they may have switched to tactile foraging at night.

3.2.7 Stilt Breeding ecology — Numbers, Distribution, Laying Dates and Success

Stilts attempted to breed at the Main Lagoon at Newington, at Mason Park and at the Waterbird Refuge. At the Main Lagoon laying occurred in two periods; 15 pairs laid during October 1993 and seven pairs during the latter half of November and the first week of December 1993. It is not known whether or not the second period involved some failed breeders from the first period or whether they were newly breeding pairs. At Mason Park five pairs laid during the latter half of November and at the Waterbird Refuge one pair laid in the last week of November.

On the Main Lagoon the nests were built along the western edge between 30 and 60 m from the shore in a dense mat of filamentous green algae. The birds constructed nest mounds entirely of algae which had to be constantly built up during incubation to offset sinking from the consolidation and compaction of algae. Both sexes participated but the males seemed to do most of the nest maintenance. At Mason Park more flimsy nests consisting of only a few stems of grass and sedge were constructed on top of small saltmarsh islets. The single pair at the Waterbird Refuge laid on a small islet of pebbles and debris at the north-eastern corner with no evident nest material. All of the nests were completely surrounded by water at the time of laying.

When the study started, the birds involved in the first breeding period at Newington were already part-way through incubation. However, the sequence of behavioural changes associated with the start of breeding were observed for birds in the second breeding period at the Main Lagoon and at Mason Park. The most noticeable change was a sudden and marked increase in aggressiveness. Birds that had established a pair bond began to attack other birds, often flying up to 50–70 m to do so. Both males and females were involved. This rapidly developed into defence of specific areas so that by the time nest building started each pair possessed a territory within which they bred or attempted to breed. Hence, nests at the Main Lagoon and Mason Park tended to be regularly spaced. Sample sizes (5–7) were too small to test the spacings statistically but mean distances to neighbouring nests were 39.5 ± 3.1 m (n = 5) at Mason Park and 10.6 ± 0.50 m (n = 14, October nests) and 19.1 ± 1.3 m (n = 7, November/December nests) at the Main Lagoon for the first and second laying periods respectively. This territorial behaviour could have limited the density of breeding pairs of stilts, but there was no evidence that it actually did so on either lagoon. The nature of the areas defended on the two lagoons differed. At Mason Park members of the nesting pair did all of their feeding within the defended areas, whereas at the Main Lagoon almost all of feeding was done well away from the area around the nest which being a solid mat of filamentous algae was unsuitable for foraging. Nest spacing for the first nesting period was less than half that for the second period, when there was half the number of pairs. The spacing was probably brought about through aggressive behaviour but the actual distances between nests may have been a consequence of the number of pairs settling. It is not known if any pairs were prevented from breeding, so the question of density limitations remains open.

Clutch sizes were determined for 13 of the 28 clutches laid. All were of four eggs. None of the clutches at Mason Park hatched. All were abandoned following a rapid fall in water levels which occurred progressively from within about one week of laying. Two of the clutches from the second period of laying at the Main Lagoon were also abandoned before hatching but not in response to changing water levels. Chicks hatched from all other clutches (21) but it was not possible to obtain data on the exact numbers that hatched as visits could not be made daily. Nevertheless broods could be followed through development and the numbers of full-grown young produced per pair was established. In total 38 young were produced in 18 broods. Overall, including all pairs that laid (28), average productivity was 1.38 young per pair.

Young stilts hatch synchronously and are then immediately (within 1 day) led by the adults to the shore adjacent to their nests (Pierce 1982). At the main lagoon the chicks had to swim up to 60 m and also negotiate the thick algal growth on the surface before reaching the shore. Two broods were observed undertaking this movement and had not completed it within 2 hrs of observation. The chicks were clearly wetted and in some distress. Five broods were observed at hatching; four were of four chicks and one was of three chicks. However, the sizes of six broods observed at about five days old were between 1–3. This suggests that a substantial fraction of chick losses occurred soon after hatching. The period of movement from nest to shore may have been a vulnerable period. Stilts did not breed at Newington in 1992 probably because algal growth was not extensive enough for them to construct nests (Straw, *pers. comm.*).

The main potential predators of eggs and chicks of stilts at Newington were ravens *Corvus cornoides* and goshawks *Accipiter fasciatus*. When stilts were incubating or had chicks less than 10 days old, a total of 23 raven incursions were recorded into the nesting area during 9 hrs of observation. When there were no eggs or chicks less than 10 days old available only five incursions were recorded during 6 hrs of observation. The difference is significant ($X^2 = 5.72$, $p < 0.05$). This suggests that ravens may have been attracted to the area mainly when eggs or small chicks were available to them, but on none of these incursions were ravens seen to take eggs or chicks. On all occasions they were attacked by groups of up to seven stilts as soon as they reached the edge of the lagoon and chased persistently until they left the area (Table 12). Some incubating birds left their clutches to join attacks. Group nesting in areas vulnerable to predation is probably advantageous. There was a large population of ravens around the Newington wetlands: up to nine individuals were seen at a time. They were also able to approach close to the stilt nesting area by moving through the adjacent tree cover. The presence of dense woodland immediately adjacent to stilt nesting areas may be undesirable but more extensive observations are needed to establish the impact of raven predation on eggs and chicks and the influence, if any of close woodland cover. The presence of ravens and the fact that clutches were sometimes left exposed while the adults attacked human intruders near the nesting area would render the stilts potentially vulnerable to human disturbance.

Table 12 Number of breeding black-winged stilts participating in attacks against Australian ravens that intruded into the breeding area at the Main Lagoon, Newington November-December 1993.

Number in attacking group	1	2	3	4	5	6	7
Number of occasions	0	2	5	4	10	3	4

3.2.8 Habitat Selection and Foraging Behaviour of Chicks

Records were kept of the locations, in relation to the shore, of chicks that were observed foraging at the Main Lagoon and at the Waterbird Refuge. Only one brood of three chicks hatched at the Refuge but many from the Main Lagoon were led to the Refuge by their parents from the age of about 40 days onwards, when they could fly well. Most observations of chicks younger than this were made at the Main Lagoon.

The chicks showed a marked tendency to forage close to the shoreline. Up to the age of 40 days almost all sightings of chicks around the lagoon were within 5 m of the water's edge (Table 13). Chicks less than about 5 days old usually fed within about 2 m of the saltmarsh edge on the exposed substrate.

During mid to late February observations were made at the Waterbird Refuge of young that were all within the age range of 60-90 days. They still showed a marked preference for the lagoon edges whereas adults recorded simultaneously showed no such preference, most feeding farther from the edge than 5 m (Table 14, Fig. 24).

Two factors were probably responsible for the chicks' preference for edge areas: predator avoidance and foraging behaviour. The responses of adults and their chicks were observed to 31 potential predator intrusions over the lagoon; 25 from ravens, four from sea eagles *Haliaeetus leucogaster* and

Table 13 Distance from water's edge at which black-winged stilt chicks fed at Main Lagoon, Newington. Figures are numbers of observations. The depth at 10 m from water's edge was 3-4 cm and at 30 m 5-6 cm. Chicks older than 10 days could have waded at all depths as their legs were longer enough but they chose to stay at the water's edge.

Age of chick (days)	Feeding on exposed substrate above water line	Feeding in water- distance from water's edge (m)			
		0-5	6-10	11-20	21-30
1-5	32	0	0	0	0
6-10	2	27	0	0	0
11-20	0	35	0	0	0
21-30	0	24	0	0	0
31-40	0	25	0	0	0
41-50	0	29	2		

two from brown goshawks *Accipiter fasciatus*. While the chicks were foraging their parents were often up to about 50 m away but spent a proportion of their time being vigilant. Adults responded to potential predators by flying up and calling loudly. Small chicks, especially those less than about 20 days of age, invariably responded by running into the cover of saltmarsh, crouching and freezing. Close proximity to cover afforded by such edge habitats presumably reduced predation rates. Until the chicks were approximately 30 days old their parents defended a territory of about 100 m of shoreline within which the chicks fed. All other stilts and their chicks as well as other shorebirds and ducks were excluded from this area. Ducks were attacked persistently when they approached to within about 5 m of the chicks. Presumably, some duck species could be potential competitors with or predators of young chicks. This territorial behaviour might limit the number of broods that are able to occupy the lagoon edges.

Table 14 Comparisons of foraging locations of adult and juvenile black-winged stilts at the Waterbird Refuge, February 1994. Edge = within 5 m of the water's edge, centre = greater than 5 m from water's edge. Data are from 5 sample counts over the entire refuge on 5 separate days. All juveniles were between 60 and 90 days old.

	Mean number foraging at edge +SE	Mean number foraging at centre +SE
Adults	16.6 ± 0.9	127.0 ± 4.1
Juveniles	17.6 ± 0.9	2.0 ± 0.8

Chicks less then 5 days old foraged only over wet exposed substrates or on top of algal mats, close to the edge. They were never seen to forage while wading. They picked small items off the substrate surface. By the time they reached 6-10 days of age this had changed with most foraging while wading. Mostly, they waded up to around the depth of their 'ankle' (tibiotarsus-tarsometatarsus joint). This preference for foraging in the water column persisted thereafter and the most frequently recorded foraging depths were between the middle of the tarsometatarsus and the 'ankle' (Table 15). For chicks of ages 6–10, 11–20, 21–30, 31–40 days old the actual depths most frequently recorded were about 25–30 mm, 35-40 mm, 41–55 mm, and 56–70 mm respectively. Especially for the younger chicks, these depths occurred only close to the shoreline.

Table 15 Foraging depths of chicks in relation to age at Newington, Main Lagoon. 0 = foraging on exposed substrate. Foraging in Water: 1 = to half-way up tarsometatarsus, 2 = from half-way up tarsometatarsus to tarsometatarsus/tibiotarsus joint, 3 = from tarsometatarsus/tibiotarsus joint to half-way up tibiotarsus, 4 = from half-way up tibiotarsus to tibiotarsus/femur join

	Foraging depth				
Age of chick (days)	0	1	2	3	4
1-5	32	0	0	0	0
6-10	2	4	23	0	0
11-20	0	2	24	4	5
21-30	0	6	18	0	0
31-40	0	8	15	2	0
> 40	0	18	13	0	0

Older chicks (40-60 days) tended to wade well below their ‘ankle’ joint and could presumably have waded in deeper water. This apparent preference for shallower water was studied in more detail at the Waterbird Refuge during February 1994 when the young had reached 60-90 days of age and their growth was complete. Young birds that foraged along the edge of the Refuge within 5 m of the shore (see above), waded in shallower water than did adults feeding within the same zone and also significantly shallower than those at which other young birds foraged in the central areas of the lagoon (Table 16). These central-foraging young birds had significantly lower prey

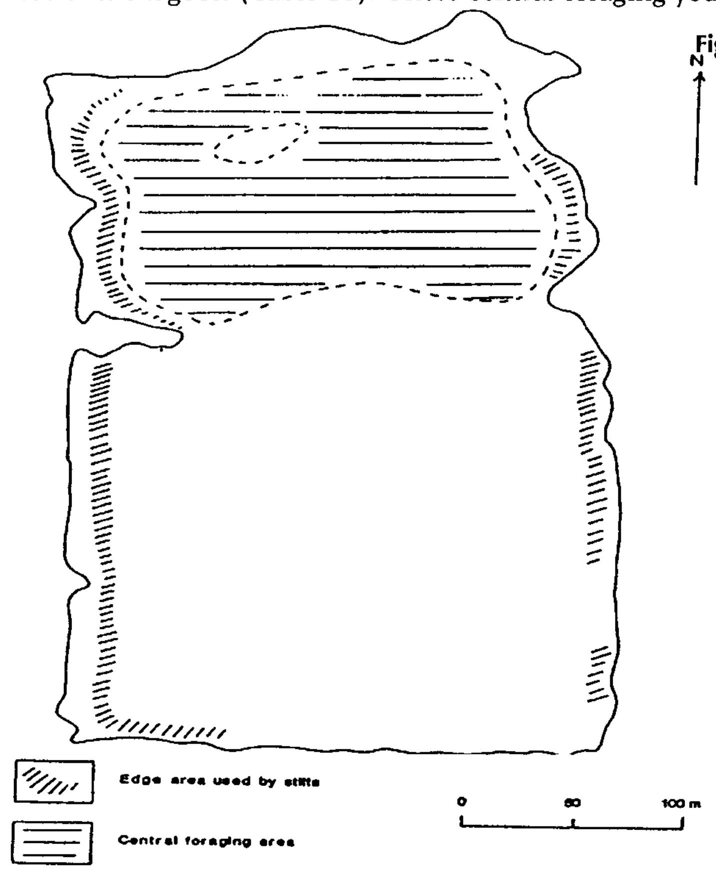


Figure 24. Juvenile black-winged stilts at ages 60-90 days preferred to forage along the shallow edge areas of the Waterbird Refuge whereas adults preferred to forage in central areas. (see Tables 13 and 14).

Table 16 **Comparison of foraging depths of adult and juvenile (60-90 days) black-winged stilts feeding in edge habitats, within 5 m of the shoreline, at the Waterbird Refuge, February 1994. Depth categories: 1 = 0-1.4 cm; 2 = 1.5-4.2 cm; 3 = 4.3-7.0 cm; 4 = 7.1-9.8 cm; 5 = 9.9-12.2 cm; 6 = 12.3-14.2 cm; 7 = 14.3-16.2 cm; 8 = 16.3-18.2 cm; 9 = 18.3-19.2 cm. Juveniles fed significantly more often in shallower water than did adults Mann-Whitney U-test. Z (corrected for ties) = -3.977, $p < 0.001$.**

Foraging depth	Adults	Juveniles
1	0	0
2	1	16
3	4	11
4	6	9
5	21	10
6	13	11
7	8	5
8	4	1
9	0	0

capture rates than adults feeding alongside them at the same water depths and also significantly lower prey capture rates than the young that fed along the edge of the lagoon (Table 17). This applied particularly to prey items captured from the substrate surface through the water column. Capturing such items is presumably more difficult than capturing surface items as their real position will be distorted by refraction of light at the water surface. The birds must learn to make the appropriate compensations and this will be especially difficult if the water surface is rippled by wind or the presence of other birds wading close-by. Often, young birds up to 6 months old were often observed to place their bills more than half-way into the water and pause, looking into the water, before making an attempt to capture bottom-living prey items. This behaviour would have minimised the amount of disruption to the water surface caused by the probe and by reducing the distance from bill tip to prey item presumably reduced the chances of error. Even so, a sample of approximately 6 month old young observed foraging in the same water depths as adults still had lower capture rates of bottom items (Table 18).

Table 17 **Table 17. Comparisons of prey capture rates of adult and juvenile black-winged stilts feeding in edge (within 5 m of water's edge) and centre (further than 5 m from water's edge) habitats at the Waterbird Refuge, February 1994. t-test comparisons: Adults 1 vs 3 - t = 0.867, $p < 0.001$; 2 vs 4 - t = 5.01, $p < 0.001$; Juveniles 1 vs 3 - t = 3.70, $p < 0.001$; 2 vs 4 - t = 2.87, $p < 0.01$.**

	1 Centre bottom items	2 Centre surface items	3 Edge bottom items	4 Edge surface items
Adults	13.1 ± 0.7 (80)	5.2 ± 0.5 (80)	5.2 ± 0.7 (78)	11.1 ± 0.8 (78)
Juveniles	1.9 ± 0.4 (49)	6.1 ± 0.4 (49)	5.7 ± 0.8 (77)	8.9 ± 0.7 (77)

It seems likely that the preference shown by young stilts for shallow edge habitats arises from a combination of constraints imposed by their lower proficiency in prey capture and, in the early stages, of their need for cover to avoid predators.

Table 18 Comparison of prey capture rates of adult and juvenile (4-5 months old) black-winged stilts feeding together in a flock in the central areas of the Main Lagoon, Newington. Even at this age the juveniles still had a lower capture rate of bottom items (chironomid larvae) than did the adults ($t = 3.84$, $p < 0.001$). The juveniles tended to capture surface items at slightly faster rates than did the adults but not significantly so ($t = -1.75$, $p = 0.083$).

	Bottom items			Surface items		
	mean rate	SE	n	mean rate	SE	n
Adults	6.2	0.5	50	1.5	0.3	50
Juveniles	3.1	0.5	32	2.6	0.6	32

We were unable to assess the diet of edge feeding young birds as we were unable to locate droppings. However, lagoon edges where the birds fed had high densities of mosquito larvae, especially in water close to saltmarsh. Mosquito larvae were also seen in the algal mats. There were also dead insects, mainly dipterans, washed into the shoreline. Mosquito larvae were not numerous away from the lagoon edges in areas of open water; where the main prey available were chironomid larvae.

Young birds less than 30 days old fed entirely by pecking items from the surface of the substrate, water or algae (Table 19) rather than by probing through the water column to the underlying substrate. Although not quantified, mosquito larvae were often the only or main items available at the water surface, close to the shore. Chironomid larvae were not available at the water surface but were available on wet mud substrates that had recently been uncovered by falling water levels. It seems likely that mosquito larvae were important prey for the chicks but this needs to be verified by further research.

Table 19 Relationship between age of stilt chicks and their peck success. All of the chicks observed pecked at and took items only from the surface of water, algal mats or moist substrates.

Age	No. of chicks	No. of pecks	No. of successes	% success
1-5	12	127	45	35.4
6-10	22	452	147	32.5
11-15	15	173	71	41.0
16-20	15	259	141	54.4
21-30	8	126	82	65.1
31-40	4	43	29	67.4
41-50	17	159	126	79.3
51-60	21	326	126	84.4
Adult	14	547	483	88.3

3.3 Discussion

The black-winged stilt was the most abundant shorebird in the Homebush area and the only species to breed there in large numbers. One of the most widespread and numerous of Australia's resident shorebirds, it has an estimated total population size in the order of 250 000 individuals (Watkins 1993). It occupies a wide range of freshwater and saline habitats but prefers areas of open shallow water (Blakers *et al.* 1984). Hence, the birds are affected by seasonal patterns of inundation and by longer term periods of drought. They undertake long distance movements within Australia in response to changing conditions, in particular, moving from inland to coastal areas as the former dry out (Lane, 1987). Thus although abundant they rely upon a network of suitable habitat being available to them and are potentially vulnerable to progressive habitat loss especially in coastal areas. The concentration of over 200 at Homebush during the summer months is important within New South Wales. With appropriate management it should be possible to improve the quality of habitat available to the birds and hence to increase their numbers yet further, if this was considered desirable.

At Homebush, adult black-winged stilts foraged on areas of open shallow water in the saline lagoons. At the Waterbird Refuge, where a detailed study of their behaviour was done, variations in the density of foraging adult stilts were significantly correlated with variations in prey density (chironomid larvae). The birds were highly aggressive towards each other while feeding and interactions among individuals increased as the density of foraging birds increased. It is probable that this aggressive behaviour served to limit the densities of stilts and that the densities observed were the maximum attainable under the prevailing conditions of prey abundance. The Main Lagoon at Newington and Mason Park Lagoon had lower densities of chironomid larvae than had the Waterbird Refuge and also had lower densities of stilts so it seems probable that densities were also being regulated on these sites. In the only other study of stilt foraging, on a freshwater lake habitat in New Zealand, the density of stilts was also correlated with the density of their prey which in this case were the larvae of *Deleatidium* (Ephemeroptera) (Pierce 1985). Thus a close relationship between density of the birds and of their food supply may be a general phenomenon among foraging stilts. Densities at Homebush could be increased further by increasing the density of prey (chironomid larvae and perhaps oligochaetes) available there.

The number of stilts foraging on the Waterbird Refuge was closely correlated with water depths. The significance of changing water depths was that they resulted in changes in the extent of suitable habitat for stilts. Variations in chironomid densities were independent of variations in water levels and changes in the numbers of stilts were not simply correlated with changes in their own density. Increases in stilt numbers thus arose mainly through additional birds moving into the lagoon to occupy additional areas of suitable habitat when water levels fell and *vice versa*. This is consistent with the proposition that the birds limited their own densities at particular prey densities by their aggressive behaviour towards each other. Such birds would be attracted into the lagoons and allowed to settle from the general 'pool' of mobile individuals that are known to move to coastal regions from drying-out inland areas as the summer progresses.

Densities of foraging adult stilts were higher at water depths between 10 to 15 cm than at depths below or above this suggesting that the ideal foraging habitat for them would be provided by a lagoon of completely uniform water depths within these limits. However, this would conflict with the needs of immature stilts and other shorebirds such as curlew sandpipers whose preferences were for shallower water. Thus to achieve successful breeding of stilts and the highest overall

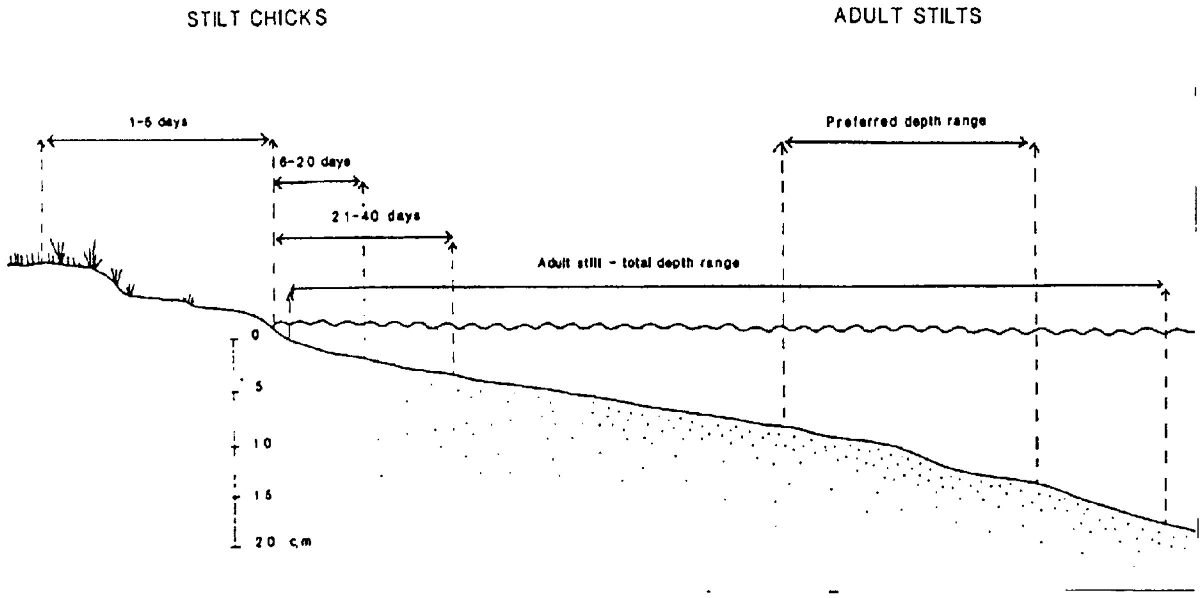


Figure 25. Diagrammatic representation of microhabitat selection among foraging black-winged stilts in the Homebush Bay Lagoons. Adult stilts prefer to forage in water depths between about 10 to 15 cm. Young chicks less than about 5 days prefer to forage on exposed substrates around the lagoon edges. Older chicks and juveniles prefer to forage in shallow water around lagoon edges.

diversity of shorebird species, compromises in water depths would be needed. In the present state of the lagoons, the Waterbird Refuge, with its gently sloping bottom, offers the greatest potential to achieve a variety of water depths for a range of species, but the Main Lagoon at Newington with its more uniform bottom is probably best managed primarily for stilts. At Newington, the Wharf Pool, 33-Marsh Lagoon and Corner Marsh Lagoon were dry, or nearly so for most of the summer of this study. The Mason Park Lagoon was also well below its maximum extent for most of this period.

Chick and juvenile stilts occupied different habitats from the adults, preferring to forage close to the lagoon edges rather than in central open areas. Instead of capturing prey mostly from the substrate as did the adults, they took most of their prey from the water surface or from just underneath. Mosquito larvae were the only prey available at the surface in these edge areas and although it could not be proven it is almost certain that these were the main prey of young stilts probably up to about 80–90 days of age. Young stilts probably preferred these items because being closer to the surface they were easier to capture. Even at about 80-90 days old the young stilts were unable to capture bottom living prey at rates equivalent to those achieved by the adults. High densities of mosquito larvae around the lagoon edges especially those adjacent to saltmarsh, which the birds used for cover, were probably essential for successful growth and development of the chicks. This requirement may conflict with mosquito control programs.

Apart from one pair of stilts that reared 3 young at the Waterbird Refuge the Main Lagoon at Newington was the only lagoon on which the stilts bred successfully. There are no published data for stilt breeding success in Australia, but a study in New Zealand found that only 69 young fledged from 1014 eggs in 125 nesting attempts, a production of only 0.56 young per nest (Pierce 1986). In Europe the average brood size of the subspecies *H. (himantopus) leucocephalus* was 1.4 (Lippens *et al.* 1966). Production from the Newington breeding birds averaged 1.14 fledged young per pair (n = 22), comparing favourably with these other areas. Conditions on the Main Lagoon in 1993/94 thus seem to have been relatively favourable.

4 CURLEW SANDPIPER

4.1 METHODS

Curlew sandpipers were counted at the same time and by the methods as used for the stilts. However, the data on water depths were not precise enough to allow conversion of numerical values to densities per unit of suitable habitat, as was done with the stilt data. A limited number of faecal pellets were examined for prey remains but none were found. The items taken by the sandpipers were too small to be identified visually. The sandpipers foraged mainly by tactile methods and their probe rate was too high to be quantified by direct observation as was their success rate. The sandpipers' daily activity budgets were quantified at the Waterbird Refuge during February 1994 by the same methodology used for the stilts.

4.2 RESULTS AND DISCUSSION

4.2.1 Numbers

Curlew sandpipers occurred mostly at the Waterbird Refuge and at the Mason Park Lagoon. Only small numbers (<10) occurred on the Main Lagoon at Newington. Within the total study area they were present in reasonable numbers until late February, after that few individuals were seen (Table 20).

Total numbers varied considerably between November and February, from low values of around 50 to a maximum of 157. There was no seasonal trend in these variations. Overall, the Waterbird Refuge tended to support higher numbers than Mason Park Lagoon. Numbers at the former tended to increase from November to February whereas numbers at the latter tended to decline. Numbers using the two lagoons were significantly negatively correlated ($r = -0.63$, $n = 14$, $p = 0.016$) suggesting the possibility of a link between them. Indeed, small flocks of curlew sandpipers were often seen to move directly between the two lagoons, flying along Powells Creek. They treated the lagoons as a single ecological unit. The increase in numbers at the Refuge occurred over the period of decreasing water levels there and sandpiper numbers were significantly negatively correlated with water depth (Fig. 26). As curlew sandpipers foraged while wading at

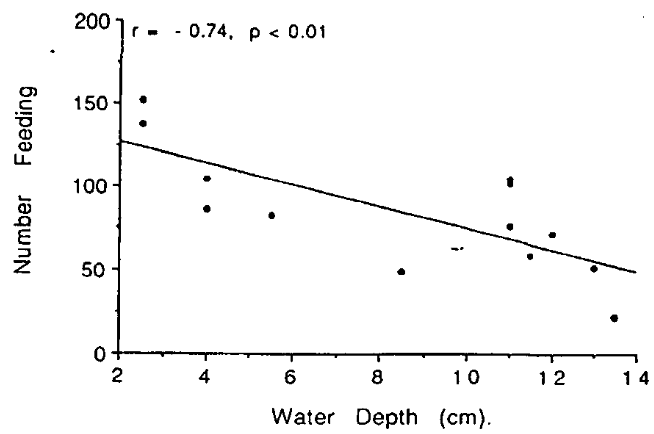


Figure 26. Number of curlew sandpipers feeding at the Waterbird Refuge in relation to water depths recorded at measuring gauge at the northern end of the lagoon, November 1993 to February 1994. Decreasing water depths resulted in increases in the area of the lagoon with water depths suitable for the sandpipers. $r = -0.74$, $p < 0.01$.

this site (see below) a decrease in water depths would have resulted in an increase in the extent of water at depths suitable for them, in the same manner as was earlier described for black-winged stilts. The sandpipers were able to forage in depths up to 6 cm (Table 21).

Curlew sandpipers at Mason Park also foraged in Powells Creek. As the tide ebbed from the creek the sandpipers were seen to fly to it from the lagoon (Table 22). They used only a small area of raised sediment about 20 m below the junction of Powells and Saleyard Creeks and several raised areas within Powells Creek.

When variations in the number of sandpipers within the various wetlands at Homebush are taken into account, the total number over the whole area still showed considerable variation. There must therefore have been movements into and out of the Homebush wetlands. The nature of the variations, with frequent increases and decreases over short time periods suggests that the sandpipers might not have been travelling far to alternative feeding areas. The only other area in the upper Parramatta estuary where curlew sandpipers fed was Hen and Chicken Bay. There was more uniformity in total sandpiper numbers, especially between December and January, when

Table 20 Total numbers of curlew sandpipers recorded at the Homebush wetlands and at Hen and Chicken Bay, November 1993 to March 1994. - = no observations made

Date	Waterbird Refuge	Mason Park	Newington	Homebush Total	Hen and Chicken Bay	Grand total
12/11/93	76	0	0	76	-	-
18/11/93	22	29	0	51	-	-
22/11/93	0	74	0	74	-	-
23/11/93	7	126	2	133	7	140
29/11/93	51	94	1	145	77	222
15/12/93	75	34	0	109	-	-
22/12/93	59	0	6	65	47	112
04/01/94	109	8	4	121	-	-
19/01/94	49	0	0	49	66	115
01/02/94	83	0	7	90	-	-
08/02/94	60	85	0	145	-	-
10/02/94	105	6	0	111	17	128
15/02/94	152	5	0	157	-	-
16/02/94	138	6	0	156	-	-
01/03/94	0	18	0	18	-	-
08/03/94	0	6	0	6	4	10
17/03/94	0	5	0	5	-	-
22/03/94	0	4	0	4	0	4
28/03/94	0	0	0	0	-	-

those foraging in Hen and Chicken Bay were also taken into account, suggesting that there may have been interchanges of birds over all of these sites (Table 20).

Table 21 Foraging depths of curlew sandpipers feeding on the Waterbird refuge on 15th and 16th February 1994. Number of observations (%). Depths: 0 = on substrate; 1 = water depth 1-15 mm; 2 = 16-30 mm; 3 = 31-45 mm; 4 = 46-60 mm; 5 = 61-76 mm.

Water Depth	0	1	2	3	4	5
Number of birds (%)	0	0	16 (11.0)	47 (32.4)	82 (56.6)	0

Table 22 Counts of curlew sandpipers foraging on the lagoon at Mason Park and in the immediately adjacent Powells and Saleyard Creeks on 23.11.93. As the tide ebbed birds moved from Mason Park Lagoon where they foraged for about the following 2.5 hrs until the tide recovered the substrate again. Between 1100 and 1115 a small flock of 18 sandpipers flew into Powells Creek from the direction of the Refuge and between 1145 and 1200 hrs all were seen to fly down Powells Creek towards the Waterbird Refuge demonstrating the linkage between these sites. Powells Creek is an important feeding site for this small population. Sediment clearing operations in the creek should not be done from September to March when the birds are present.

Time	Number feeding in Mason Park	Number feeding in creeks
08 30	49	0
09 00	56	0
09 15	56	0
09 30	53	0
09 45	47	6
10 00	46	7
10 15	23	28
10 30	21	27
10 45	25	22
11 00	0	56
11 15	0	73
11 30	0	62
11 45	0	15
12 00	0	0
12 15	0	0
12 30	0	0

4.2.2 Foraging Behaviour

In the lagoon habitats curlew sandpipers foraged while wading. Most frequently they waded between their 'ankle' (tibiotarsus-tarsometatarsus joint) and belly, at depths up to 6.0 cm (Table 21). When water levels were high they were restricted to edge areas up to these depths, but when levels were low at the end of February, they foraged in open areas up to about 75 m from the nearest edges, at the northern end of the lagoon. Their dispersion patterns when foraging were variable, ranging from single individuals and small groups up to distinct flocks of between 100 and 150 birds. Spacing between individuals was variable; birds were seen foraging alone with up to 20 m to the next individual and flocks were seen with individuals almost touching each other to spacings of up to 5 m or so. Aggressiveness to each other was also variable, from little apparent aggression in flocks to frequent attacks and displacements by birds foraging alone. It also looked as though there was considerable mutual avoidance when feeding alone or in highly spaced flocks. It is possible that there might have been limitation of the density of foraging sandpipers through aggression or avoidance. The increase in the numbers foraging in the Waterbird Refuge as the area available for them increased suggests that this might have been the case.

Curlew sandpipers foraged using tactile or chemosensory techniques in which the head was usually immersed and the bill thrust into the substrate with a rapid jabbing motion. These jabs usually occurred in quick succession in a fast 'stitching' action, especially when the birds were feeding in tight flocks. There were only two possible prey items in or on the substrates of the submerged areas where they fed; chironomid larvae and oligochaete worms. Their foraging technique would have enabled them to detect and capture both of these. The items were also similar in size, and within the preferred size range for curlew sandpipers (Puttick 1978), so they may have fed on both prey items available.

4.2.3 Daily Activity Budgets

The curlew sandpipers' daily activity budgets were studied at the Waterbird Refuge on 15th and 16th February 1994. There was no significant difference in the results for the two days so they were pooled. During the first hour after dawn there was a low level of foraging activity involving less than half the population. This was followed by intense foraging involving most birds for approximately the next 8 hrs until about 1500 hrs. For the remaining 4 hrs foraging levels were

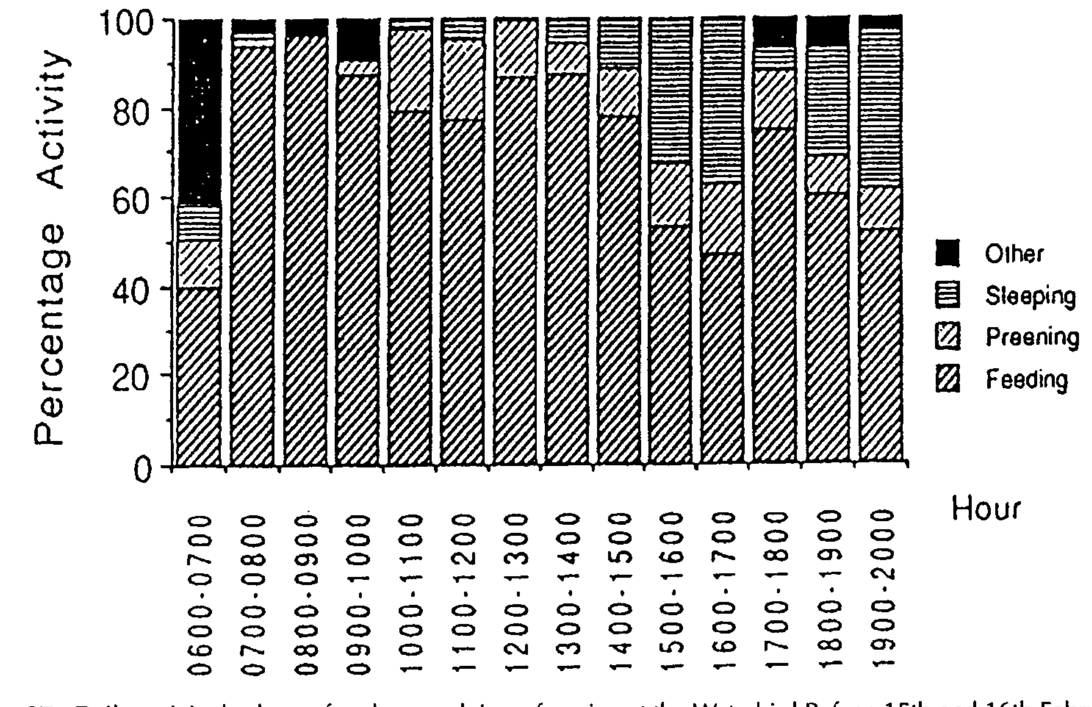


Figure 27. Daily activity budgets of curlew sandpipers foraging at the Waterbird Refuge 15th and 16th February 1994, immediately prior to their northward migration. Data are from 3 total scans each hour, averaged over the 2 days sampled, numbers varied from 95-149.

lower with only about half the birds foraging at any time and on both days activity increased again for one hour in the evening, between 1700 and 1900 hrs (Fig. 27). Averaging values over the whole day, the sandpipers spent 73.1% and 71.5% of their daylight hours foraging on 15th and 16th February respectively. This suggests that they were able to obtain their daily food requirements relatively easily and hence that food availability in the lagoon was probably adequate. The study period coincided with the birds' premigratory fattening period when their energy needs would have be maximal.

When not foraging the birds spent most of their time asleep (12.5%, averaged over 2 days), preening (10.2%) or standing vigilant (5.1%). They roosted at the Refuge on an exposed islet of pebbles at the northern end and on the edge at the north-eastern corner and usually either simply walked into the water or made short flights of less than 100 m to start foraging. The flights were so infrequent that they were not recorded during any of the sample scans. Flying to and from foraging areas took up a minor portion of the birds' daily time budget and energy expenditure.

5 BLACK-FRONTED PLOVER

5.1 METHODS

Black-fronted plovers were counted with the other shorebirds on surveys over all of the wetlands. Up until April only single individuals were observed at any site and it was not possible to obtain quantitative ecological information on their foraging behaviour or habitat selection. However, during April to June small flocks moved into the area and on 22nd June observations were made of a flock of 12 to 20 individuals foraging in the southwest corner of the Main Lagoon at Newington. The area consisted of saltmarsh, exposed substrate and shallow water (Fig. 28). The substrate was divisible into two categories: moist firm substrate with no surface water and soft wet substrate with a film of surface water. Water levels had fallen by about 2 cm during the 10 days prior to the observations. The plovers foraged on both substrate types and in the adjacent shallow water. To determine any microhabitat preference, eight scans of all plovers over the whole area were made at 30 mins intervals and the numbers foraging on each microhabitat recorded. At 15 mins intervals the foraging depths of all individuals feeding in the water were recorded by comparing with the birds' tarsus length (26.3 mm), subdivided into four categories. The extent of each substrate type and of water at two depth categories (1–13 mm and 14–26 mm) was assessed by direct mapping onto a base map prepared from an aerial photograph. Peck rates (number per 15 sec) were recorded from a sample of birds selected randomly in each microhabitat. A sample of birds was selected in each microhabitat and success quantified for pecks that were in clear view of the observer.

Comparisons of densities among substrates were made by analysis of variance, data were tested for normality and homogeneity of variances using the F max test. Differences in peck success among habitats were tested using a chi-square test and regression analysis was used to test relationships between water depths and prey capture rates.

5.2 RESULTS AND DISCUSSION

Black-fronted plovers were recorded foraging on all of the lagoons throughout the wetlands. From November to February only 1-4 individuals were recorded over the whole area per visit, with no evidence of breeding. From March to June, after the species' breeding season in New South Wales numbers increased and the birds formed small flocks (Table 23). In May, 27 were recorded in one flock on 33-Marsh Lagoon at Newington and in June a flock of 20 was recorded on the Main Lagoon.

The birds observed in May on 33-Marsh were feeding on an extensive area of wet mud substrate left around the lagoon by rapidly falling water levels. High densities of chironomid larvae were the only potential prey observed on the surface of the substrate so the plovers were probably taking these items. By June water levels had risen again covering this foraging area.

On the Main Lagoon the birds fed in water, on wet substrate with a film of water over its surface and on moist, firm substrate with no surface film of water. The highest densities occurred on the moist substrate which was preferred over the other microhabitat types (Table 24). The birds' peck rates did not differ among microhabitats but peck success was significantly higher on the moist substrate (Table 25). The birds thus preferred to forage on the most profitable microhabitat.

Table 23 Total number of black-fronted plovers recorded on all of the Homebush Bay Lagoons combined, November 1993 to June 1994.

Month	Number of counts	Average per count
November	5	1.4
December	2	3.5
January	2	1
February	2	2
March	4	5.7
April	1	10
May	1	33
June	1	23

When foraging in water the birds showed a significant preference for depths of 1.3 cm and less (Fig. 29). Maximum observed foraging depth was 2.6 cm. Peck rates declined significantly with increasing water depth, from 36.4 per min at 0.7 cm to 6.4 per min at 2.6 cm (Fig. 30). This species has a typical plover foraging technique consisting of scans for visual cues followed by a series of rapid steps before stopping to peck at the potential prey item. Deep water impedes the technique.).

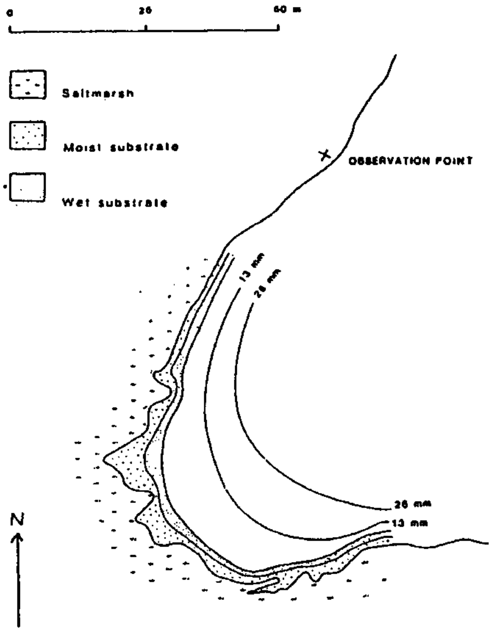


Figure 28. Detail of the intensive study area for black-fronted plover observations in the extreme southwest corner of the Main Lagoon, Newington.

Table 24 Microhabitat selection of black-fronted plovers in a study area at the south-west corner of the Main Lagoon. Data from 8 counts of all birds foraging within study area. Average densities differed significantly among microhabitats (ANOVA, F^{2}_{21} = 23.84, p < 0.001, n = 8), with the birds preferring to forage on moist, firm substrates rather than wet substrates or in water.

	Water	Wet substrate	Moist substrate
Average number (+/- SE)	3.75 (0.92)	2.38 (0.42)	8.38 (1.12)
Average density (+/- SE)	0.20 (0.05)	0.89 (0.16)	1.86 (0.25)

Table 25 **Table 25. Foraging behaviour of black-fronted plovers in relation to microhabitat in a study area at the south-west corner of the Main Lagoon. Peck rates did not differ significantly among habitats. (ANOVA, F^{2}_{92} = 1.71, p = 0.19). Peck success was significantly higher on moist substrates compared with wet substrates and water (X^2 =7.63, $p < 0.05$).**

	Water	Wet substrate	Moist substrate
Mean peck rate/15 secs ± S.E. (n)	7.10 ± 0.64 (30)	8.37 ± 0.44 (30)	7.48 ± 0.37 (36)
Number of pecks (no. of birds sampled)	104 (6)	64 (18)	83 (8)
Number successful	56	33	59
Percentage successful	53.9	51.6	71.1
Items/mins (peck rate x success)	15.31	17.30	21.30

5.3 Discussion

Seasonal changes in numbers and in flocking behaviour are known to occur in this species. Long distance movements have not been recorded and the flocking is believed to involve only local movements and concentrations (Lane 1987). The species is widespread, particularly in eastern Australia, and its numbers in New South Wales probably exceed 6000 (Smith 1991). Nevertheless local concentrations of the numbers recorded at Newington are scarce and only 4 other sites have so far been recorded in New South Wales with higher numbers (Lane 1987). The Newington lagoons are therefore locally important for the species.

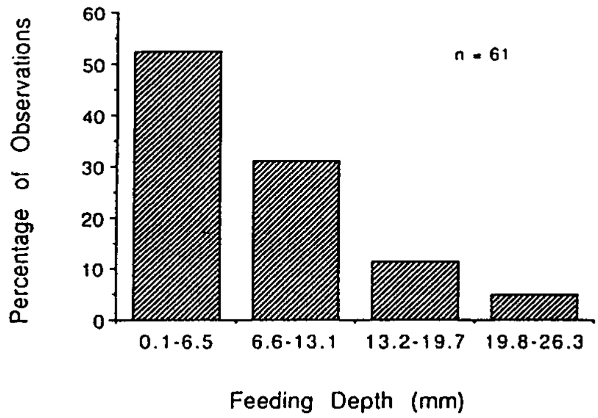


Figure 29. The wading depths of black-fronted plovers foraging in water at the edge of the Main Lagoon, Newington. The birds preferred to forage in shallower water. Comparing distribution of birds with area of water available from 0-13 mm and 14-26 mm, X^2 =24.47, 1 df, $p < 0.001$.

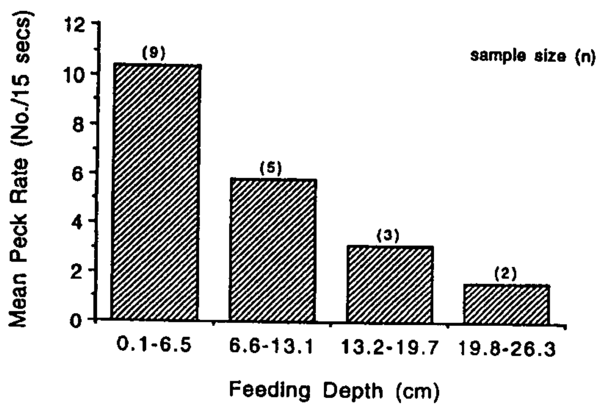


Figure 30. Peck rates, in relation to water depth (cm), of black-fronted plovers foraging whilst wading at the edge of the Main Lagoon, Newington. r = - 0.81, p < 0.001.

The species' habitat selection and foraging behaviour have not been studied in Australia and the work done in this project was limited. Nevertheless, it had a preference for feeding on areas of firm moist substrate that had recently been uncovered by falling water levels (Fig. 31). Such areas had high densities of dipteran larvae in the substrate. The areas that were most likely to meet these requirements on the basis of existing substrate types and water levels were the Main Lagoon and 33-Marsh Lagoon, where the birds were found. The western edge of the Corner Marsh Lagoon and the southern section of the Back Pool had suitable substrates but were flooded at the time the plovers moved into the area and the southern part of Mason Park Lagoon also had suitable firm substrate but was dry. An appropriate habitat management regime for the species would involve regular changes in water levels on all of these lagoons so that areas of freshly exposed moist substrate were always available. It should be stressed that any changes to water levels etc should be careful monitored to ensure that the desired results are being obtained.

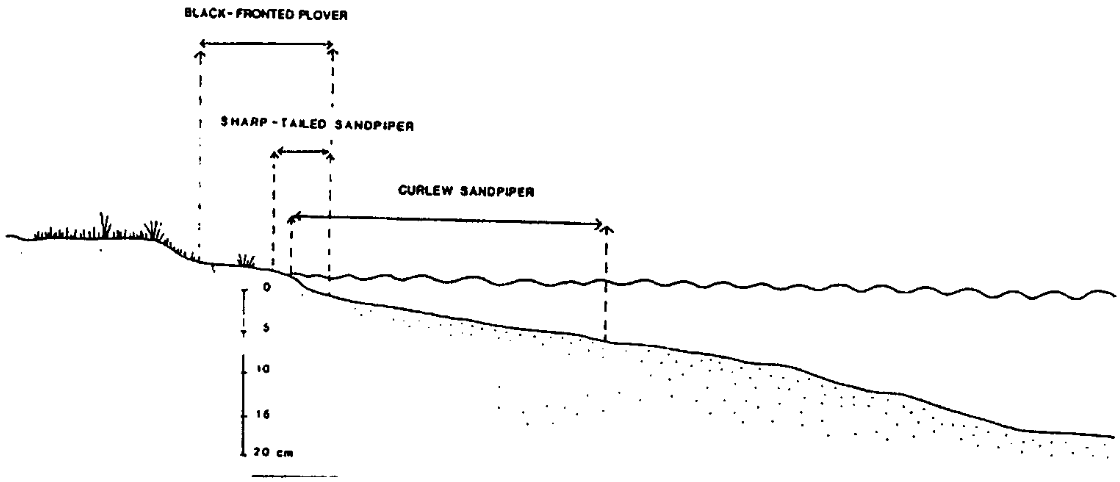


Figure 31. Diagrammatic representation of microhabitat selection among foraging shorebirds in the Homebush Bay Lagoons. Curlew sandpipers prefer to forage in water at depths of between 3 and 6 cm, sharp-tailed sandpipers prefer to forage close to the water's edge and black-fronted plovers prefer to forage over firm moist substrates that have recently been uncovered by falling water levels

6 Sharp-tailed Sandpiper

Sharp-tailed sandpipers occurred at the Waterbird Refuge, Mason Park and the Main Lagoon at Newington from the start of the study in November until early February, when the birds began the return migration to their Siberian breeding areas (Table 26). Total numbers in all lagoons combined were less than 30 except on one occasion in early February when 44 were recorded. Most of these (35) were in a single flock at Newington and were probably birds passing through on migration. At other times numbers varied greatly between counts showing little sign of any stability or trend.

All of the sharp-tailed sandpipers recorded were foraging and utilised edge habitats, always within a few centimetres of the water's edge. They foraged on wet substrates and in water up to about 2 cm deep, often close to dense vegetation.

Table 26 Numbers of sharp-tailed sandpiper recorded at the Waterbird Refuge, Mason Park Lagoon and Newington Lagoons.

Date	Waterbird Refuge	Mason Park	Newington	Total
12/11/93	16	0	7	23
18/11/93	22	5	0	27
22/11/93	3	6	0	9
23/11/93	3	16	0	19
29/11/93	1	15	0	16
15/12/93	7	3	0	10
22/12/93	3	0	0	3
04/01/94	3	2	0	5
19/01/94	16	2	0	18
01/02/94	0	0	0	0
08/02/94	7	2	35	44
10/02/94	8	2	0	10
15/02/94	0	0	0	0
16/02/94	0	0	0	0
01/03/94	0	0	2	2
08/03/94	0	0	0	0
17/03/94	0	1	0	1
22/03/94	0	0	0	0
28/03/94	0	0	0	0

7 Red-Kneed Dotterel

Red-kneed dotterals lack the salt secreting glands found in most shorebirds and thus have preference for less saline conditions than most (McLean 1977).

This species was recorded at Mason Park, the Back Pool and once at 33-Marsh, Newington. Mostly, only 1–3 individuals were recorded in total although up to five occurred on the Back Pool in February. The birds at the Back Pool were observed taking items from the surface of wet substrate and also whilst wading up to belly depth.

8 Lesser Golden Plover

Lesser golden plovers occurred only at the Mason Park Lagoon. The numbers recorded varied from 0–18 (Table 27). Some of the birds made brief attempts to search for prey but mostly they spent their time roosting, either asleep or standing vigilant. They occupied areas of tussocky saltmarsh in the centre of the lagoon, surrounded by water where they were highly cryptic and some of the variation in estimated numbers may have been errors of detection.

During fieldwork at Hen and Chicken Bay lesser golden plovers were recorded foraging on firm intertidal substrates at the extreme southern end of the bay. In February and March counts of the plovers at Hen and Chicken Bay were followed up within 15 mins by counts at Mason Park. On five occasions when a flock of 15-18 plovers were observed at Hen and Chicken Bay none were at Mason Park and on three occasions when none were recorded at Hen and Chicken Bay a flock of 15–18 birds was recorded at Mason Park. In late March when the birds were moulting into their breeding plumage detailed records were made of plumage characteristics for all individuals. There was an exact match-up of birds from the two locations. Lesser golden plovers were never recorded at any other site during the study and it therefore seems fairly certain that there was only a single flock in the area that roosted at Mason Park and sometimes fed at Hen and Chicken Bay. Records of the plovers at Hen and Chicken Bay were mostly in March (5 out of 6 occurrences). When they roosted at Mason Park they spent the whole day there. It seems probable that they fed nocturnally for most of their stay at Homebush, probably taking invertebrates from the extensive areas of short grass on playing fields in the area, and that the daytime foraging at Hen and Chicken Bay may have been associated with the need to extend foraging time during the pre-migratory fattening period.

Table 27 Numbers of lesser golden plover recorded roosting during daytime counts at the Mason Park Lagoon.

Month	Number of counts	Mean number recorded	Maximum number recorded
November	7	7.9	16
December	6	10.8	16
January	2	11.5	12
February	3	10.3	18
March	6	10.5	17
April	2	0	0

The lesser golden plover is among the least abundant of the migrant shorebirds that spend the southern summer in Australia with an estimated New South Wales population of under 2000 (Smith 1991). The small flock of just under 20 at Mason Park Lagoon thus represented about 1% of this total. The quality of this roosting place could probably be secured by ensuring that water levels in the lagoon were kept high so that the saltmarsh islets in the centre where the birds roosted were always surrounded by water. The birds that roosted at Mason Park were almost certainly the same individuals that were recorded foraging at Hen and Chicken Bay so their future may depend upon events there as much as at the lagoon. It is important to maintain the quality of the foraging area at Hen and Chicken Bay.

9 Masked Lapwing

Masked lapwing occurred widely over the area, foraging on intertidal flats but mostly on areas of short grassland found on the many playing fields and areas of parkland. Counts were made of birds on the lagoons during counts of other shorebirds but no attempt was made to estimate total numbers over the whole area. The birds used the saltmarsh areas of the lagoons for roosting only with the largest concentration at the Main Lagoon at Newington. The lagoon was an important area where they could rest undisturbed. Counts at high tide were consistently around 22–24. They also roosted in the centre of Mason Park Lagoon with high tide numbers usually of between 10 and 20. They were recorded only once (a single bird) at the Waterbird Refuge.

During December and January three separate broods of young with parents were seen on the extensive grasslands within the Newington area. This was the only site in the area where they could nest free of human disturbance.

10 Intertidal Habitats

10.1 Introduction

The objective of this part of the work was to evaluate the significance of the intertidal areas of Homebush Bay for shorebirds. The main area of shorebird habitat is at the south end of Homebush Bay, in the area referred to as Refuge Bay (Fig. 32). In order to place Refuge Bay in context and to cater for the possibility of movements of shorebirds among the various areas of mudflat in the upper Parramatta estuary, the study included all intertidal areas from Hen and Chicken Bay to Silverwater Bridge.

Three species of shorebird occurred in these intertidal areas and are considered in this section. These were bar-tailed godwit, curlew sandpiper and lesser golden plover. The numbers and densities of these species were estimated over the study area from November 1993 to June 1994. To assess the relative quality of Refuge Bay as a foraging area, a detailed comparison was made of the foraging behaviour and ecology of bar-tailed godwits at Refuge Bay, Major's Bay and Hen and Chicken Bay. This included study of their diet, their tidal foraging periods and activity budgets and the rates at which they captured prey items. Invertebrate densities were also estimated at the three sites. Sediment samples were taken at these three sites.

Silver gulls are known to follow bar-tailed godwits and other shorebirds and to attempt to steal food items. Daan (1979) suggested that such food stealing could have a negative effect on the foraging efficiency of bar-tailed godwits. Densities of godwits at particular sites therefore may be influenced by the densities and activity of the gulls and this was investigated.

10.2 Study Areas

10.2.1 Refuge Bay

The main intertidal areas of Homebush Bay that provide potentially suitable habitat for shorebirds are in the south of the bay (Fig. 32). On spring tides extensive areas of mudflat are exposed, mainly on the eastern side of Powell's Creek (Fig. 1) and another small area (A on Fig. 32) extends into the mangroves at the southern end. The mudflat area is immediately adjacent to the Waterbird Refuge. The entire eastern bank of the bay has been subject to reclamation and has a sandstone embankment with no natural vegetation zone. A walking track extends along the eastern side from which observations of birds foraging in the bay were made. Sediment samples were taken in Refuge Bay to determine the textural composition of the sediments and the % of organic carbon and sulphur. For detailed sediment analysis see original report

10.2.2 Hen and Chicken Bay

Hen and Chicken Bay is approximately 2.5 km long and is subdivided into a number of minor bays all of which have at least some shorebird habitat. However, its entire perimeter has been reclaimed and has concrete or sandstone embankments with no saltmarsh and only isolated mangroves. The most extensive areas of intertidal substrates are on the eastern side where observation of godwit foraging behaviour were made. An intensive study area (area 1, Fig. 33) was selected for most of the work but a more extensive area (area 2, Fig. 33) was used for some aspects to gain larger sample sizes and for sampling the invertebrate populations.

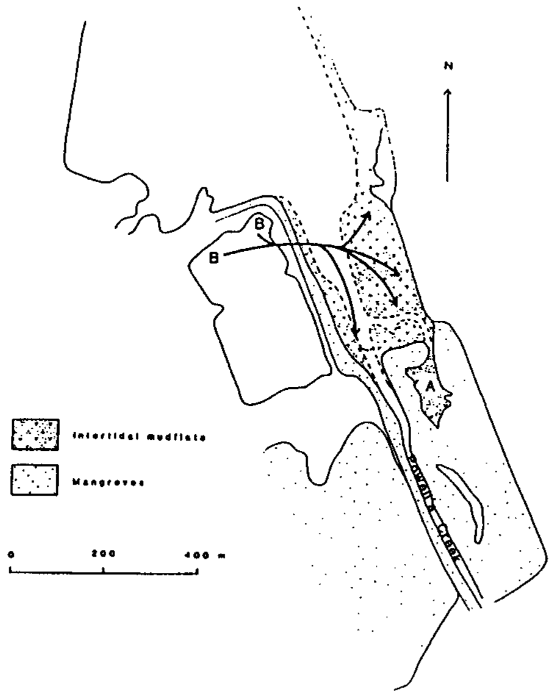


Figure 32. The intertidal areas of Refuge Bay at the extreme southern end of Homebush Bay. Bar-tailed godwits were the only species of shorebird to use these areas regularly. A small extension of the mudflat (A) was the only area available for foraging on extreme neap tides and its presence is essential for continued use of the area by the godwits. The godwits using these intertidal areas roosted at the Waterbird Refuge in Bicentennial Park (B), and their movement to the feeding area is indicated by the arrows.

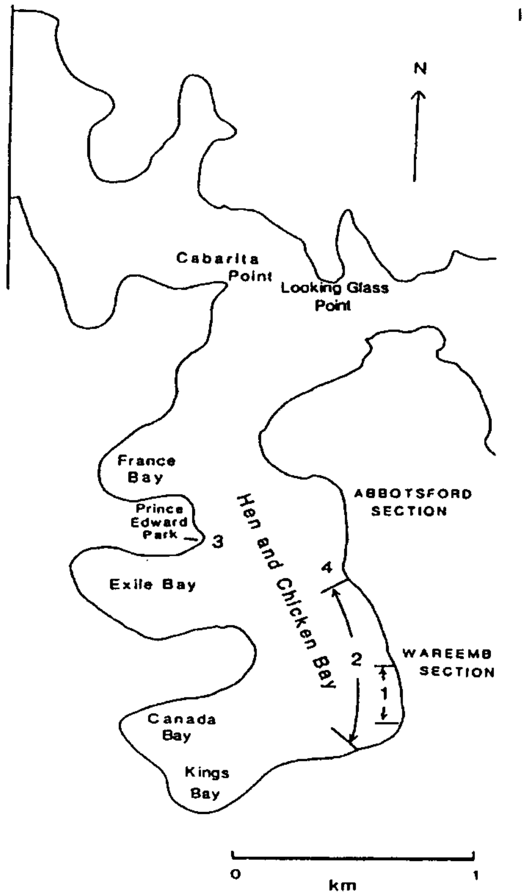


Figure 33. Hen and Chicken Bay. 1 = intensive study area for godwit observation, 2 = extensive godwit study area and invertebrate sampling area, 3 = main shorebird roost site, 4 = roost site used on some neap tides and when disturbed from 3.

Sediment samples were taken in Hen and Chicken Bay to determine the textural composition of the sediments and the % of organic carbon and sulphur determined.

10.2.3 Major's Bay

Major's Bay is a small southern embayment of the Parramatta River between Refuge and Hen and Chicken Bays (Fig. 2). It has been subject to past reclamation and like the other study areas has embankments around its entire perimeter. However, it has been subsequently recolonised by mangroves which now extend in a narrow zone around most of the mudflats, observations could be made only from the extreme south of the bay and from a point midway along the eastern shore but from each of these the entire bay could be seen.

Sediment samples were taken in Major's Bay to determine the textural composition of the sediments and the % of organic carbon and sulphur determined.

11 METHODS

11.1 SHOREBIRD NUMBERS AND DENSITIES

Two preliminary surveys were conducted during November 1993 covering all intertidal areas with habitat that was potentially suitable for shorebirds between Iron Cove and the Silverwater Bridge. Iron Cove only supported small numbers of bar-tailed godwits (<15) and was omitted from subsequent surveys. The areas included in subsequent surveys were Refuge Bay, Meadowbank and Ermington Bays, Brays Bay, Yaralla Bay, Major's Bay and Hen and Chicken Bay. From December to March these areas were surveyed twice monthly and from April to June, once monthly. Counts of shorebirds at all sites were made within 1.5 hrs either side of low tide by moving rapidly from one end of the study area to the other.

Bar-tailed godwits fed mostly along or close to the tide-line. To compare densities of godwits among sites the numbers recorded at low tide were divided by the length of shoreline at low tide at each site, measured from aerial photographs. The position of low tide was noted on the ground by reference to fixed objects which were subsequently identified on the photos. These objects were all above high tide so that it was unimportant when the photos were taken in regard to the tidal cycle.

During November searches were made of the whole study area at high tide to locate roost sites. Only one site was found, at Prince Edward Park on the west shore of Hen and Chicken Bay (Fig. 33). After December a second roost site became established at the Waterbird Refuge. To assess total numbers in the area and as a check on the low tide survey results, counts of all shorebirds were undertaken at these roost sites twice monthly on spring tides.

11.2 DIET

Comparisons were made of the diet of bar-tailed godwits at Refuge, Major's and Hen and Chicken Bays. Roosting godwits were not observed to produce oral pellets and none were located on searches of the roosts. Faecal pellets were examined under the microscope but contained no identifiable remains often a problem with faecal analysis. The godwits' diet was therefore determined by direct observation. The birds proved to be tolerant of human observers and could be watched at distances down to about 10 m without disturbance. Observations at each site were made using a 25x – 23x telescope of birds at a range of about 25 m. Prey items could be seen as they were pulled free of the substrate. Birds were selected randomly and a maximum of five items recorded for each before moving to another. Records were kept separately for males and females distinguished by their overall size, leg lengths and bill lengths. Records were also made of the microhabitat within which the bird under observation was foraging. Categories used were: 1. foraging in water, 2. foraging on wet substrates, and 3. foraging on areas of raised, relatively dry, substrate. Lengths of prey were estimated by comparison with the birds' bills. With polychaetes because of their 'elasticity' lengths were estimated into broad classes of 3 cm range. Despite the obvious limitations in this methodology, it gave a standardised means of comparing the sizes of polychaetes taken at different study sites. More precise comparisons could have been done only by examining the gut contents of a large sample of dead birds. Such an approach was not possible in this study as there was a definite and demonstrated risk that capturing and subsequent handling of the birds could have been harmful to them.

Comparisons of the lengths of worms caught by males and females, at the different study sites and on different substrate types were made using chi-square tests.

11.3 Prey capture rates

Prey capture rates of bar-tailed godwits were quantified at the three study sites for each hour that the birds were feeding over two complete low tide cycles in January and February. One-mins sample periods were used during which all capture attempts and captures were recorded. Records were maintained separately for males and females and also of the nature of the substrate on which the birds foraged (see Diet, above). Individuals were selected randomly and reselected after each sample period.

Most of Refuge Bay could be observed from positions along the eastern shore and prey capture rates were sampled for birds feeding over most of the intertidal area. At Major's Bay samples were taken along the eastern side of the bay where most birds fed. At Hen and Chicken Bay all samples were taken within a 500 m long section of the eastern shore (Wareemba section — see Fig. 33). This area had densities of godwits similar to most of the rest of the bay and usually contained 15–20% of all birds that fed in the bay.

Analyses of variance were used to compare prey capture rates among sexes, substrates and study sites. Data were tested for normality and homogeneity of variances using the *F* max test.

11.4 Invertebrate Prey

Invertebrate populations in intertidal substrates were sampled at Refuge Bay, Major's Bay and Hen and Chicken Bay. At Refuge Bay the substrate was too soft to walk on and sampling was done from a boat as the tide receded. Random core samples were taken at the southern end of the bay, from within an area of 80 x 40 m. This area had densities of godwits similar to other parts of the bay so was considered to be representative. At Major's Bay random core samples were taken along a transect on the eastern shore approximately 10 m to seaward of the mangroves.

At Hen and Chicken Bay random core samples were taken along the eastern shore in the Wareemba section (Fig. 33). The substrate was clearly divisible into wet depressions with fine particle sizes and raised drier ridges with coarser particle sizes. These were sampled as separate strata. In each, quadrats of 10 x 20 m were set up within which core samples were selected randomly.

At all sites cores of 5.5 cm diameter were used to a depth of 17 cm. This was approximately the maximum depth at which polychaetes were found, this was determined after a pilot study. Godwits can probe only to about 10 cm but had cores been taken only to this depth many polychaetes that may have been near the surface and hence available to the birds could have withdrawn to greater depths and not been sampled. Cores were placed directly in a 1 mm mesh bag and fixed in 7% formalin without seiving. In the laboratory the cores were briefly washed and the sediment sorted under a binocular microscope to extract all the invertebrates removed which were then identified and counted. It is likely that polychaetes respond to bird feeding by burrowing deeper but the depth we suggest is limited by the highly anaerobic sediment present with increasing depth at all sampling sites, during the pilot study no worms were found deeper than 17 cm.

Ash free dry masses of polychaetes were obtained by incinerating to a constant weight at 600°C for 4 hrs.

11.5 Low tide foraging periods

Bar-tailed godwits fed whilst wading so were able to start feeding before the receding tide had uncovered the substrates. Direct observation of the godwits was thus the only accurate way to assess the lengths of time over the low tide cycle for which they fed. The length of foraging period was taken as the time from the start of feeding by the first bird to the end of feeding of the last. Observers arrived at each site when the water still covered the substrate at depths that would have precluded feeding by godwits and remained until the last bird had stopped feeding. Assessments were made at each site over a range of tide heights from neap to spring tides.

11.6 Daily activity budgets

At Refuge Bay and Major's Bay the percentage of all godwits that were foraging was recorded four times per hour during each hour of two complete low tide cycles each month in January and February. These data were summed to give average values for foraging each hour. At Hen and Chicken Bay the same procedure was adopted for the intensive study area (Fig. 33) but additionally, once each hour, the percentage of all godwits foraging on the eastern shore of the bay was recorded. This area gave sample sizes of 2–3 times those of the intensive area and was used to validate the general applicability of data from the intensive area.

11.7 Silver gull food stealing

During quantification of prey capture rates at each sample site a record was kept of any gull stealing food from the godwit under observation in the 1–min sample period. An attempt was defined as any deliberate move towards a godwit by a gull that caused the godwit to alter its behaviour. An attempt was defined as successful if the godwit was forced to drop its prey, rather than just to abandon a probe. These data gave estimates of the frequency of gull food stealing attempts and the rate of loss of prey items by the godwits but they did not give a full picture of the impact of the gulls' behaviour. Often gulls followed foraging godwits causing them to spend time being vigilant and taking evasive action. The time lost by godwits in this way was quantified at all sites by selecting godwits randomly and recording the amount of time devoted to vigilance and walking or running away from gulls during sample periods of 60 secs. Most time was lost in avoidance and this was easily distinguishable. Increased vigilance occurred when gulls approached rapidly or followed godwits closely. The godwits could clearly be seen to stop foraging behaviour and look at such gulls. This behaviour could be distinguished and quantified but it is possible that more subtle increased vigilance was also occurring that could not be distinguished.

The numbers of gulls feeding at Refuge, Major's and Hen and Chicken Bays were recorded twice monthly at low tide on spring tides from December to March. Gull densities at each site were calculated by dividing by the area of habitat exposed at low tide.

12 RESULTS

12.1 BAR-TAILED GODWITS

12.1.1 Numbers and Densities

Bar-tailed godwits were the only shorebird species to forage in Refuge Bay apart from occasional black-winged stilts from the Waterbird Refuge. Counts of foraging godwits at low tide covered all of the intertidal areas from Hen and Chicken Bay to Silverwater. On all counts less than five godwits in total were recorded in Kendall, Yaralla, Brays, Meadowbank and Ermington Bays combined. Only three bays consistently supported higher numbers: Hen and Chicken, Major's and Refuge Bays. Between November and mid March the average numbers at each of these sites from 10 counts were 184, 21.2 and 12.6 respectively (Table 28). The birds that foraged in Hen and Chicken Bay and Major's Bay were seen to fly to roost on a flat rocky headland at Prince Edward Park on the west shore of Hen and Chicken Bay (Fig. 33). On spring tides birds that fed at Iron Cove (usually 10 to 15 individuals) also roosted there. The small group that fed in Refuge Bay were observed to move to the Waterbird Refuge to roost at high tide. The average number recorded from 8 counts at the Prince Edward Park roost from November to mid March was 231.8. This compares with the average value of 205.2 birds feeding at Hen and Chicken Bay and Major's Bay combined during that period and a value of around 225 if the Iron Cove birds and the small number from the other bays are included. The Prince Edward Park roost was the only roost site discovered in the whole of the upper Parramatta, apart from that at Refuge Bay/Waterbird Refuge. The figures therefore show a close match between numbers at the roost and those in the feeding areas and it is unlikely that more than a few foraging birds were missed at the low tide counts. Thus, on average, around 75% of the entire godwit population in the upper Parramatta estuary fed in Hen and Chicken Bay, whereas only 5.2% fed in Refuge Bay.

Numbers of godwits remained reasonably constant in the Hen and Chicken Bay/Major's Bay population over the summer months from December to the second half of March. Between about 20th March and 5th April all of the adult godwits left the area on the start of their northward migration. Most males in breeding plumage left about a week or so before most females and the last was seen on the 5th April. Thereafter, the area supported a population of around 70 first year birds.

The Refuge Bay population of godwits showed a different seasonal pattern. A small number (<10) fed in the bay during November and early December but numbers rose approximately 3–fold in mid December and remained around this level until late February. Numbers fell rapidly after the start of March and none was seen after mid March. Thus these Refuge Bay birds left their feeding area some four weeks or so earlier than did those at Hen and Chicken Bay. Numbers feeding at Hen and Chicken Bay rose slightly during the first half of March compared with earlier months and it is possible that the Refuge Bay birds moved there, although without marked birds this is conjectural.

In order to make a more meaningful comparison of the abundances of godwits in the different feeding areas, numbers were converted to densities (Table 29). Godwits showed a distinct tendency to follow the tide line when foraging. Although some birds, especially males, fed away from the waters' edge, the great majority of individuals fed either in the water or within 5 m or so of it. The most appropriate method for calculating densities was therefore to express them as birds per 100 m of shoreline, taking the length of shoreline as that at low tide on an average low tide.

Between the start of December and mid March, average densities from eight counts at Hen and Chicken Bay, Major's Bay and Refuge Bay were 5.9, 1.6, and 1.4 birds/100 m respectively. Thus Refuge Bay not only supported low numbers of godwits compared with Hen and Chicken Bay but also had average densities of around only 24% of those at Hen and Chicken Bay. Major's Bay had densities that were just slightly above those of Refuge Bay..

Table 28 Numbers of bar-tailed godwits foraging in intertidal habitats in the upper Parramatta estuary, November 1993 to June 1994.

Date	Hen and Chicken Bay								
	Abbotsford Section	Wareemba Section	Kings & Canada Bay	Exile Bay	France Bay	Total	Major's Bay	Refuge Bay	Grand Total
23/11/93	44	71	0	12	21	148	4	5	157
29/11/93	37	60	20	32	23	172	58	3	233
08/12/93	31	95	8	8	14	156	41	8	205
20/12/93	26	94	1	2	18	141	52	27	220
13/01/94	58	106	5	15	18	202	14	23	239
24/01/94	36	99	7	24	19	185	7	13	205
10/02/94	39	94	3	53	21	210	9	16	235
24/02/94	42	101	3	27	18	192	9	22	221
08/03/94	48	128	9	14	14	213	10	5	228
15/03/94	61	128	3	13	16	221	8	4	233
28/03/94	4	24	0	26	10	64	13	0	77
30/03/94	36	53	3	8	10	110	25	0	135
05/04/94	8	27	1	10	0	46	21	0	67
11/04/94	29	21	0	3	1	54	19	0	73
12/05/94	13	37	1	5	6	62	12	0	74
21/06/94	11	35	3	5	5	59	4	0	63
Mean of 08/12/93 - 15/3/94						**184**	**21.2**	**12.6**	

12.1.2 Diet

In all three bays the godwits fed mainly on polychaete worms (Table 30) ranging in length from about 2-9 cm although the infaunal invertebrate communities at each site included oligochaete worms, amphipod crustaceans and bivalve molluscs (Table 31). (In Table 30 the majority of the unidentified prey were probably polychaetes, they certainly were not molluscs or crustaceans but as they were less than 1 cm in length they could not be positively identified as polychaetes and as Table 31 shows there were no other groups of animals present). Individuals belonging to the polychaete families Nereididae and Nephtyidae were observed being taken on a few occasions when the birds were very close and light conditions were good, but in the great majority of cases no better resolution than polychaetes was achieved. At Hen and Chicken Bay there were no differences between sexes or among substrates in the estimated lengths of polychaetes taken

Table 29 **Densities of foraging bar-tailed godwits (no./100 m of shoreline) in the upper Parramatta estuary, November 1993 to June 1994. Figures are given for individual subdivisions of Hen and Chicken Bay and the combined total for the bay**

Date	Hen and Chicken Bay						Major's Bay	Refuge Bay
	Abbotsford Section	Wareemba Section	Kings & Canada Bay	Exile Bay	France Bay	Total		
23/11/93	11.0	5.3	0	2.0	3.8	4.6	0.4	0.5
29/11/93	9.3	4.5	6.5	5.3	4.1	5.4	5.0	0.3
08/12/93	7.8	7.1	2.6	1.3	2.5	4.9	3.6	0.7
20/12/93	6.5	7.1	0.3	0.3	3.2	4.4	4.5	2.5
13/01/93	14.5	7.7	1.6	2.5	3.2	6.3	1.2	2.1
24/01/93	9.0	7.4	2.3	4.0	3.4	5.8	0.6	1.2
10/02/94	9.8	7.1	1.0	8.8	3.8	6.6	0.8	1.5
24/02/94	10.5	7.6	1.0	4.5	3.2	6.0	0.8	2.0
08/03/94	12.0	9.6	2.9	2.3	2.5	6.7	0.9	0.5
15/03/94	15.3	9.6	1.0	2.2	2.9	6.7	0.7	0.4
28/03/94	1.0	1.8	0	4.3	1.8	2.0	1.1	0
30/03/94	9.0	4.7	1.0	1.3	1.8	3.4	2.2	0
05/04/94	2.0	2.4	0.3	1.7	0	1.4	1.8	0
11/04/94	7.3	1.9	0	0.5	0.2	1.7	1.7	0
12/05/94	3.3	2.8	0.3	0.8	1.1	1.9	1.0	0
21/06/94	2.8	2.6	1.0	0.8	0.9	1.8	0.4	0
Mean of 08/12/93 - 15/03/94						**5.9**	**1.6**	**1.4**

(Table 32) and there were also no differences between sexes at Refuge Bay or Major's Bay (Table 33). Combining data for sexes and substrates, and comparing the numbers of worms in each size class, godwits foraging at Hen and Chicken Bay took significantly more worms in the larger size classes than those foraging at either Refuge Bay (X^2 =16.8, $p < 0.001$) or Major's Bay (X^2 = 77.7, $p < 0.001$). These results do not necessarily mean that the godwits actually took longer worms: it may have been that they were able to secure longer fragments of worms without actually taking entire worms.

Table 30 **Prey taken by bar-tailed godwits at Refuge Bay, Major's Bay and Hen and Chicken Bay, January to February 1994.**

Location	Sex	Polychaetes	Molluscs	Crustaceans	Unidentified
Refuge Bay	Male	162	0	0	17
	Female	121	0	0	21
Major's Bay	Male	66	0	0	12
	Female	58	0	0	7
Hen and Chicken Bay	Male	291	0	0	34
	Female	230	0	0	41

Table 31 List of invertebrate fauna recorded from December 1993 to April 1994 in the 3 intertidal localities (Abundant++; Present+, blank indicates species absent from that site)

Species	Locality		
	Hen & Chicken Bay	Majors Bay	Refuge Bay
POLYCGAETA: CAPITELLIDAE			
Notomastus torquatus	++	++	++
Barantolla lepte	++	++	++
NEPHTYIDAE			
Nephtys australienis	++	++	++
NEREIDIDAE			
Australonereis ehlersi	++	+	+
Ceratonereis aequisetis			
AMPHIPODA: AMPHELISCIDAE			
Amphelisca euroa	+		
COROPHIIDAE			
Gammaropsis sp.1	+		
ICILIIDAE			
Icilius australis	+		
LEUCOTHOIDAE			
Leucothoe assimilis	+		
LILJEBORGIIDAE			
Liljeborgia sp. (damaged)	+		
MELITIDAE			
Victoriopisa australiensis	++	++	++
TANAIDACEA: PARATATANIDAE			
sp. 1	+		
ISOPODA (ANTHURIDEA): ANTHURIDAE			
Cyathura hakea	++	+	
ISOPODA (FLABELLIFERA): CIROLANIDAE			
Cirolana sp. 1		+	
DECAPODA (CARIDEA): ALPHEIDAE			
Alpheus sp. (juvenile)	+		
PALAEMONIDAE			
sp. (damaged)			
MOLUSCA: MACTRIDAE			
Notospisula trigonella	+	+	+
MYTILIDAE			
Xenostrobus securis			+
NASSARIIDAE			
Nassarius jonasi	+		
PSAMMOBIIDAE			
Soletellina donaciodes	++	+	+
TELLINIDAE			
Tellina deltoidalis	++	++	++

Table 32 Lengths of polychaete worms caught by male and female bar-tailed godwits feeding at Hen and Chicken Bay, January to March 1994. Percentage in brackets. Data are subdivided according to microhabitat type: water; wet substrate (with an obvious surface layer of water in lower lying trough areas) and relatively dry substrate (moist but with no surface water on raised ridges). There were no differences among habitats in the lengths taken by either sex, nor any differences between sexes.

Microhabitat type	Length classes	Number of items (%)	
		Males	Females
Water	0.1 - 3.0	59 (51.3)	54 (46.6)
	3.1 - 6.0	46 (40.0)	47 (40.5)
	6.1 - 9.0	10 (8.7)	15 (12.9)
Wet substrate	0.1 - 3.0	45 (54.9)	29 (35.4)
	3.1 - 6.0	29 (35.4)	39 (47.6)
	6.1 - 9.0	8 (9.8)	14 (17.1)
Dry substrate	0.1 - 3.0	44 (46.8)	12 37.5)
	3.1 - 6.0	33 (35.1)	13 (40.6)
	6.1 - 9.0	17(18.1)	7 (21.9)

Table 33 Lengths of polychaete worms taken by male and female bar-tailed godwits at Refuge Bay and Major's Bay, January to March 1994. Percentage in brackets. There were no significant differences between sexes.

Length Class (cm)	Refuge Bay		Major's Bay	
	Number of items (%)		Number of items (%)	
	Males	Females	Males	Females
0.1 - 3.0	124 (76.5)	90 (74.4)	61 (92.4)	50 (86.2)
3.1 - 6.0	20 (12.3)	22 (18.2)	5 (7.6)	8 (13.8)
6.1 - 9.0	18 (11.1)	9 (7.4)	0	0

12.1.3 Prey Capture Rates

The godwits foraged in water and also over exposed substrates. They tended to follow the water's edge as the tide ebbed and flowed. Differences in prey capture rates that might have existed between Refuge Bay and Hen and Chicken Bay in particular, may have been complicated by whether or not the birds fed in water or over exposed substrate. The state of the tide and also the birds' sex might also have had an influence. Thus, it was important to identify and control for any such effects when comparing sites. To do this, multifactorial analyses of variance were carried out on the data sets for each site.

At Refuge Bay there were no differences between sexes or among substrate types ($F_{2, 609} = 0.3$, $p = 0.74$; $F_{2,609} = 0.33$, $p = 0.57$ respectively) and there were no significant interactions among independent variables. However, there was significant variation in prey capture rates in relation to the state of tide ($F_{5,606}$ = 21.07, p < 0.0001). Capture rates were highest as the tide began to ebb, decreased towards low tide and showed a substantial increase again during the birds' last feeding hour of the flow tide. The overall prey capture rate, averaged over the entire tidal cycle, was 1.24 items/mins (Table 34, Fig. 34).

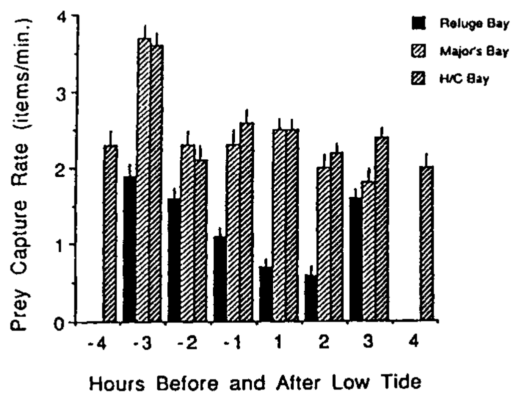


Figure 34. Prey capture rates (no. items caught / mins ± SE) of bar-tailed godwits in relation to tide at Refuge Bay, Major's Bay and Hen and Chicken Bay.

At Major's Bay there were no significant interactions among independent variables. There was no variation in prey capture rates in relation to substrate types (p = 0.65) or to the sex of the birds (p = 0.97), but as at Refuge Bay there was a significant effect of tide (Table 34, Fig. 30). During each hour of tide, prey capture rates at Major's Bay were significantly higher than those at Refuge Bay (p < 0.001, in all cases).

For Hen and Chicken Bay there were no significant interactions among independent variables. There was no significant difference in prey capture rates between sexes. There was a major effect of substrate on capture rates. Birds that foraged in water had significantly higher prey capture rates than those that foraged over exposed substrates and birds that foraged over wet substrates had higher capture rates than those that foraged over dry substrates (Table 35). There was a significant effect of tide on prey capture rates ($F_{7,1452}$ = 7.29, p < 0.0001). The magnitude of this

Table 34 Prey capture rates (mean no. items/mins) of bar-tailed godwits in relation to the state of tide at Refuge Bay, Major's Bay and Hen and Chicken Bay, January and February 1994. (- 4 = during the 4th hour before low tide etc., - indicates no birds feeding).

	Refuge Bay		Major's Bay		Hen & Chicken Bay	
State of tide	Mean ± SE	n	Mean ± SE	n	Mean ± SE	n
-4	-		-		2.28 ± 0.24	99
-3	1.94 ± 0.19	36	3.71 ± 0.27	62	3.55 ± 0.18	170
-2	1.55 ± 0.10	123	2.25 ± 0.21	108	2.06 ± 0.21	118
-1	1.06 ± 0.09	160	2.28 ± 0.20	118	2.54 ± 0.18	166
+1	0.73 ± 0.12	91	2.47 ± 0.16	184	2.46 ± 0.15	246
+2	0.63 ± 0.11	113	1.96 ± 0.19	122	2.15 ± 0.15	230
+3	1.55 ± 0.12	89	1.80 ± 0.21	100	2.44 ± 0.15	252
+4	-		-		2.01 ± 0.18	179
Mean	**1.24 ± 0.05**	**612**	**2.42 ± 0.08**	**694**	**2.44 ± 0.06**	**1460**

effect was not however as strong as in Refuge and Major's Bays. For each hour of tide, capture rates were significantly higher ($p < 0.001$, in all cases) at Hen and Chicken Bay than at Refuge Bay. Overall, the prey capture rate achieved at Hen and Chicken Bay, averaged over the tidal cycle, was 2.45 ± 0.06 items per mins.

Thus, Refuge Bay was a considerably poorer foraging area for the godwits compared with the other sites. On average, birds foraging there achieved intake rates of almost exactly half those foraging at Hen and Chicken Bay.

Table 35 Prey capture rates of bar-tailed godwits foraging at Hen and Chicken Bay in relation to microhabitat or substrate types ($F_{2,1457} = 57.59$, $p < 0.0001$).

Foraging Habitat	Mean prey capture rate ± SE	n
Water	2.95 ± 0.12	802
Wet substrate	2.33 ± 0.14	409
Dry substrate	1.12 ± 0.17	249

12.1.4 Densities of invertebrates

Around 85% of all prey items taken by godwits at the three study sites were identified as polychaetes (Table 30). The densities of these prey are therefore likely to be of greatest importance in understanding the distribution and foraging of the birds on the Parramatta.

Data on polychaete densities were obtained for three time periods: December to March when both adult and first year godwits were present, April, and July, when only first year godwits were present. Considering the first period only, there were no significant differences among months in the mean densities of polychaetes at any site so data were lumped at each site for subsequent analysis. At Hen and Chicken Bay there was a significant difference between microhabitats: raised ridge areas with coarser, drier sediments had higher densities than had wet trough areas with finer particle sizes. Comparing sites, densities at Refuge Bay and Major's Bay were significantly lower than those at Hen and Chicken Bay (Table 36). The Refuge Bay densities were only just over 20% of those in wet substrate and 13% of those in dry substrates at Hen and Chicken Bay. Ash free dry masses of polychaetes were also lower at Refuge and Major's Bay than at Hen and Chicken Bay.

When data for Hen and Chicken Bay are examined over the longer time period (December to July) there was evidence of seasonal change. Densities of polychaetes fell during March and April compared with December and January and had risen again by July. However, the average ash free dry mass per individual worm in July on wet substrates was only 28% of that in April and on dry substrates 13%, suggesting that the change in density occurred through an increase in the numbers of smaller worms (Table 37).

Other invertebrates in the substrates at the study sites included oligochaete worms, crustaceans (amphipods) and bivalve molluscs (Table 38). A list of species is given in Table 31.

The results of the sediment analyses for Refuge Bay indicate the extremely high % of mud present in the samples both when organics and non organics are considered. The % of organic carbon by weight varied from 4.9–5.0%.

The results of the sediment analyses for Hen and Chicken Bay indicate the extremely high % of sand present in samples taken from both wet depressions and dry ridges and also when the Bay as a whole is considered. The % of organic carbon by weight varied from 0.5%–3.4% which were among the lowest values obtained from any locations sampled during the study. The results of the sediment analyses for Major's Bay indicate that the sediment is characterised by a mixture of sand and mud, and that sediment types are relatively consistent over time. The distribution of the invertebrate populations are largely determined by the sediment characteristics and by the organic content of the sediment However it should be noted that the sampling of sediment was only to provide some indication of the characteristics of the areas and not to provide detailed sediment distribution within an area which may be very patchy and change over time as a result of storms or flood events. The % of organic carbon by weight varied from 2.1%– 6.0%.

Table 36 **Comparisons of densities (mean no./core sample) and ash free dry mass (gm^{-2}) of polychaete worms at Refuge Bay, Major's Bay and Hen and Chicken Bay, December 1993–March 1994. Comparing densities among sites: 1. using wet substrate means at Hen and Chicken Bay, ANOVA, $F_{2,160} = 26.01$, $p < 0.0001$; 2. using dry substrate means at Hen and Chicken Bay, ANOVA $F_{2,160} = 54.05$, $p < 0.0001$. Comparing wet and dry substrates at Hen and Chicken Bay, ANOVA, $F_{1,118} = 4.64$, $p = 0.012$.**

Site	Mean density ± SE (mean no./core sample)	Mean ash free dry mass ($g\ m^{-2}$)	No. of cores
Refuge Bay	0.50 ± 0.25	1.40	33
Major's Bay	0.73 ± 0.17	0.84	70
H & C Bay - wet substrates	2.32 ± 0.24	3.93	60
H & C Bay - dry substrates	3.74 ± 0.32	2.39	60

Table 37 **Seasonal changes in the densities (mean no./core sample) and ash-free mass of polychaetes (all species combined) at Hen and Chicken Bay. Comparing months: ANOVA wet substrates $F_{4,95} = 6.47$, $p < 0.0001$; dry substrates $F_{4,95} = 3.38$, $p = 0.012$.**

Month	Wet substrates			Dry substrates		
	Mean density (mean no./core sample) ± SE	Ash-free dry mass gm^{-2}	No. of cores	Mean density (mean no./core sample) ± SE	Ash-free dry mass gm^{-2}	No. of cores
December	2.5 ± 0.5	5.05	20	2.5 ± 0.6	2.53	20
January	2.5 ± 0.4	3.70	25	3.7 ± 0.6	2.36	25
March	1.9 ± 0.6	2.81	15	5.6 ± 0.7	2.25	15
April	1.8 ± 0.7	2.53	10	3.4 ± 0.9	5.05	10
July	4.6 ± 0.4	1.68	30	4.6 ± 0.5	0.98	30

Table 38 **Densities (no./core ±.S.E.) of bivalve molluscs, crustaceans (amphipods) and oligochaete worms recorded at Refuge Bay, Major's Bay and Hen and Chicken Bay (H/C), December 1993 to March 1994. Data for Hen and Chicken Bay are divided into wet substrates in trough areas and relatively dry substrates in raised areas.**

Site	No. cores	Molluscs	Crustaceans	Oligochaetes
Refuge Bay	33	1.4 ± 0.2	0.2 ± 0.1	1.7 ± 0.2
Major's Bay	70	1.5 ± 0.3	0.9 ± 0.2	1.2 ± 0.3
H/C Bay (wet)	60	1.6 ± 0.2	0.3 ± 0.1	4.6 ± 0.7
H/C Bay (dry)	60	1.3 ± 0.2	0.1± 0.1	3.6 ± 0.6

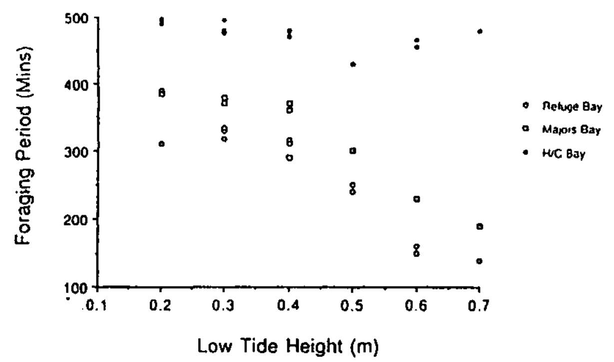


Figure 35. Length of low tide foraging periods of bar-tailed godwits at Refuge, Major's and Hen and Chicken Bays.

12.2 FORAGING PERIODS

Bar-tailed godwits foraged over the low tide part of the tidal cycle when substrates were exposed and when the water was shallow enough for them to wade. Differences in the total length of this suitable foraging period were examined at the three study sites. At Hen and Chicken Bay the foraging period varied little over the spring/neap cycle. The birds fed for about 30 mins longer on the highest spring tide compared with the lowest neap tide. However, at both Refuge Bay and Major's Bay there was a marked influence of tide height on foraging periods (Fig. 35). At Refuge Bay the birds fed for only about 140 mins on the lowest neap tides rising to 367 mins on the highest spring tide. The equivalent figures for Major's Bay were 205 mins and 407 mins respectively. At the lowest neap tides only a small area of the mudflat at the extreme south end of Refuge Bay became shallow enough for the birds to feed and they fed there by wading. At Major's Bay they also fed by wading on these tides.

Compared with Hen and Chicken Bay the feeding areas at both Refuge and Major's Bays were available for a much shorter time at low tide over the entire range of tide heights recorded. On the highest spring tides the godwits were able to feed at Hen and Chicken Bay for about 120 mins longer than at Refuge Bay but at the lowest neap tide the difference increased to 316 mins. The birds at Refuge Bay responded in two ways to the short feeding periods on neap tides. When they moved into the Waterbird Refuge after the intertidal foraging area had become covered they attempted to forage by probing in the substrates of the lagoon. The only items available there were chironomid larvae and oligochaetes less than 1 cm in length. Their energy intake levels could not be estimated but must have been low compared with intake rates when feeding on polychaetes in the intertidal area. Their other response was to forage on low tides at night. Visits to Refuge Bay were made twice at night during January and February and similar visits were made to Hen and Chicken Bay. Godwits were observed foraging in Refuge Bay but not in Hen and Chicken Bay. Night viewing equipment was not available so precise details of numbers or of prey capture rates were not be obtained. Nevertheless, on one of the nights at least eight godwits were seen foraging in Refuge Bay compared with 13 seen during the next daytime low tide. It is possible that the whole population of Refuge Bay fed at night as well as during the day.

12.2.1 Activity Budgets

Godwits at Refuge Bay and Major's Bay foraged for 96–98% of the time available to them during low tide period. At Major's Bay there was a consistent pattern. The birds foraged without breaks for the first 3 hrs of the low tide period and devoted a small percentage of their time to washing and preening in the following two hrs (Table 39).

For Hen and Chicken Bay data from the extensive study area that usually contained about 30–40% of the whole population agreed closely with data from the intensive study area that supported around 10–15% of the population. Overall, the birds spent most of the low tide period foraging but there was a tendency for the amount of foraging time to increase seasonally from around 83% of their time in December to 94% in March. This may have been associated with the birds' need to increase energy intake levels during the premigratory period (Table 40, Figs 36,37,38). Compared with Refuge Bay and Major's Bay the godwits at Hen and Chicken Bay devoted only marginally less of their time to foraging during January and February even though they had at least 2 hrs more foraging time over the low tide cycle on spring tides and 5 hrs more on neap tides.

Table 39 Tidal activity budgets of bar-tailed godwits foraging at Refuge Bay and Major's Bay. The figures show the percentage of the population foraging each hour taken from 4 scans of the entire population each hour averaged over 2 complete low tide cycles on spring tides

Hour ± LT	Refuge Bay		Major's Bay	
	January	February	January	February
-3	no birds feeding	97.4	100	100
-2	100	97.3	100	100
-1	97.4	98.8	100	100
+1	92.5	95.2	96.2	91.5
+2	100	100	92.1	90.0
+3	100	100	100	100
Total	**97.9**	**97.9**	**97.4**	**96.3**

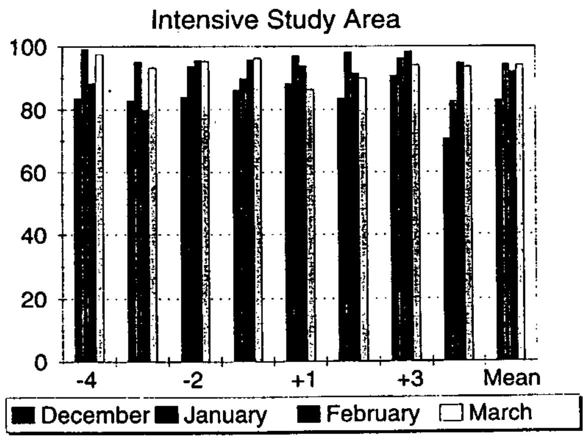


Figure 36. The tidal activity budgets of bar-tailed godwits foraging in the intensive study area (Area 1 on Fig. 33). The histogram shows the % of the population foraging each hr (4 hr on either side of the low tide) from 3 scan samples from December to March over 2 complete low tide periods each month, together with a mean value for all study periods. For actual % see Table 40. (-4 = 4 hr before LT and +4 = 4hr after LT).

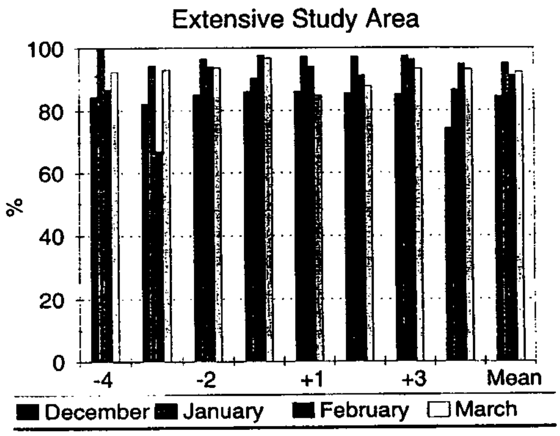


Figure 37. The tidal activity budgets of bar-tailed godwits foraging in the extensive study area (Area 2 on Fig. 33). The histogram shows the % of the population foraging each hr (4 hr on either side of the low tide) from 1 scan samples from December to March over 2 complete low tide periods each month, together with a mean value for all study periods. For actual % see Table 40. (-4 = 4 hr before LT and +4 = 4hr after LT).

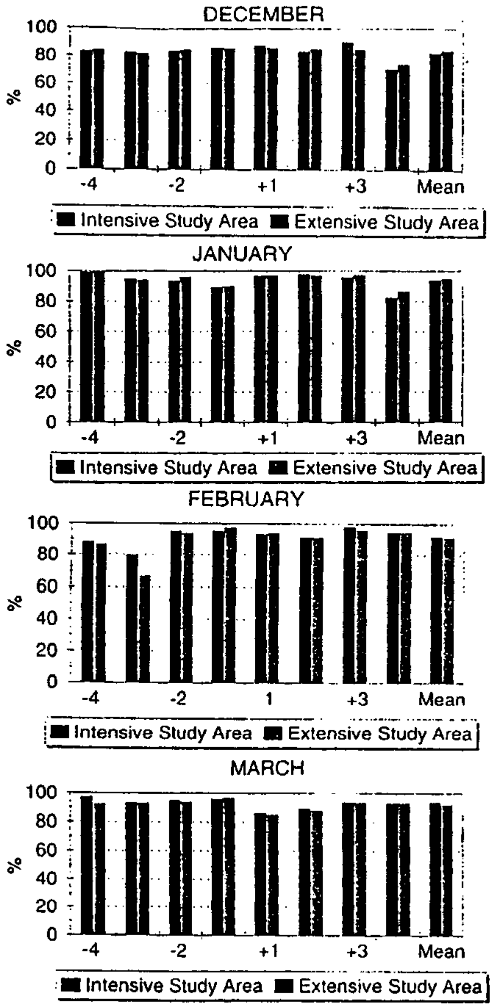


Figure 38. The tidal activity budgets of bar-tailed godwits foraging in the intensive and extensive study areas (Areas 1 & 2 on Fig. 33). The histogram compares the % of the population foraging each hr (4 hr on either side of the low tide) on a mnthly basis over 2 complete low tide periods each month, together with a mean value for all study periods. For actual % see Table 40. The figure shows that similar patterns of foraging occurred in both study areas. (-4 = 4 hr before LT and +4 = 4hr after LT).

12.2.2 Silver gull food stealing

Silver gulls occurred on all intertidal areas on the Parramatta estuary where they foraged by walking slowly over the substrate, picking items off the surface. Average densities at Refuge Bay, Major's Bay and Hen and Chicken Bay over the period of November to March were similar, at 27.4, 26.4 and 30.0 birds per hectare respectively (Table 41). This may have been a consequence of regular spacing behaviour among the gulls while foraging. Because of the large differences in the densities of godwits recorded at these sites, the ratios of gulls to godwits also differed considerably (Table 40). At Refuge Bay the gull/godwit ratio was about 10 times greater than at Hen and Chicken Bay.

The frequency of gull attacks on godwits averaged 4.2, 1.4 and 3.8 per hour of godwit foraging at Refuge, Major's and Hen and Chicken Bays respectively (Table 42). The average times spent by the godwits avoiding gulls at the three sites were 1.52, 0.1 and 1.76 sec per 60 sec of foraging time, (2.5%, 0.2% and 2.9%) respectively (Table 43).

Thus at all sites the impact of silver gull food stealing was not important. The godwits did not lose a major percentage of their prey items and they did not spend a large proportion of their time avoiding silver gulls. The presence of silver gulls cannot explain variations in foraging success or in densities of godwits among sites.

Table 40 Tidal activity budgets of bar-tailed godwits foraging at Hen and Chicken Bay. The figures show the percentage of the population foraging each hour from 3 scan samples of all birds in the intensive study area and 1 scan sample of all birds in the extensive study area over 2 complete low tide periods each month.

Hours ± LT	December	January	February	March
		Intensive study area		
-4	83.7	99.2	88.5	97.6
-3	83.0	95.2	80.0	93.3
-2	84.2	93.9	95.7	95.3
-1	86.3	89.9	95.8	96.3
+1	88.3	97.1	93.9	86.4
+2	83.7	98.1	91.5	89.9
+3	90.9	96.3	98.4	94.1
+4	70.8	82.7	94.9	93.5
Mean	**83.1**	**94.3**	**92.1**	**94.1**
		Extensive study area		
-4	84.5	100	86.8	92.5
-3	82.4	94.4	67.0	93.1
-2	85.1	96.4	94.0	93.8
-1	86.1	90.4	97.6	96.8
+1	86.1	97.2	94.1	84.9
+2	85.6	97.2	91.3	87.9
+3	85.2	97.5	96.3	93.5
+4	74.2	86.6	94.9	93.3
Mean	**84.5**	**95.2**	**91.3**	**92.4**

Table 41 The numbers and densities of silver gulls foraging at low tide in relation to bar-tailed godwit numbers on the intertidal areas of Refuge Bay, Major's Bay and Hen and Chicken Bay. December 1993 to March 1994. Number of counts at each site 8.

Site	Mean no. gulls ± SE	Mean gull density ± SE per ha.	Mean no. godwits ±SE	Mean ratio gulls/godwits ± SE
Refuge Bay	418.6 ± 63.9	27.4 ± 4.2	12.6 ± 3.1	23.7 ±6.4
Major's Bay	169.5 ± 28.9	26.4 ± 4.5	18.1 ± 6.4	19.3 ± 6.0
Hen & Chicken Bay	215.8 ± 47.8	30.0 ± 6.6	175.5 ± 13.4	2.3 ± 0.2

Table 42 The frequency of silver gull food stealing attacks on bar-tailed godwits and the percentage of prey items lost by the godwits at Refuge Bay, Major's Bay and Hen and Chicken Bay. December 1993 to March 1994. Number os days of observation at each site 8.

Site	No. one-mins sample periods	No. of gull attacks	Gull attacks per 10 mins godwit foraging	No. prey items cuught by godwits	No. lost to gulls	% lost
Refuge Bay	688	48	0.70	717	7	1.0
Major's Bay	693	16	0.23	1646	2	0.1
Hen & Chicken Bay	2815	177	0.63	6020	37	0.6

12.3 CURLEW SANDPIPER AND LESSER GOLDEN PLOVER

Curlew sandpipers and lesser golden plovers were never recorded in the intertidal areas of Refuge Bay and they were the only other shorebird species recorded at Hen and Chicken Bay (Tables 44 and 45).

Table 43 **Average amount of time ± SE (secs/60 secs) spent by bar-tailed godwits foraging time avoiding silver gulls.**

	Refuge Bay	n	Major's Bay	n	Hen & Chicken Bay	n
Time spent avoiding gulls ± SE/60 secs	1.52 ± 0.44	51	0.08 ± 0.08	30	1.76 ± 0.10	258

Table 44 **Number of curlew sandpipers (average/count) foraging in the intertidal areas of Refuge Bay, Major's Bay and Hen and Chicken Bay, November 1993 to March 1994. Number of counts at each site 2.**

Month	Average number foraging		
	Refuge Bay	Major's Bay	Hen & Chicken Bay
November	0	0	24
December	0	0	60
January	0	0	55
February	0	0	17
March	0	0	2

Table 45 **Number of lesser golden plovers (average/ count) at Refuge Bay, Major's Bay and Hen and Chicken Bay, November 1993 to March 1994. Number of counts at each site 2.**

Month	Average number foraging		
	Refuge Bay	Major's Bay	Hen & Chicken Bay
November	0	0	0
December	0	0	0
January	0	0	0
February	0	0	0
March	0	0	15

The curlew sandpipers at Hen and Chicken Bay normally formed from 2–3 flocks and were seen at three sites: at the extreme south end of the main bay, along the northern shore of Exile Bay and along a narrow strip of shore at the extreme northern end of the Wareemba section. These areas had similar characteristics of substrate with fine silt deposited in amongst stones or larger rocks. The birds fed by rapid probing, using tactile methods and were seen to catch small polychaete worms.

Lesser golden plovers foraged at Hen and Chicken Bay only during March, when a small flock of 14-18 individuals was seen regularly. These birds were moulting into their breeding plumage so each individual was slightly different from the others. Their plumage characteristics matched up exactly with the group of birds that roosted at Mason Park and there seems little doubt that they were the same birds. The birds were seen to forage only at the extreme southern end of the main section of Hen and Chicken Bay.

13 Discussion

13.1 Bar-tailed godwits

Bar-tailed godwits were the most numerous shorebirds in the intertidal areas of the upper Parramatta estuary and with the exception of occasional black-winged stilts, the only shorebird to use Refuge Bay. The total population in the estuary was around 250 individuals and thus not large enough to be considered of exceptional importance at the state level. The estimated total bar-tailed godwit population of NSW in mid summer is estimated at 5085 and the equivalent figure for all of Australia is 165 000 (Watkins 1993). Nevertheless, the population is important at the local level. The intertidal areas of Refuge Bay supported only 10% of the total. These birds seemed to form a distinct subgroup, roosting within the Waterbird Refuge close to their foraging area rather than at Prince Edward Park where most of the population roosted. Average densities of godwits in Refuge Bay were sparse compared with those in Hen and Chicken Bay (1.4 per 100 m of shoreline compared with 5.9 per 100 m) suggesting that it was not a preferred feeding area.

The low densities at Refuge Bay can be understood by examining a number of factors that operated simultaneously. Godwits foraging there achieved lower prey capture rates than those foraging at Hen and Chicken Bay and also caught smaller items of prey. Their rate of energy intake was thus considerably lower. Densities of polychaete worms, the godwits' prey species, expressed either in numbers or as ash-free dry mass per unit area were lower in Refuge Bay than in Hen and Chicken Bay.

In addition to having lower intake rates when foraging the godwits at Refuge Bay also had substantially shorter periods at each low tide during which they could forage. Compared with Hen and Chicken Bay their foraging period was 2–3 hrs less on spring tides but as much as 6 hrs less on neap tides. Birds at Hen and Chicken spent around 85–95% of their time actively searching for prey during the low tide period whereas those at Refuge Bay spent about 98% of their time feeding. The small additional time spent feeding was inadequate to compensate for the lower intake rates and shorter foraging periods. From all of these aspects examined, Refuge Bay was a poor quality foraging area for godwits compared with Hen and Chicken Bay.

Most of the godwit population disappeared from Refuge Bay sometime around the end of February even though the bulk of the population of the Parramatta River did not leave on their northward migration until the end of March. To accumulate the necessary reserves of fat and protein for their northward migration, bar-tailed godwits must increase their net energy intake rates in the 4 to 6 weeks prior to departure (Piersma and Brederode 1990). It is likely that the inadequacy of Refuge Bay as a foraging site became critical at that period and that the birds moved to a site where they could achieve the required increase.

13.2 Curlew Sandpiper and lesser golden plovers

Although the population of lesser golden plovers was less than 20, this species is not abundant in the state and efforts should be made to secure their habitat at Hen and Chicken Bay as well as at Mason Park. There seem to be two main threats to the intertidal habitat; invasion by mangroves and extensive bait digging. The area used by the birds at the extreme south end of the Bay was the main area of mangrove colonisation in the bay and was also the main area for bait digging. The plovers' foraging style requires open areas of exposed substrate. Bait digging leaves a highly disrupted surface however, it may increase the aeration of the soil and be beneficial to infaunal populations. However theis should become less of a problem as the NSW Fisheries legislation on bait digging in Sydney Harbour is enforced. The mangroves will colonise most of the preferred feeding area, if left unchecked.

The above comments are also relevant to the curlew sandpiper.

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Wetlands Study

Wetlands Study

M.D. Burchett and A. Pulkownik
Centre for Ecotoxicology
Department of nvironmental Biology and Horticulture
University of Technology
Sydney
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SUMMARY

I. PROJECT GOALS

The final goal of the current project is to assist in the conservation, restoration and management of the Homebush Bay wetlands by providing information on the present structure and performance of the saltmarsh and mangrove communities, their seasonal dynamics, the factors influencing the health and performance of the stands, and their transplantability.

The specific experimental aims of the project were initially focused on the saltmarsh community, as follows:

- i To distinguish the environmental factors affecting the seasonal growth and viability of the saltmarsh species, by conducting longer-term studies of the ecology of the saltmarsh communities of the Royal Australian Navy Armaments Depot (RANAD) Newington, and adjacent areas.
- ii To produce pilot stock for transplantation in regeneration sites in Homebush Bay, by carrying out greenhouse transplantation trials of selected saltmarsh species, and investigating responses of the cuttings to salinity. The methods are also of potential use elsewhere in NSW.
- iii To conduct experimental plantings of the transplant stock at an experimental site prepared adjacent to Haslams Creek, Homebush Bay.

More recently (October, 1994), the study has been extended to include the mangrove stands, which in NSW form a mosaic with the saltmarsh swamps in the intertidal ecosystem. The specific aims of the mangrove component of the study, are to investigate the distribution, structure and seasonal dynamics of the mangroves, and the factors which appear to affect their health and performance.

II. FINDINGS AND RECOMMENDATIONS — SALTMARSH

Environmental factors and seasonal growth — saltmarsh species

Three sites have been subjected to seasonal sampling of plants and substrates in the RANAD Newington, with a supplementary study at the 2KY site. Comparative data are also included from other studies which we have made in the Homebush Bay area.

Newington

The main saltmarsh species encountered in this project were *Sarcocornia quinqueflora*, *Suaeda australis*, *Triglochin striata*, *Sporobolus virginicus*, *Juncus acutus* (exotic), *Juncus kraussii*, and the three rare species *Halosarcia pergranulata*, *Wilsonia backhousei*, and *Lampranthus tegens*. The main findings are summarised below.

- a) Some of the sediments which formed the marsh substrates were found, as expected, to be generally high in fine matter (silt and clay , salinity and exchangeable sodium), although there were marked differences among the sampled areas in Newington. This is a common feature of dumping sites.
- b) Some of the sediments were found to be contaminated with heavy metals.

c) No close correlations were found between substrate salinity, or other physico-chemical parameters, except for pH, and the presence or zonation of the various species Longer term studies would be needed to reveal clearer relationships. It is likely, as is the case in other wetlands, that hydrology is the determining factor in distribution. Hydrological studies were beyond the scope of this project, and the hydrological chart that was available for the Newington wetlands was found to be too coarse for the interpolation of the sampling data. Meanwhile, it seems that, provided the substrate is saline enough to keep out other terrestrial competitors, the factor which dominates the zonation is water availability at any given level in the marsh.

2KY Site

a) The subsidiary study at this site involved an examination of the distribution of the three rare species, along with others, down a slope into a drainage valley on the site. The substrate is composed of saline dredge-fill. However, no trends in substrate parameters were found down the slope, which indicates that no significant profile differentiation has yet occurred in the material. In the absence of slope gradients, no correlations could be made between them and the distribution of plant species., which were nevertheless in the expected sequence down the slope, no doubt reflecting general patterns of water supply.
b) This is a site contaminated by heavy metals. The concentrations of the two metals were in the same range as have been found in the mangrove stands of Bicentennial Park.
c) There is a number of weed species on the 2KY site, which is surprising having regard to the high levels of salt and metals. From a purely scientific point of view, it would be interesting to carry out some ecophysiological studies of acclimation and genetic population selection of the exotic species at this site, as well as differences in uptake and bioaccumulation among the native species, across all of the sites under investigation.

Saltmarsh Transplantation Studies

Six species were used in the cutting-propagation and transplantation trials: the common species *Sarcocornia quinqueflora*, *Suaeda australis*, *Sporobolus virginicus*, and the three rare species, *Halosarcia pergranulata*, *Wilsonia backhousei* and *Lampranthus tegens*. The most easily propagated species was *Lampranthus tegens*, which has horticultural potential as an ornamental ground cover. Its survival under the transplantation conditions, however, with no follow-up watering after the first week, was very low.

The survival and growth of the common species up the gradient were as predicted from ecological studies. Highest survival and growth rates were obtained for *S. quinqueflora*, on the lower half of the gradient, *S. virginicus* in the upper most levels, and *H. pergranulata* across the whole gradient.

From the studies the following conclusions can be drawn:

a) The propagation techniques used for producing transplant stock in this trial have been successful.
b) The propagation techniques could be improved by further horticultural manipulation, although the spring cutting time seems appropriate.
c) Transplantation can accelerate the process of colonising the territory.
d) In a normal site development project, transplantation efforts should be concentrated on planting out the appropriate species at the various tidal heights up the gradient.

e) It is clear from the transplantation site and the other, older, dump-fill sites as well, provided that the right tidal estuarine hydrology is present on site, mangrove and / or saltmarsh communities will establish themselves. The common species commence colonisation simultaneously at the various levels suitable to each, within 1 to 2 seasons.

f) Depending on the particular needs of the project, some future regeneration strategies might place more emphasis on transplanting the rare species at their appropriate levels, with only minimal planting of the commoner species, allowing the bulk of the latter to establish themselves as they will. This would not be a suitable strategy, however, if an instant sward were needed by management; in this case, equal emphasis would have to be given to planting all of the species concerned.

g) Whether saltmarsh plant regeneration will be accompanied by the faunal colonisation of the substrate is as yet unknown. Presumably both sediment characteristics and the quality of the water in the system are involved in ensuring the re-establishment of a fully functioning intertidal ecosystem.

Assessment of the Three Rare Species

From the transplantation project, confirmed by the ecological studies at both Newington and the 2KY site, it appears that although *Halosarcia pergranulata* is capable of survival and growth at any level within the marsh, it is commonly found at the top of the marsh and in non-tidal areas on saline substrate. *Wilsonia backhousei* favours the low to mid marsh areas, often found in association with *Sarcocornia quinqueflora*, with which, however, it may be a poor competitor in the long term. *Lampranthus tegens* is less common than the other two species, although it does form swards in a few specific areas at the top edges of the marsh. Its position within the marsh makes it vulnerable to dry substrate conditions, and it appears very susceptible to seasonal dieback.

III. Findings and Recommendations — Mangroves

Historical Mapping Survey

This study revealed that over the last 60 years there has been a reduction of 25% in the area of mangroves in Homebush Bay and adjacent areas of the Parramatta River, and a 60% decline in saltmarsh areas. The Newington forest area has been reduced by about 20% over the same period.

Current Distribution in Newington Wetland

The whole area of Newington wetlands is showing signs of stress, with dieback and loss of canopy cover in the mangroves. Only about 15% of the mangrove community appears 'healthy', that is, with a foliage projective cover of over 50%. This season's summer rains are now bringing about some recovery, but mangroves are slower to respond than the saltmarsh.

Structure, status and heavy metal levels of mangroves

This study has just been commenced, and reference sites on the Parramatta and Lane Cove Rivers have been investigated before the Newington sites, to ensure that comparative judgements can be made on the way. Similar studies carried out by this laboratory in other areas show that the methodology being used is a powerful means of elucidating the performance of mangrove communities.

IV. Summary of Outcomes and Future Studies

The studies have provided a better understanding of the species composition, structure, sediment characteristics and seasonal dynamics of the saltmarsh communities, and the historical and current distribution of both saltmarsh and mangrove communities of the area.

All of the projects reported above are continuing,to throw light on the structure and performance of the mangrove communities, and longer term influences on the seasonal growth of all of the wetland communities. Investigations are also planned for monitoring other scattered, isolated patches in the Newington wetlands, that are not part of the intensive study sites, but contain one or other of the rare species, and sometimes other species of uncommon growth forms.

The information derived from the studies will assist in determining strategies for the successful restoration and management of the wetland systems of the Homebush Bay area. Many of the findings have more general implications for estuarine communities of this State.

1 INTRODUCTION

The saltmarsh and mangrove communities that form a major part of the estuarine intertidal ecosystem along the east coast of Australia, have over the 200 years of European settlement been subjected to destruction and a variety of disturbances including bunding, draining, dredge-fill dumping and industrial and domestic waste dumping. The Homebush Bay wetlands, which comprise the largest remaining stands of these communities in Port Jackson, are no exception (Katchka, 1992).

The final goal of the current project is to assist in the conservation, restoration and management of the Homebush Bay wetlands by providing information on the present structure and performance of the saltmarsh and mangrove communities, their seasonal dynamics, the factors influencing the health and performance of the stands, and their transplantability.

The specific experimental aims of the project were initially focused on the saltmarsh community, as follows:

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More recently (October, 1994), the study has been extended to include the mangrove stands, which in NSW form a mosaic with the saltmarsh swamps in the intertidal ecosystem. The specific aims of the mangrove component of the study, are to investigate the distribution, structure and seasonal dynamics of the mangroves, and the factors which appear to affect their health and performance.

Preliminary results of the saltmarsh studies were presented in our previous report (February, 1994). Further information on the saltmarsh study are presented here below, along with the initial findings of the mangrove investigations. Continuing studies have included both the Newington Depot and the 2KY sites, for various aspects of the work. Both of these locations include both the common dominants of Sydney saltmarsh communities, and the three rare species *Halosarcia pergranulata*, *Wilsonia backhousei* and *Lampranthus tegens*, which are now largely confined to various stands in the Homebush Bay area. For the full species list of species encountered in the course of this study, see Table 1.

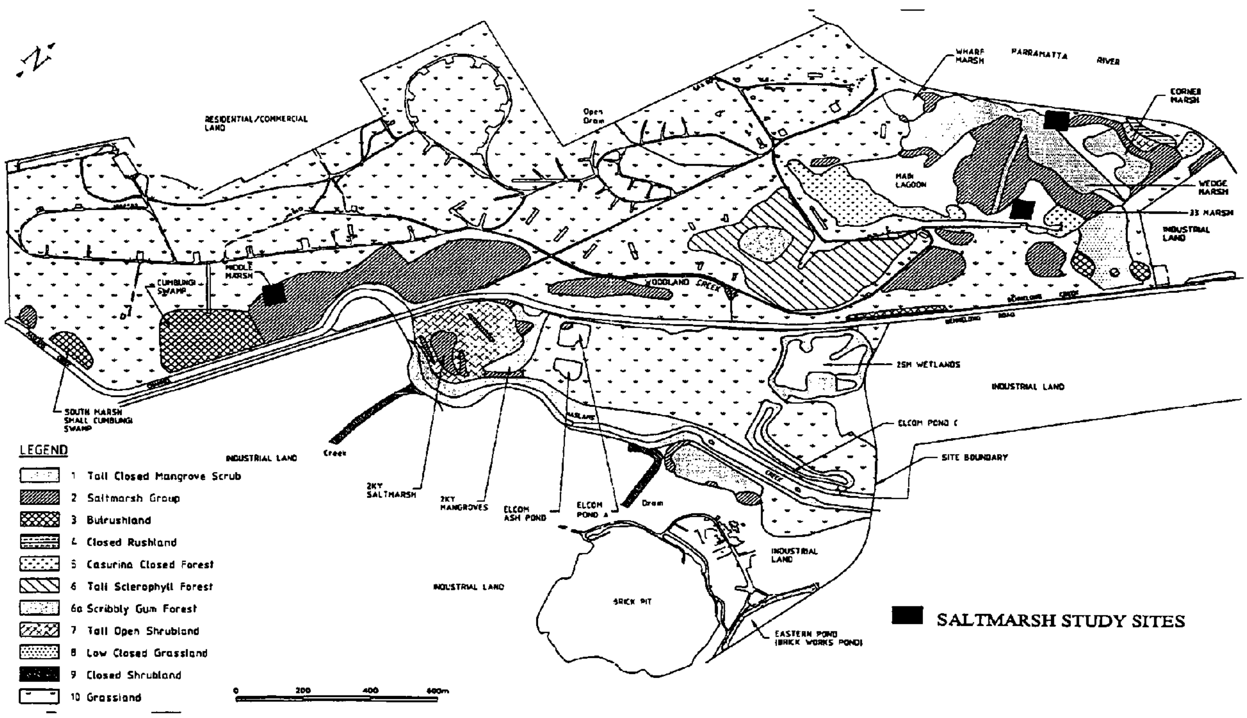


Figure 1. Map indicating three saltmarsh study sites: Key # = study site.

2 SALTMARSH ECOLOGICAL STUDIES

2.1 NEWINGTON ARMS DEPOT

2.1.1 Methodology

2.1.1.1 Site Descriptions

Three sites were chosen for seasonal sampling of the saltmarshes (see Fig. 1). Sites 1 and 2 are located within the main wetland area (Fig. 2). This area retains characteristics of the intertidal zone, although it is no longer subject to full tidal flushing, as the result of bunding and blocked drainage channels. However, the area is generally moist to wet, with free water in some patches (Fig. 2, Plates 1 and 2).

Site 1a (Plate 3) is a mixed stand with none of the three rare species, while Site 1b adjacent to it includes a fairly large patch (approx. 10 x 10 m) of *W. backhousei*, along with *S. quinqueflora* and *T. striata*. (Plate 4).

Site 2, (Plate 5) adjacent to the river, is a mixed stand including some *W. backhousei* within it.

Site 3, (Plate 6) lies in the valley area of the stormwater drain to Haslams Creek, which is no longer intertidal, but is upon still saline substrate. This area contains all three rare species in a mixed stand with the two species (native and exotic) of *Juncus*.

2.1.1.2 Sampling Methods

At each of Sites 1a, 2 and 3, a transect was run the length of the wetland (approximately north-south orientation), and at either end and across its midpoint, five $0.025m^2$ permanent quadrats were marked out, one on the transect line and two at right angles on either side of the transect. Distances of the quadrats from the transect varied from 1–4 m.

At Site 1a, because of the clear zonation within the marsh, separate sets of quadrats were used along the transect for areas dominated by *S. australis*, *S. quinqueflora* and *J. acutus* respectively. Because of the small size of the *W. backhousei* patch at Site 1b, five quadrats were placed directly along the transect.

At Site 2, separate sets of quadrats were laid in areas dominated by *W. backhousei*, *S. australis* and *J. acutus* respectively.

Sampling was carried out four times over a full annual cycle (October 1993 – November 1994), and is continuing.

Plant Data Within each quadrat, 5 readings of height for each species were recorded, along with foliage projective cover percentage (FPC) in total and for each species, and a notation of the percentage 'active' (ie green/ red and succulent) or 'inactive/ dead' (ie brown and driish) plant material. Flowering and fruiting were also noted. A spatial abundance index (SAI), was used as a measure of growth for each dominant species, other than *Juncus spp.*, in each quadrat set. The SAI was computed as (height in cm x FPC/ 10). It was found that this index could in most cases also act as an estimate of biomass (mass of plant material/ area), however for some species and some samplings, correlations were low . In any case, the SAI provides a direct measure of the volume of space occupied by each species. For the Juncus species, a volumetric estimate was made from diameter and height measurements.

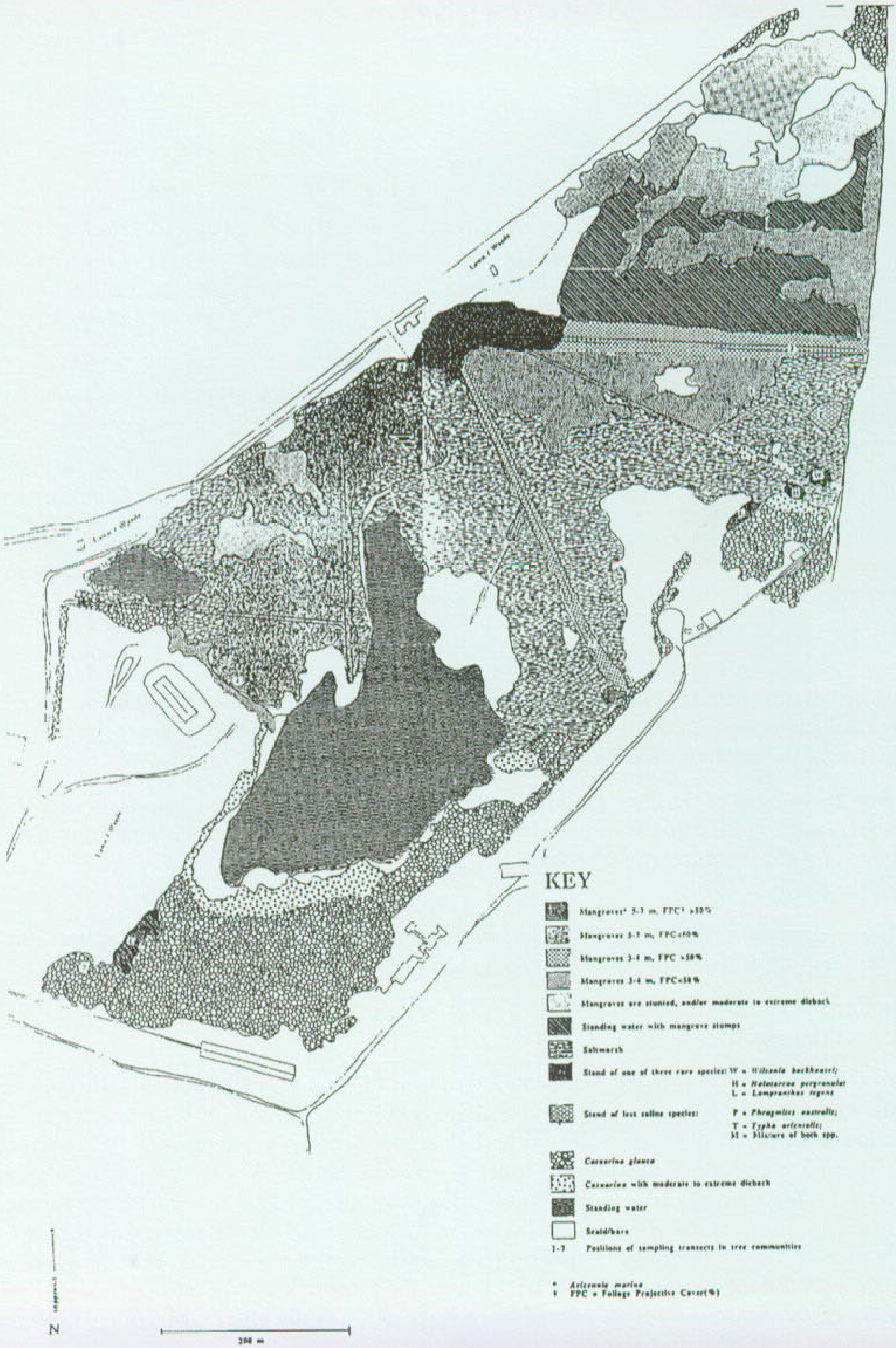


Figure 2. Vegetation Distribution Map (M.D. Burchett and A Pulkownik, 1995).

Plate 1. Mixed saltmarsh and mangroves, Newington.

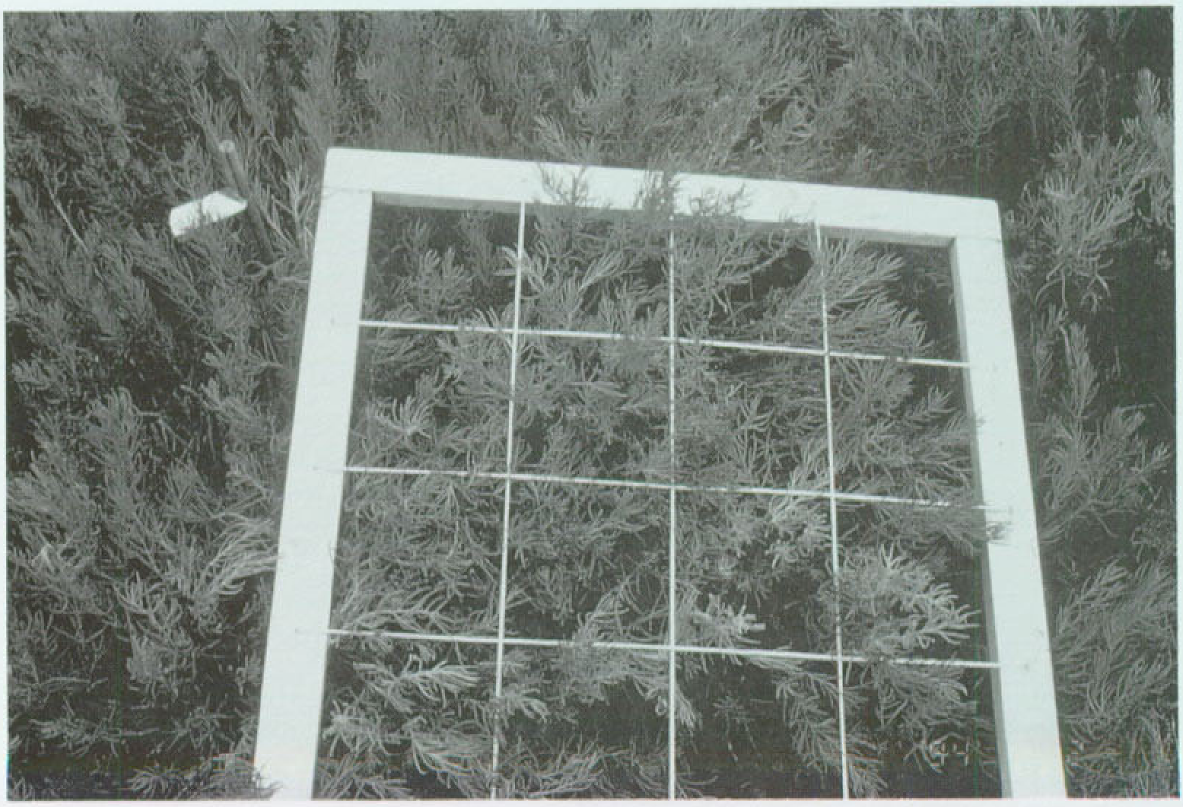


Plate 2. Suaeda patch, Site 1a, Newington.

Plate 3. Junction of saltmarsh and casuarinas, Site 1

Plate 4. Wilsonia patch, Site 1b, Newington.

Plate 5. Site 2, Newington

Plate 6. Site 3, Newington .

Table 1 Main plant species, by family, found in saltmarsh areas of Homebush Bay

Family	Botanical Name	Common Name; Comments	Level in Marsh
DICOTS			
Aizoaceae		Pig-face family	
	*Lampranthus tegens**#	Possibly from S Africa, naturalised	Upper half
	Tetragonia tetragonioides	New Zealand spinach	Upper edges
Asteraceae		Daisies	
	Cotula coronopifolia	Waterbuttons	Wet, less salty seepage areas
Caryophyllaceae			
	Spergularia marina	Sand spurry	Upper edges, uncommon
Chenopodiaceae			
	Atriplex hastata	Salt bushes	Upper edges
	Halosarcia pergranulata *#		Upper half, though seems to be able to survive throughout gradient
	Sarcocornia quinqueflora **#	Samphire, Glasswort	From low into upper half
	Suaeda australis **#	Southern Seablite	Lower to upper half
Convolvulaceae		Convolvulus or Morning Glory Family	
	Wilsonia backhousei *#	Narrow-leaved Wilsonia	Upper edges
Primulaceae		Primroses	
	Samolus repens		Upper edges
MONOCOTS			
Juncaceae			
	Juncus acutus	Aggressive weed, with sharp dangerous spikes	Mid-zone of marsh
	Juncus kraussii **#	Sea Rush Needs to be protectively managed to be sustained against *J. acutus*	Mid to upper zone
Juncaginaceae			
	Triglochin striata	Streaked Arrowgrass	Small, scattered patches, likes seepage runnels
Poaceae		Grasses	
	Sporobolus virginicus	Sand Couch	Upper edges

* Indicates categorisation of 'rare species
** Indicates that the species is a common dominant, in the sense of making up most of the ground cover at some level in the marshes in the area. However, each of the three rare species can also form mats if conditions are suitable.
\# Indicates species which we know are suitable for transplantation from cuttings.

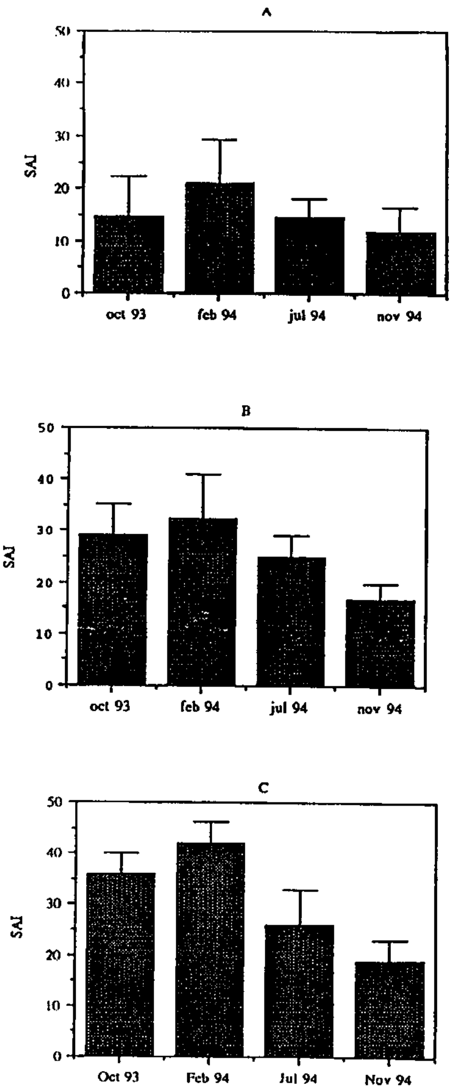


Figure 3. Seasonal changes in Spatial Abundance Index (SAI) for *Suaeda australis* within a *Suaeda*-dominant area at Site 1a at Newington: (a) North, (b) Centre, and (c) South (±SE).

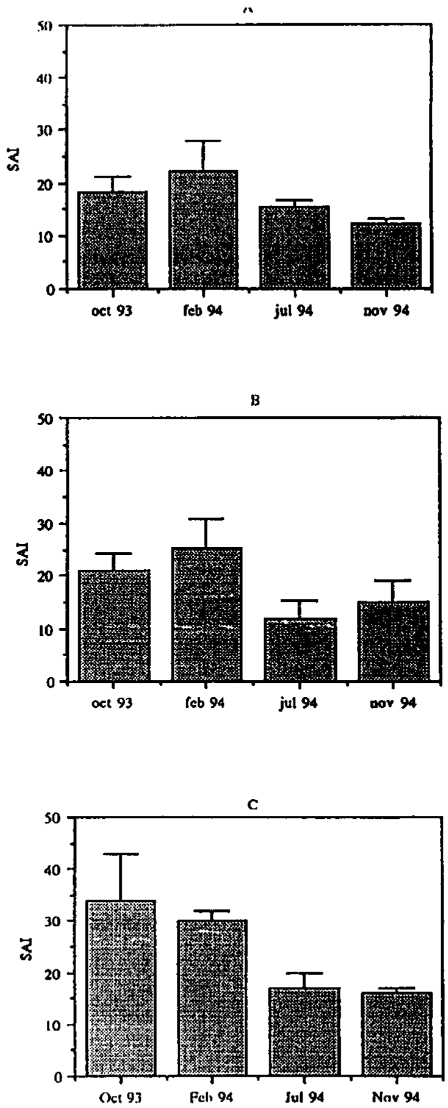


Figure 4. Seasonal changes in Spatial Abundance Index (SAI) for *Sarcocornia quinqueflora* within a *Sarcocornia*-dominant area at Site 1a at Newington: (a) North, (b) Centre, and (c) South (±SE).

Sediment Data At the three sampling points along every transect, 3 sediment cores (10 cm depth) were collected on each sampling occasion and returned to the laboratory for the following measurements: pH in water and KCl (1/3 dry-wt/v), electrical conductivity (mS/cm, 1/3 dry-wt/v) as a measure of salinity, chlorinity and gravimetric water content. For each quadrat measurements were also made of the structure (mechanical analysis), exchangeable cation concentrations, using extraction with 1M ammonium acetate (1 g dry soil/25 mL) and measurement by atomic absorption spectrometry (AAS), and organic matter (as percentage loss on ignition in muffle furnace at 450° C) of the substrate.

Statistical Analyses Means and standard errors were determined for all parameters at every sampling, and differences assessed as necessary by the use of analysis of variance and Student's t-test for the significance of differences between means.

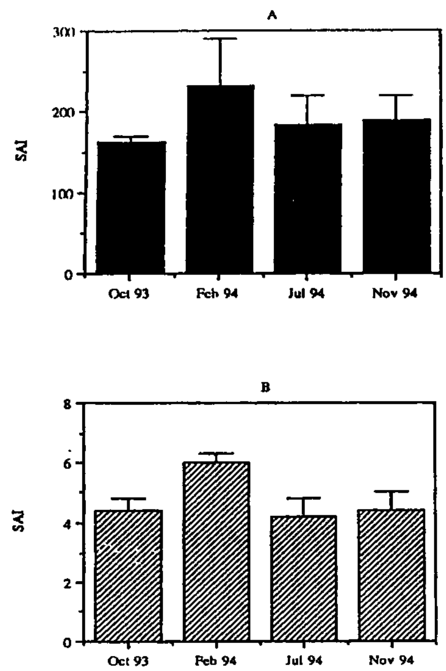


Figure 5. Seasonal changes in Spatial Abundance Index (SAI) for *Juncus acutus* at Site 1 South (a) and *Wilsonia backhousei* (b) at Site 1b at Newington (±SE).

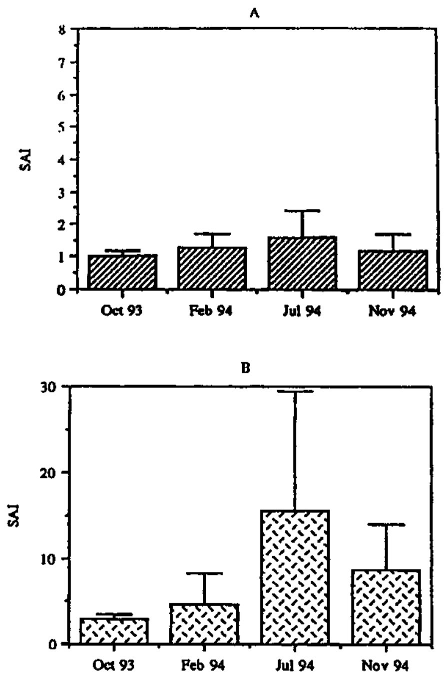


Figure 6. Seasonal changes in Spatial Abundance Index (SAI) for *Wilsonia backhousei* (a) and *Sporobolus virginicus* (b) in a *Sarcocornia*-dominant area, at Site 2 at Newington (±SE).

2.1.2 Results and Discussion — Newington Saltmarsh

2.1.2.1 Plant Distribution

The species distribution along the four transects used in the study is presented in Tables 2, along with seasonal differences in the foliage projective cover, and the proportion that was apparently active in each species.

2.1.2.2 Plant Growth

Seasonal changes in the spatial abundance index (SAI) for each dominant species in each quadrat, at each site, are shown in Figs. 3 to 10. It can be seen that within each site the seasonal trends are consistent, however there are differences in seasonal patterns among sites. At Site 1(a and b), the spatial abundance of each species was highest towards the end of summer 1994, and declined steadily thereafter to November 1994. At Site 2, *W. backhousei*, *S. virginicus* and *J. acutus* showed continued growth during winter, and if anything a peak in abundance in July, *S. australis* and *S. quinqueflora* only showing signs of a winter dieback. At Site 3, of the three dominant species recorded, there was a decline over summer followed by some recovery during winter and the following spring.

The results clearly indicate the importance of micro-habitat conditions, some of which are examined further below, in the growth of these saltmarsh species.

Table 2 **Seasonal species presence and mean foliage projective cover percentage (FPC) at the three sites, Site 1, Site 2, and Site 3 at Newington Depot. Percentages in brackets (%) give estimates of the ''active' (apparently live) plant material; p = present, but insignificant in terms of cover**

Site	Dominant Species	Other Species	FPC (%)			
			Oct '93	Feb '94	July '94	Nov '94
SITE 1 North	Suaeda	*S. australis*	60	60	64	65
		S. quinqueflora	10	20	20	10
		T striata	p	0	p	p
SITE 1 Centre	Suaeda	*S. australis*	85	75	85 (20%)	60 (20%)
		S. quinqueflora	15	20	15	30
		T striata	p	0	0	p
		S. virginicus	p	0	0	p
SITE 1 South	Suaeda	*S. australis*	95	85	90 (45%)	80 (60%)
		S. quinqueflora	5	10	10	20
		T striata	p	0	0	0
		S. virginicus	0	p	0	0
SITE 1 North	Sarcocornia	*S. quinqueflora*	95	100 (33%)	95	90
		T striata	p*	0	0	0
		S. australis	0	0	p*	5
SITE 1 Centre	Sarcocornia	*S. quinqueflora*	90	90	95	100 (55%)
		S. australis	5	5 (50%)	0	0
		T striata	p	p	p	0
		A. hastata	p	0	0	0
		S. virginicus	0	p	0	0
SITE 1 South	Sarcocornia	*S. quinqueflora*	100	80 (55%)	80 (25%)	100 (55%)
		T striata	p	0	0	0
SITE 1 South	J. acutus	*J. acutus*	95	95 (25%)	95 (55%)	100
SITE 1 Wilsonia	Wilsonia	*W. backhousei*	85	95 (15%)	85	90 (65%)
		S. quinqueflora			5	p
		T striata			5	5

Table 2 **Seasonal species presence and mean foliage projective cover percentage (FPC) at the three sites, Site 1, Site 2, and Site 3 at Newington Depot. Percentages in brackets (%) give estimates of the ''active' (apparently live) plant material; p = present, but insignificant in terms of cover**

Site	Dominant Species	Other Species	FPC (%)			
			Oct '93	Feb '94	July '94	Nov '94
SITE 2 North	Wilsonia	*W. backhousei*	40	20	20	90
		S. quinqueflora	45	40	50 (50%)	p
		S virginicus	10	p	20	0
		Sonchus olereus	5	0	0	0
		Grass spp	p	0	0	0
		T striata	0	0	0	5
SITE 2 Centre	Sarcocornia	*S. quinqueflora*	85	60	75 (75%)	60
		S. australis	10	10	0	15
		T striata	0	0	0	p
	Juncus	*J. acutus*	85	75	100 (80%)	100
		S. quinqueflora	p	1	0	0
		S australis	5	5	p	0
		T striata	0	p	0	p
SITE 2 South	Juncus	*.J. acutus*	75	80	100 (85%)	100 (70%)
		S. quinqueflora	10	25	0	0
		S. australis	p	5	0	0
		Asteraceae spp	0	p	0	0
		T striata	0	p	0	0
SITE 3 North	Wilsonia	*W. backhousei*	27	20	25	65
		J. acutus	20	20	15 (50%)	10 (80%)
		J. kraussii	20	15	15 (30%)	10
		Couch spp	p	5	10	20
SITE 3 South	Halosarcia	*H. pergranulata*	65	80	75	80
		J. kraussii	15	20	20 (40%)	20
		L. tegens	p	p	15	15
		Sonchus olereus	0	0	5	0
		Couch spp	0	0	5	p

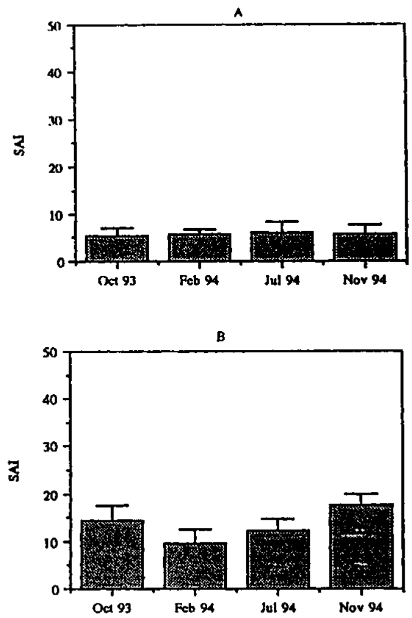


Figure 7. Seasonal changes in Spatial Abundance Index (SAI) for *Sarcocornia quinqueflora* in a *Sarcocornia*-dominant area, at Site 2, north, at Newington (±SE).

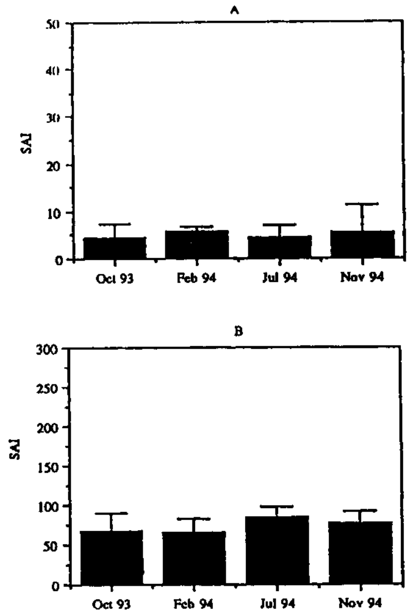


Figure 8. Seasonal changes in Spatial Abundance Index (SAI) for *Suaeda australis* and *Juncus acutus* at Site 2, centre at Newington. (±SE).

2.1.2.3 Sediment Characteristics

Mechanical analysis: Table 3 shows the results of mechanical analyses for the three Newington sampling sites. At Site 1a the fine matter (silt and clay) varied from 16%–23%, while the substrate of the *W. backhousei* stand, Site 1b, was slightly coarser in texture, with a fine matter content of approximately 13%. The sediment texture at site 3 was significantly finer than at either of the other two sites, with a fines content of over 36%, indicating a considerably greater water-holding capacity at the third site.

Organic matter: The results for the three sites are shown in Table 4. The sediment cores taken for soil analyses were always observed to contain a high percentage of roots and runners in the top 10 cm. Although Australian soils can vary in organic matter content from about 1% in desert loams to over 50% in alpine humus soils, levels typical of agricultural soils range from

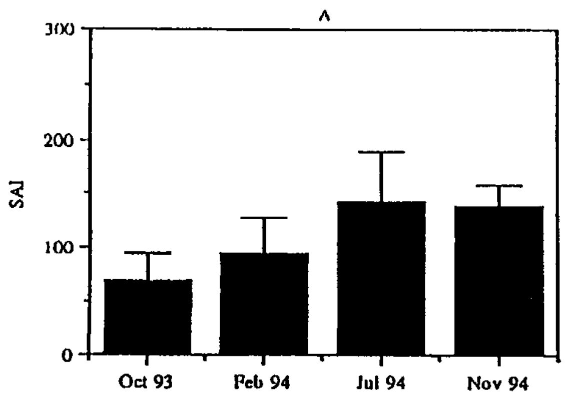


Figure 9. Seasonal changes in Spatial Abundance Index (SAI) for *Juncus acutus* at Site 2, south, at Newington (±SE).

Table 3 Mechanical analysis of sediments from the three sampling sites. Values shown as percentage proportions are means of 4 determinations (±SE).

Location	Sub-site	> 2mm	> 1mm	> 500 μ	> 250 μ	> 106 μ	< 106 μ
SITE 1	North	0.8 (0.3)	17.5 (1.8)	32.5 (2.7)	26.0 (0.4)	20.4 (1.7)	2.9 (0.3)
	Centre	0.7 (0.3)	20.8 (9.9)	32.2 (5.8)	23.9 (5.7)	19.5 (8.0)	3.1 (1.9)
	South	1.6 (1.4)	21.7 (2.9)	37.2 (0.8)	23.1 (1.7)	14.1 (1.7)	2.3 (0.7)
	Wilsonia	51.4 (8.0)	12.3 (2.0)	13.6 (3.0)	9.9 (1.5)	8.1 (1.3)	4.8 (0.3)
SITE 2	North	2.6 (0.8)	1.3 (0.3)	18.7 (1.9)	58.8 (1.2)	17.8 (1.4)	0.9 (0.1)
	Centre	1.3 (1.2)	1.4 (0.2)	23.2 (3.1)	61.3 (1.7)	11.9 (1.9)	0.9 (0.1)
	South	42.9 (13.8)	12.2 (5.1)	15.1 (3.0)	11.6 (2.3)	11.2 (0.5)	7.1 (2.8)
SITE 3		33.4 (4.8)	7.2 (2.4)	12.8 (2.4)	10.2 (2.3)	17.6 (4.0)	18.8 (1.7)

about 1.5%–4.6% (Charman and Murphy, 1991 a). All of the sediment samples from the Site 1, therefore, would be regarded as humus (peaty) soils, as would the that at the southern end of Site 2, which is discussed in more detail below. Those of the remainder of Site 2, and at Site 3, are within the normal range of garden soils, although somewhat on the high side for organic matter in most cases. The high levels of organic matter are to be expected in a community which tends to form mats below the active runners on the plants, producing thick swards in some places.

Table 4 Seasonal variation in organic matter content of the sediments from the three sampling sites. Values shown, as % loss on ignition, are means of 4 determinations (±SE). (nd = not determined.)

Location	Sub-site	October '93	February '94	July '94	November '94
SITE 1	North	23.6 (1.7)	30.1 (9.3)	23.6 (5.8)	29.8 (5.4)
	Centre	34.2 (4.8)	36.0 (2.1)	24.9 (6.8)	34.3 (7.0)
	South	34.7 (1.4)	29.8 (3.8)	33.0 (1.3)	38.3 (3.0)
	Wilsonia	nd	29.3 (29.3)	37.1 (5.7)	40.8 (2.9)
SITE 2	North	3.5 (0.6)	11.4 (1.9)	3.8 (0.5)	4.1 (0.1)
	Centre	6.2 (0.8)	9.7 (1.1)	5.6 (1.3)	6.5 (0.9)
	South	30.6 (1.3)	53.7 (11.3)	28.2 (0.7)	31.7 (1.1)
SITE 3		nd	5.7 (0.2)	7.1 (0.4)	7.7 (0.8)

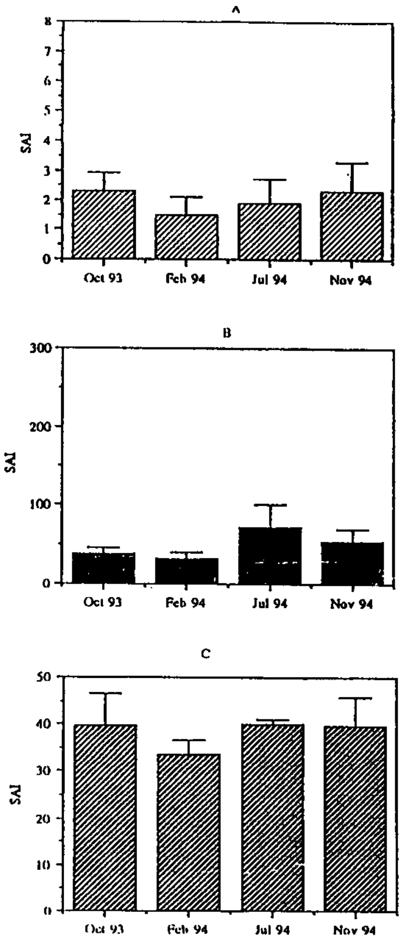


Figure 10. Seasonal changes in Spatial Abundance Index (SAI) for *Wilsonia backhousei* (a), *Juncus acutus* (b) and *Halosarcia pergranulata* (c) at Site 3 at Newington (±SE).

Conductivity and pH, Site 1: Results of seasonal sampling of other physical soil parameters for this site are shown in Table 5. The pH range (6.22 and 7.35) is to be expected in the intertidal zone where seawater influence helps maintain a buffered, neutral environment. The small differences between the water-based and KCl-based readings confirm the saturation of the sediment with exchangeable metal cations. The pH levels at Site 1b, the *W. backhousei* patch, were significantly lower than across Site 1a. This is consistent with the finding presented above, that this area has a coarser substrate than the main marsh area at Site 1.

The electrical conductivity levels in the sediments ranged from 21–95 dS/m, indicating highly saline conditions than would support only very halophytic (salt-loving) plants. According to Charman and Murphy (1991A), Australian soils are generally defined as saline if the electrical conductivity is greater than 1.5 dS/m, and only a few halophyte species are expected to survive in soils with a conductivity of > 16 dS/m.

The apparent seasonal variability among readings for the same sampling points is puzzling. This is not the result of changes in water contents at the time, since estimates are always made on a 1/3 w/v slurry of dried soil. It may be the result of small-scale variations within the substrate, or the presence of hypersaline interstitial water of variable concentrations at the times of sampling. This matter is being investigated further. The water contents which were recorded at this site showed consistently higher levels in the main marsh (1a) than in the *W. backhousei* stand (1b).

Table 5 Seasonal variation in pH, conductivity (EC), chlorinity ([Cl⁻]) and water content of the sediments at Site 1. Values shown are means of 4 determinations (±SE). (nd = not determined).

Parameter	Sub-site	October '93	February '94	July '94	November '94
pH (in H_2O)	North	6.98 (0.20)	7.35 (0.35)	6.95 (0.04)	6.26 (0.22)
	Centre	6.89 (0.10)	6.43 (0.35)	6.60 (0.03)	6.90 (0.11)
	South	6.78 (0.10)	6.77 (0.09)	6.97 (0.09)	6.53 (0.12)
	Wilsonia	nd	5.50 (0.98)	5.62 (0.33)	6.37 (0.19)
pH (in KCl)	North	6.88 (0.30)	7.37 (0.06)	6.95 (0.04)	6.14 (0.18)
	Centre	6.78 (0.20)	6.68 (0.25)	6.75 (0.07)	6.77 (0.08)
	South	6.68 (0.20)	6.79 (0.25)	6.77 (0.07)	6.39 (0.09)
	Wilsonia	nd	5.69 (0.69)	5.17 (0.17)	5.75 (0.30)
EC (dS/m)	North	32.37 (3.08)	61.78 (3.04)	56.03 (30.58)	70.07 (8.52)
	Centre	21.65 (6.75)	94.77 (5.71)	76.20 (17.76)	71.37 (13.03)
	South	23.95 (3.8)	71.57 (6.75)	58.53 (6.28)	63.95 (13.69)
	Wilsonia	nd	36.23 (19.69)	40.17 (9.59)	25.67 (2.12)
[Cl⁻] (mg/g)	North	37.29 (3.55)	71.17 (3.50)	29.30 (2.00)	92.30 (7.90)
	Centre	24.94 (4.67)	82.44 (6.58)	41.00 (4.10)	71.90 (20.30)
	South	16.55 (4.38)	82.44 (7.78)	21.90 (1.60)	80.00 (17.30)
	Wilsonia	nd	41.74 (22.68)	25.00 (6.20)	32.80 (1.30)
Water Content (%)	North	nd	nd	64.73 (10.96)	63.95 (9.09)
	Centre	nd	nd	69.54 (11.13)	70.59 (5.41)
	South	nd	nd	69.57 (4.32)	73.89 (3.11)
	Wilsonia	nd	nd	50.47 (6.41)	42.76 (0.81)

This is partly the result of the slightly higher elevation of the latter and also, no doubt, the somewhat coarser substrate, with a lower water-holding capacity than the remainder of this site.

In summary, the main differences in sediment parameters between the *W. backhousei* site and Site 1a, were in the lower clay content, lower pH and lower water content of the *Wilsonia* site.

Conductivity and pH, Site 2: The pH levels of the substrate at this site (Table 6), were found again to be generally neutral, and (as indicated by the small differences between water-based and KCl-based readings) the colloids apparently saturated with mineral cations. However there was a significant increase in acidity of the sediment at the southern end, which is occupied by a solid stand of *J. acutus*. The substrate associated with this stand is very peaty, and spongy underfoot, with the very high organic matter content, which was considered above. Apart from at the southern end, the electrical conductivity levels and chlorinity estimations for this site were significantly lower than at Site 1, although still very saline compared with normal terrestrial environments. This site lies between the 'water-bird lake' and a mangrove stand, and there may have been more freshwater runoff through this area than at Site 1. The results show that there was a consistent increase in substrate water content from north to south, that is, towards the lake, at this site.

Conductivity and pH, Site 3: At this site (see Table 7), despite the high levels of fine material in the substrate (refer to Table 2), the pH values were lower than at the other two sites, and the difference in values between the water-based and the KCl-based readings (up to 1 pH unit lower) indicate that the substrate here is not as saturated with mineral cations as at the other two sites (see also Table 8 below). In fact it would appear that either some leaching has occurred since the area has been cut off from all tidal influence, or that this is dump-fill which may have been of less saline origin than the other two areas. This view is also supported by the values for electrical conductivity and chlorinity. Although these are still high enough for the material to be classed as saline soil, they are an order of magnitude lower than those of the other two sites. This site was always much lower in water content than the other two sites. despite these differences in substrate parameters, the community that is supported here contains all three rare saltmarsh species, and is structurally composed of a mosaic of *H. pergranulata* and *J. acutus* stands, the latter being intermingled with the native species, *J. kraussii.*

Table 6 Seasonal variation in pH, conductivity (EC), chlorinity ([Cl^-]) and water content of the sediments at Site 2. Values shown are means of 4 determinations (±SE). (nd = not determined).

Parameter	Sub-site	October '93	February '94	July '94	November '94
pH (in H_2O)	North	7.68 (0.10)	7.98 (0.09)	6.39 (0.17)	6.75 (0.21)
	Centre	6.98 (0.20)	7.49 (0.22)	6.46 (0.14)	6.27 (0.30)
	South	5.58 (0.10)	6.07 (0.04)	6.13 (0.15)	5.54 (0.36)
pH (in KCl)	North	7.98 (0.30)	8.65 (0.05)	6.42 (0.13)	6.64 (0.21)
	Centre	6.98 (0.30)	8.43 (0.10)	6.54 (0.08)	6.03 (0.17)
	South	nd	6.12 (0.07)	5.95 (0.16)	5.23 (0.30)
EC (dS/m)	North	9.63 (0.95)	9.04 (0.40)	12.14 (4.07)	15.33 (2.35)
	Centre	14.12 (2.95)	13.73 (0.23)	16.51 (3.86)	19.27 (1.88)
	South	23.02 (2.10)	85.50 (5.35)	19.99 (3.49)	74.57 (9.26)
[Cl^-] (mg/g)	North	11.09 (1.09)	10.41 (0.46)	13.99 (4.69)	15.30 (2.50)
	Centre	16.27 (3.39)	15.82 (0.26)	19.02 (4.45)	19.10 (4.90)
	South	26.52 (2.42)	98.50 (6.16)	23.03 (4.02)	111.20 (20.50)
Water Content (%)	North	nd	33.20 (2.39)	26.85 (0.77)	36.90 (0.22)
	Centre	nd	35.90 (1.99)	40.80 (6.95)	49.92 (5.27)
	South	nd	85.43 (0.90)	82.80 (0.71)	79.97 (0.45)

Table 7 Seasonal variation in pH, conductivity (EC), chlorinity ([Cl^-]) and water content of the sediments at Site 3. Values shown are means of 4 determinations, (± SE). (nd = not determined).

Parameter	Sub-site	October '93	February '94	July '94	November '94
pH (in H_2O)		nd	6.75 (0.08)	6.61 (0.21)	6.59 (0.16)
pH (in KCl)		nd	5.52 (0.04)	5.64 (0.05)	5.86 (0.04)
EC (dS/m)		nd	1.93 (0.31)	1.97 (0.71)	5.77 (1.52)
[Cl^-] (mg/g)		nd	1.60 (0.40)	1.30 (0.00)	5.40 (1.90)
Water Content (%)		nd	8.15 (0.76)	12.76 (0.69)	19.20 (2.00)

The water content of the substrate was also found to be very low compared with the other sites. The runoff down the slopes and along the valley must maintain a sufficiently steady water supply to sustain the plants. On the other hand, the low water levels may explain why a patch of *L. tegens* which was included in the initial samplings disappeared completely thereafter, and another patch had to be substituted.

Exchangeable cations: Exchangeable, that is, soluble, substrate concentrations of Na, K, Ca and Mg are presented in Table 8. For comparison, the values for a range of other Australian soils in Table 9. The results show that site 1 is very high in sodium, with elevated levels also at the southern end of site 2, indicating past tidal influence. The values for the other cations are low as compared with the inland, fairly saline clayey soils of this continent, although they are comparable with other Sydney soils on a Hawkesbury sandstone parent material. The calcium and magnesium levels at site 1 were also three to four times higher than at the other Newington sites, indicating a different history of development. Both Site 2 and Site 3 show evidence of dump-filling activities.

In summary, the sediments, as expected, were found to be consistently high in fine matter (silt and clay content), salinity and exchangeable sodium.

Table 8 Exchangeable cation concentration (in meq / 100g) in the sediments from the three sampling sites. Values shown are means of 4 determinations, (± SE).

Location	Sub-site	Na	K	Ca	Mg
SITE 1	North	6.33 (1.57)	0.27 (0.04)	2.00 (0.63)	1.81 (0.38)
	Centre	6.08 (0.21)	0.25 (0.06)	1.92 (1.27)	1.67 (0.22)
	South	4.74 (0.10)	0.28 (0.03)	2.69 (0.43)	1.52 (0.02)
	Wilsonia	3.68 (0.67)	0.25 (0.02)	0.43 (0.01)	0.90 (0.10)
SITE 2	North	0.70 (0.20)	0.04 (0.00)	0.44 (0.22)	0.26 (0.06)
	Centre	0.86 (0.20)	0.05 (0.01)	0.27 (0.07)	0.34 (0.06)
	South	3.56 (0.32)	0.37 (0.01)	0.63 (0.04)	1.00 (0.09)
SITE 3		0.20 (0.05)	0.03 (0.00)	0.32 (0.03)	0.23 (0.02)

Table 9 Examples of exchangeable cation concentrations (meq. / 100 g) for other Australian soils (derived from Stace *et al.*, 1968).

State	Soil Type	Na	K	Ca	Mg
TAS.	Acid Peat	1.3	1.4	5.92	3.2
NSW	Brown Earth	1.25	0.3	11.1	7.4
QLD.	Red Earth	0.2	0.2	2.97	1.9
QLD	Black Earth	1.1	1.68	25	11.1
WA	Solonetz	3.4	0.2	2.82	1.91
SA	Red Clay	3.99	1.1	9.9	3.6
SA	Desert Loam	1.41	1.4	2.9	15

2.1.2.4 Distribution of Plant Communities in Relation to Soil Parameters

The results presented here confirm the general zonation of the south eastern Australian saltmarsh, with S. *quinqueflora* and *T. striata* occupying the lower, wetter areas of the saltmarsh with S. *australis* around the margins of the lowest zone, and the remaining species distributed in the upper levels of the marsh. In the top, drier areas S. *virginicus* is found, along with J. *acutus* and J. *kraussii* when there is a sufficient freshwater input to sustain growth . Of the three rare species, W. *backhousei* may occur fairly low, among the upper levels of the S. *quinqueflora* zone, while L. *tegens* appears in patches along the top edges of the marsh, adjacent to the *Casuarina glauca* stands behind the wetlands.

The H. *pergranulata* at Newington is also found in the drier areas, and one patch of this species (not yet included in this survey) is in an isolated area well away from any other saltmarsh vegetation, though it is presumably on a saline substrate

The results of the transplantation experiment, discussed below (Section 3) show that H. *pergranulata* can survive at any height in the marsh. This suggests that this species may have some unknown competitive disadvantages compared with the other dominants.

Most of the saltmarsh species showed some degree of dieback in the dry summer 1994 (Plates 7 and 8). In some places, for example to the west of the bank running along the eastern boundary of Site 1, fingers of dieback occurred the shapes of which suggested runnels of some chemical substance leaching out from the bank. The dieback continued during spring and early summer at the end of 1994, but was relieved by summer rains in January 1995 (Plate 9) For saltmarsh plants drought means not only a shortage of water, but also increasing substrate salinity, eventually to toxic levels. These species however quickly recover following rain.

The results do not overall reveal any close correlation between substrate salinity and the distribution, that is the zonation, of the plants. Longer term studies may reveal a clearer relationship It would appear, meanwhile, that provided the substrate is saline enough to keep out other terrestrial competitors, the factor which dominates the zonation in the saltmarsh is water availability.

Plate 7. Tongues of dieback, near Site 2b.

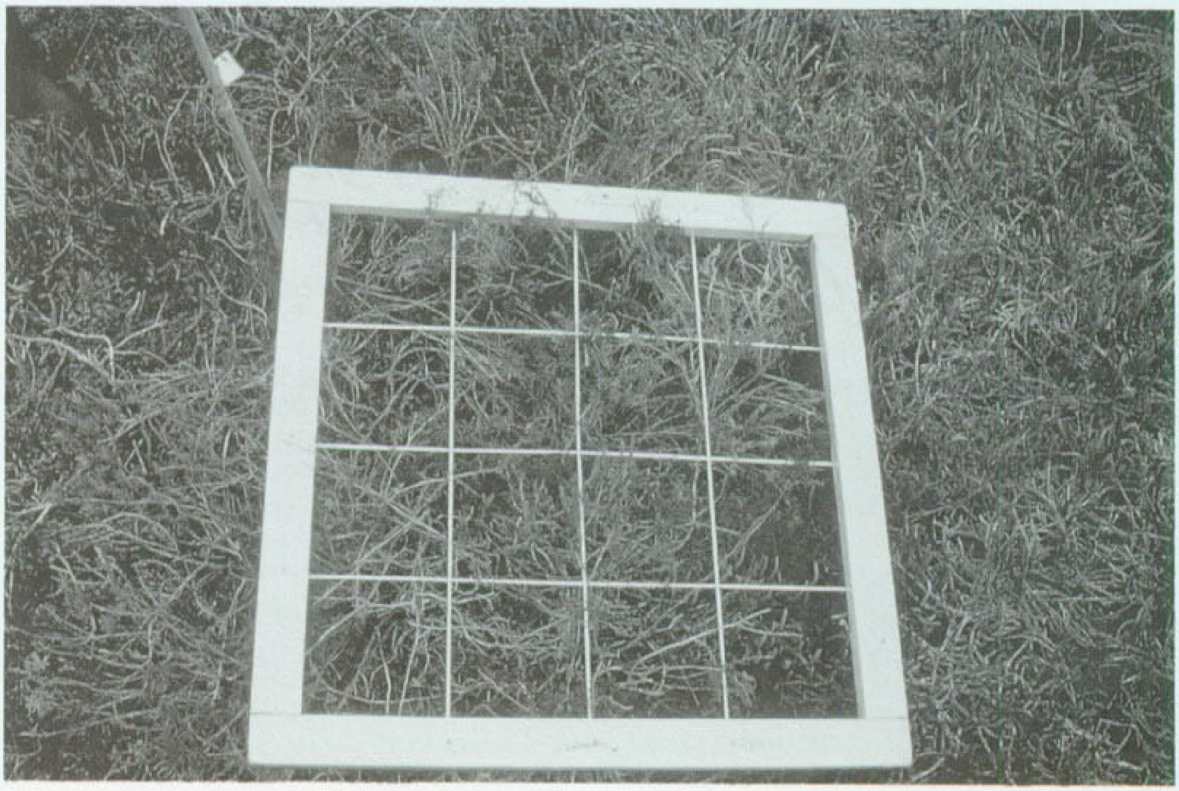


Plate 8 Dieback in Suaeda patch, Site 1a.

Plate 9. Regeneration after summer rains, Newington.

Plate 10. Saline dump-fill, 2KY Site.

2.2 Saltmarsh Survey at 2KY Site

2.2.1 Introduction

Aim of study The aim of this subsidiary saltmarsh study was to compare the species composition, including weed species, of a section of the community containing all three rare species, and to compare the sediment structure and water content down a topographical gradient at the site. Sampling was carried out in August / September 1994.

Site Description The site is located on the northern bank of Haslams Creek, which was subjected to dredge-filling during the 1950s (Clarke and Benson, 1988), so that most of it is now above the intertidal zone (Plate 10). The area was described by Clarke and Hannon (1969) as a 'rotten spot'. The saline nature of the fill is clear from the abundant presence of shells in the sediment/soil. The particular sampling site lay down a slope, about 1/2 to 1m in depth, into a drainage ditch towards the centre of the site.

2.2.2 Methodology

*Plant Distribution and Abundance:*Two transects were laid down the slope, the first 12 m in length which ran in a north-westerly direction, the second of 9 m, which lay in an approximately northerly direction. At 1m intervals along each transect plant species were recorded that lay below the tape, or within 10 cm to either side. In addition, 0.125m^2 quadrats were placed at those points along the transects which overlay the following species of interest: *L. tegens*, *H. pergranulata*, *W. backhousei*, *S. quinqueflora* and *J. acutus*. In each case three quadrats were placed within the area of each of the selected dominants, and species presence and foliage projective cover percentage recorded.

Table 10 Species found at 1m intervals below or within 10 cm of the line, along 2 transects at the 2KY site.

Interval (m) from top	Transect 1 (Depth slope 0.3m)	Transect 2 (Depth slope 0.7m)
1	*H. pergranulata*	*J. acutus*
2	*H. pergranulata*	*Spergularia marina**
3	*L. tegens/Parapholis incurva**	*L. tegens / S. virginicus*
5	*L. tegens*	*Medicago sp.*/ P. incurva**
6	*S. quinqueflora*	*H. pergranulata/ Medicago sp.**
7	*H. pergranulata*	*H. pergranulata/ S. virginicus*
8	*H. pergranulata*	*H. pergranulata/ S. virginicus*
9	*H. pergranulata*	*H. pergranulata/ S. virginicus*
10	*H. pergranulata*	*S. quinqueflora/ S. virginicus*
11	*S. quinqueflora*	*W. backhousei*
12	*H. pergranulata*	

* Exotic species

Table 11 Sediment characteristics at top, mid-point and bottom of slope at 2KY site (±SE).

Characteristic	Position on Slope		
	Top	Mid-point	Bottom
Sand (%)	57 (4)	72 (0.7)	69 (5)
Silt (%)	38 (5)	26 (2)	29 (5)
Clay (%)	5 (0.1)	2.3 (1.4)	2.5 (0.4)
Water content (%)	6 (1)	5 (0.5)	6 (0)
pH (H_2O)	6.4 (0.03)	6.9 (0.04)	6.76 (0.62)
pH (KCl)	6.4 (0.05)	6.76 (0.1)	7.0 (0.26)
EC (μS/cm)	65.0 (0)	45.0 (7)	65 (7.1)
Na (meq/100g)	12.5 (0.24)	6.0 (0.84)	12.5 (1.3)
K (meq/100g)	0.68 (0.03)	0.66 (0.32)	0.64 (0.04)
Ca (meq/100g)	29 (3.8)	13.6 (1.1)	11.8 (0.9)
Mg (meq/100g)	0.48 (0.004)	0.36 (0.004)	0.51 (0.65)
Cu (ppm)	48 (3)	54 (5)	30 (3)
Zn (ppm)	116 (6)	182 (7)	280 (10)

Sediment analysis: Samples were taken at top, midpoint and bottom of the slope, from the top 10 cm of sediment. Samples were weighed, dried and the following measurements made in triplicate: gravimetric water content, mechanical composition, pH (in water and in KCl), electrical conductivity, organic matter (loss on ignition), and levels of Na, K, Mg, Ca, and the heavy metals Cu and Zn, as previously described.

2.2.3 Results and Discussion

Species Distribution: Species presence and distribution at 1m intervals down each transect are shown in Table 10. These results also indicate something of the general distribution of local saltmarsh species. The *H. pergranulata* appears to be capable of surviving in a number of micro-habitats, while *L. tegens* is found only towards the top, and *S. quinqueflora* towards the bottom of the slope. In this case *W. backhousei* and *S. virginicus* are also found only at the bottom of the slope, although elsewhere they can be found at higher elevations. A number of weed species were also found, intermingled with the native flora. In general, it was found that *L. tegens* was consistently associated with more exotic species than were the other saltmarsh species.

Sediment Analyses: The results of the sediment analyses are presented in Table 11. The results reflect the history of the area, in that they all point to the recent, unconsolidated and relatively unweathered nature of the sediments. Whereas in a sequence of soils down slopes silt and clay content, and cation contents normally increase from top to bottom, there is no such pattern evident here. Even the water content shows no trend down slope. The pH values of the samples are comparable with those from Newington, and the electrical conductivity is in the same range.

All of the metal ions assayed showed higher levels at this site than in Newington, and the Cu and Zn concentrations are in the same range as the mangrove stands of Bicentennial Park.

No clear trends in substrate parameters were found from samples taken down the slope, which indicates that no significant profile differentiation has yet occurred in the dredge-fill material. In the absence of slope substrate trends, no correlations could be made between them and the distribution of plant species.

There is a number of weed species on this site, which is surprising having regard to the high levels of salt and metals. From a purely scientific point of view, it would be interesting to carry out some ecophysiological studies of acclimation and genetic population selection of the exotic species at this site, as well as differences in uptake and bioaccumulation among the native species, across all of the sites under investigation.

3 Transplantation of Saltmarsh Species

3.1 Methodology

3.1.1 Propagation

As indicated in our previous report, it was found that plantlets could be successfully propagated from cuttings in all of the species tested. Standard horticultural techniques were used, including the use of fogging tents and bottom heat to accelerate rooting (Plate 11). No salt was added to the growth medium. Plantlets were salinated to 100% seawater over a period of two weeks prior to planting out.

3.1.2 Experimental Transplant Site

The experimental plot, on the northern bank of Haslams Creek, east of the 2KY site, has approximate dimensions 50 x 50m, with a slope of approximately 1/50, from the mean high tide level, commencing 10m from the back of the mangrove stand.

Soil levels were taken over the site, using a laser beam to establish elevations. At 10 cm intervals above the mean high water mark, from 10–40 cm, 20 stakes were positioned across the site, and at each stake 2 plantlets of the following species were transplanted: S. *quinqueflora; S. australis*, H. *pergranulata, W. backhousei and* S. *virginicus*, together with 4 plantlets of L. *tegens*. In addition, seeds of J. *kraussii* were broadcast over the site.

Two series of cuttings were taken, in November 1993 and in May 1994. Growth measurements were made at the experimental site in July and November 1994 (Plates 12, 13).

3.2 Results and Discussion

3.2.1 Survival and Growth of Plant Materials

A summary of survival rates and growth for each species at each tidal level, for both plantings, are presented in Fig. 11–16. It can be seen that, as expected, the planting of cuttings taken in spring was much more successful than that of cuttings taken in autumn. The results also show the differential survival rates of different species at different tidal heights, and the relative growth of each species at each tide height.

The most successful of the species in survival and growth from cuttings were S. *quinqueflora*, S. *virginicus* and the rare species, H. *pergranulata*, the first surviving particularly well across the lower half of the slope, while the other two species survived to some extent across the whole gradient. *Suaeda australis*, along with the other two rare species *W. backhousei* and L. *tegens* had low survival rates, and those of the two rare species which survived, did so on the upper half of the gradient. (from 30cm above mean high tide level).

The seeding trial was unsuccessful, no J. *kraussii* plants establishing from this method. Nothing is known of the seed biology of this species. It may be that a period of dormancy is necessary; perhaps other plants need to be present to retain the seed on site; or perhaps had they been broadcast at another time of year they would have been more successful.

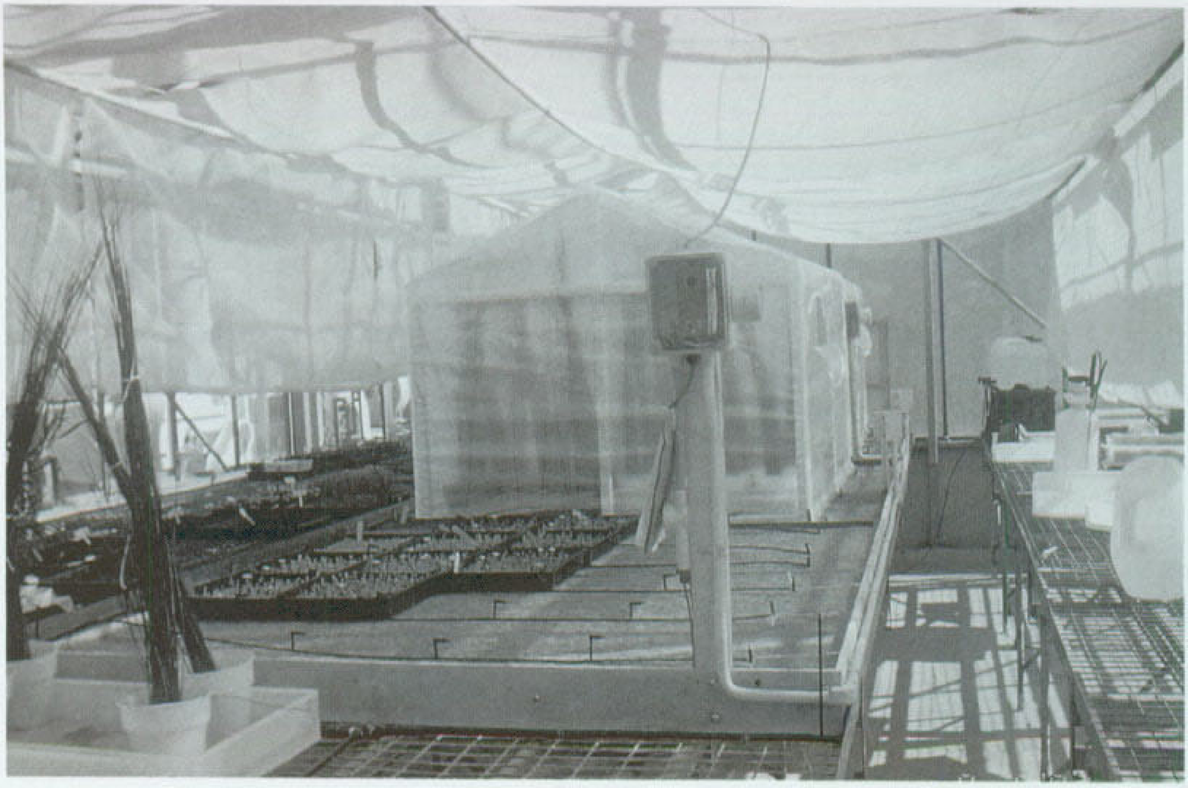
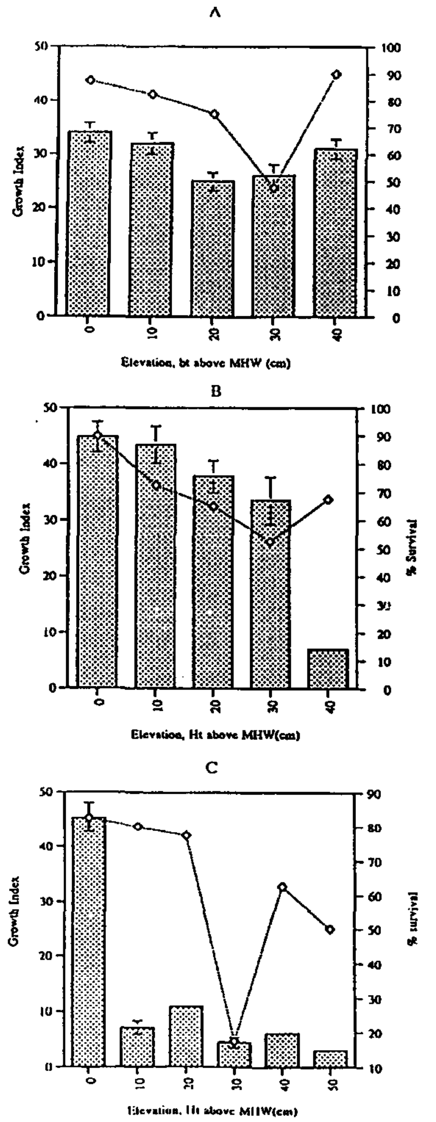


Plate 11. Propagation bench with fogging tent, UTS.

Plate 12. Transplant site, July 1994.

Plate 13. Transplant site, April 1995.

Plate 14. Sampling of Mangroves.



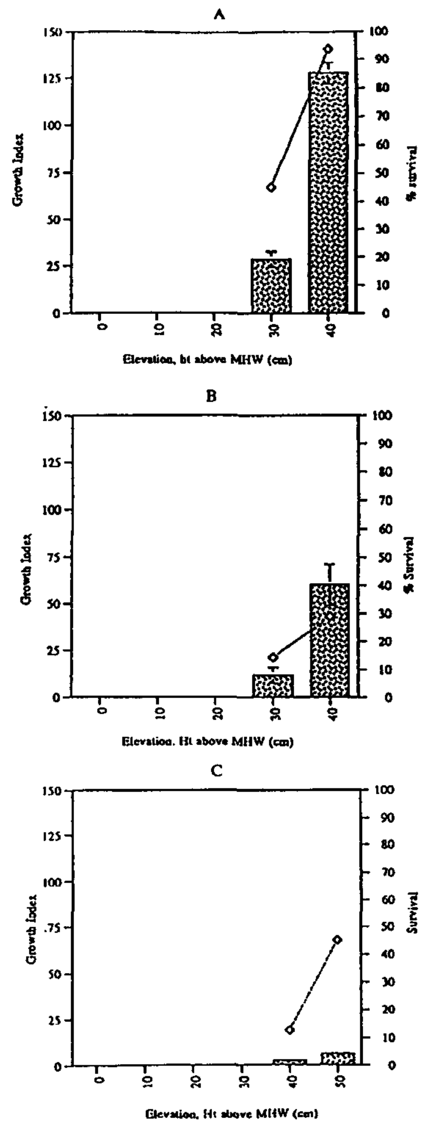


Figure 11. Growth index and survival (%) of *Sarcocornia quinqueflora* at the transplant site: (a) 1st planting, measured in July '94, (b) 1st planting, measured in November '94, (c) 2nd planting, measured in November '94; (± SE).

Figure 12. Growth index and survival (%) of *Lampranthus tegens* at the transplant site: (a) 1st planting, measured in July '94, (b) 1st planting, measured in November '94, (c) 2nd planting, measured in November '94; (± SE).

3.2.2 Other Growth at Transplant Site

Over the nearly two years since the site was prepared, a forest of mangrove seedlings (*Avicennia marina*) has sprung up immediately behind the established mangrove stand, in the lower reaches of the tidal gradient. At various points across the rest of the site a number of 'volunteer' saltmarsh plants have also appeared, including *S. quinqueflora* and *S. australis*. Zonation is again evident among these species, both of which are to be found in the lower levels of the marsh, with *S. australis* above *S. quinqueflora*. It is interesting to note that the plants which have spontaneously appeared on site are growing more vigorously than the transplants. Again, this

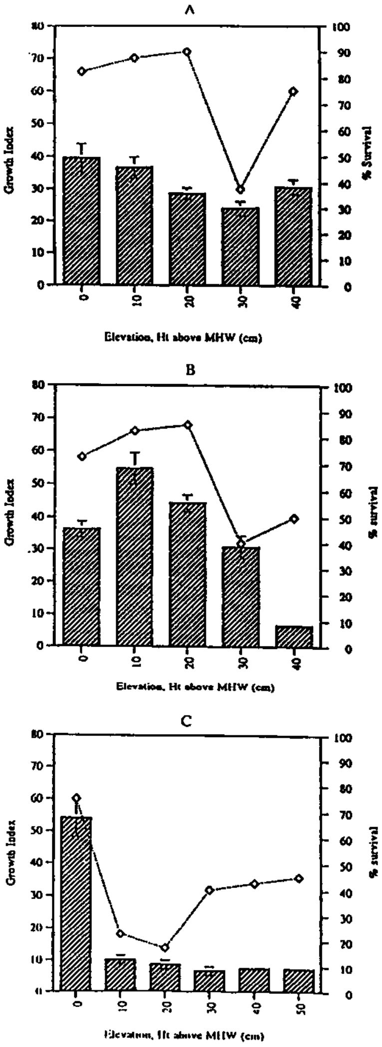


Figure 13. Growth index and survival (%) of *Halosarcia pergranulata* at the transplant site: (a) 1st planting, measured in July '94, (b) 1st planting, measured in November '94, (c) 2nd planting, measured in November '94; (± SE).

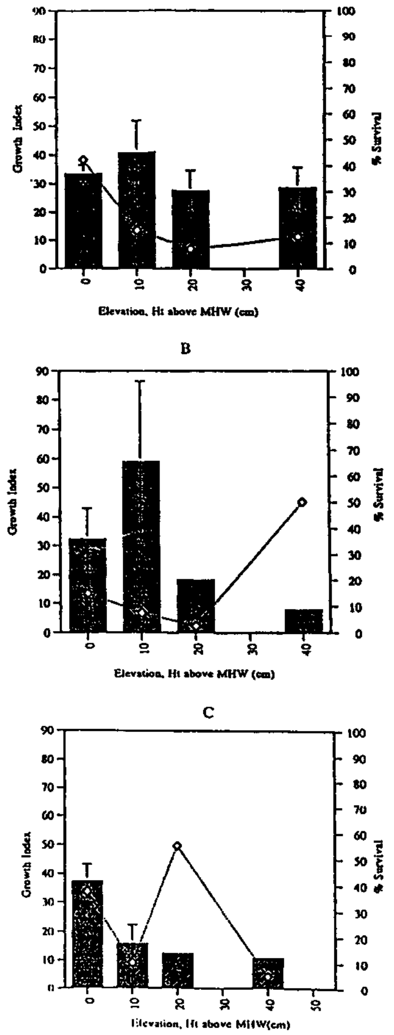


Figure 14. Growth index and survival (%) of *Suaeda australis* at the transplant site: (a) 1st planting, measured in July '94, (b) 1st planting, measured in November '94, (c) 2nd planting, measured in November '94; (± SE).

points to the need for further horticultural development of transplant methods. However, it is also to be expected that the volunteers will 'choose' the ideal conditions in which to establish; that is, from seed germination, they are presumably unlikely to survive in much less favourable conditions than the ones in which they are found.

3.2.3 Conclusions from Transplant Trial

Six species were used in the cutting-propagation and transplantation trials: the common species *Sarcocornia quinqueflora*, *Suaeda australis*, and *Sporobolus virginicus*, and the three rare species, *Halosarcia pergranulata*, *Wilsonia backhousei* and *Lampranthus tegens*. The most easily propagated species was *Lampranthus tegens*, which has horticultural potential as an ornamental ground cover.

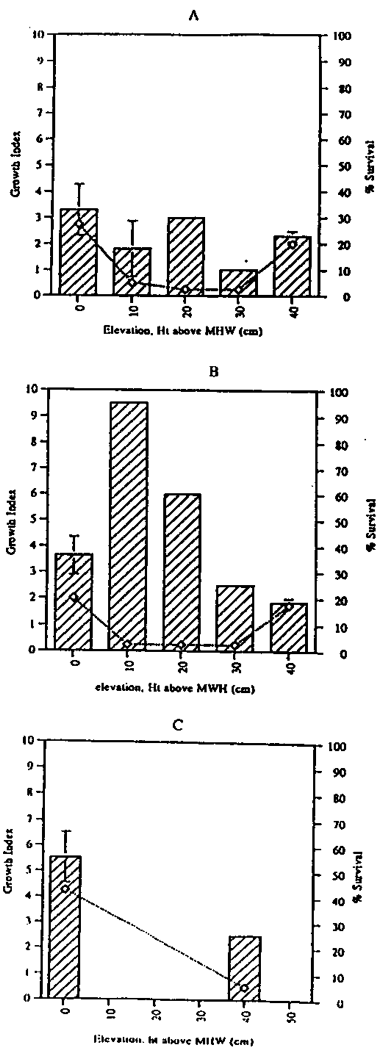


Figure 15. Growth index and survival (%) of *Wilsonia backhousei* at the transplant site: (a) 1st planting, measured in July '94, (b) 1st planting, measured in November '94, (c) 2nd planting, measured in November '94; (± SE).

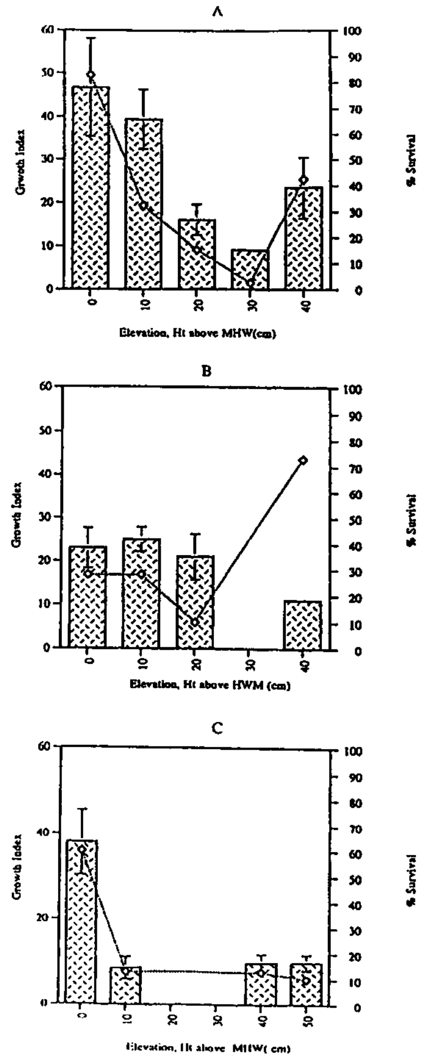


Figure16. Growth index and survival (%) of *Sporobolus virginicus* at the transplant site: (a) 1st planting, measured in July '94, (b) 1st planting, measured in November '94, (c) 2nd planting, measured in November '94; (± SE).

Its survival under the transplantation conditions, however, with no follow-up watering after the first week, was very low.

The survival and growth of the common species up the gradient were as predicted from ecological studies. Highest survival and growth rates were obtiained for S. *quinqueflora*, on the lower half of the gradient, S. *virginicus* in the upper most levels, and H. *pergranulata* across the whole gradient.

The experimental results and other field findings of the transplant trials lead us to several conclusions.

The propagation techniques used for producing transplant stock in this trial have been successful.

i The propagation techniques could be improved by further horticultural manipulation, although the spring cutting time seems appropriate.

ii Transplantation can accelerate the process of colonising the territory,

iii In a site development project, transplantation efforts should be concentrated on planting out the appropriate species at the various tidal heights up a gradient.

iv It is clear from the transplantation site and the other, older, dump-fill sites as well, provided that the right tidal estuarine hydrology is present on site, mangrove and / or saltmarsh communities will establish themselves. It appears that the common species commence colonisation simultaneously at the various levels suitable to each.

v Depending on the particular needs of the project, some future regeneration strategies might place more emphasis on transplanting the rare species at their appropriate levels, with only minimal planting of the commoner species, allowing the bulk of the latter to establish themselves as they will. This would not be a suitable strategy, however, if an instant sward were needed by management; in this case, equal emphasis would have to be given to planting all of the species concerned.

vi Whether saltmarsh plant regeneration will be accompanied by the faunal colonisation of the substrate is as yet unknown. Presumably both sediment characteristics and the quality of the water in the system are involved in ensuring the re-establishment of a fully functioning intertidal ecosystem.

4 Preliminary Mangrove Studies

4.1 Introduction

Investigations of the mangrove communities were added in October 1994 to the longer-term ecological studies of the Homebush Bay wetlands. The addition was made because it was recognised that a full understanding of the saltmarsh communities could not be achieved without a consideration of the dynamic balance between the two major plant communities of the wetland ecosystem, and the possible changes to that balance that could result from any future management decisions on preservation, restoration or replacement of wetland areas.

Preliminary studies to date have included, first, an historical survey of the wetland and associated areas over the last 60 years, to obtain a more detailed picture of the changes in total wetland area and relative areas of the component communities over that period. Secondly, a detailed structural map of the current intertidal wetland area of the Newington Depot has been carried out, and their apparent health status (Fig 2). The results of this study were included in our report to CH2M Hill in January 1995. Thirdly, a detailed comparative analysis of the structure, biomass and apparent health status of the various mangrove stands of the Newington wetlands is now underway, using other reference sites also in the Port Jackson estuary.

4.2 Methodology — Mangrove Studies

4.2.1 Historical Mapping Survey

A sequence of seven aerial photographs of the Homebush Bay wetlands provided by the Homebush Bay Corporation , comprising the Newington Depot, the areas surrounding Haslams Creek, Duck River and Bicentennial Park, were examined for the period 1930 - 1988, and the total and relative areas of mangrove, saltmarsh, casuarina and terrestrial forest vegetation estimated from them.

4.2.2 Mapping of Current Wetland Areas

Following the field observations which had been made as part of the saltmarsh ecology study, several transects were placed in mangrove stands of different heights and habits in the Newington wetlands, and the first ten trees on each transect were measured for height, girth at breast height (GBH), and extent of dieback (on a 4 -point scale of severity). These details were then interpolated on to a map which was derived from the latest available aerial photograph of the area, taken 4 October, 1994.

The map includes mangroves, saltmarsh, casuarinas, open water, scald areas, and some small stands of less saline species. From the map, the current proportional distribution of mangroves, saltmarsh, casuarinas, open water and scald areas was also derived. The five mangrove subsystems in Newington, identified on the map (Fig. 2), are as follows:

height 5 – 7m and a FPC > 50%;
5 – 7 m, FPC < 50%;
3 – 4 m, FPC > 50%;
3 – 4 m, FPC < 50%; and
stunted with moderate to severe dieback.

Table 12 Areas (in hectares) of estuarine wetlands at Homebush Bay and nearby northern shore of Parramatta River during the period 1930– 1988.

Site	Community	1930	1942	1955-56	1965	1978	1986	1988
Homebush Bay (a)	Mangroves	30	31	22	16	13	15	14
	Saltmarsh	41	50	48	49	42	17	23
	Native forest	7	6	7	6	7	6	5
	Casuarinas	0	0	0	1	3	2	3
Bicentennial Park (b)	Mangroves	10	4	22	22	17	19	19
	Saltmarsh	38	33	26	22	10	5	6
TOTAL (a) + (b)	Mangroves	40	35	45	38	30	33	33
	Saltmarsh	79	82	75	72	52	21	29
Duck River	Mangroves	6	7	9	8	6	5	4
	Saltmarsh	14	22	11	3	5	1	1
Ermington /Meadowbank	Mangroves	4	4	5	5	6	7	7
	Saltmarsh	0	0	0	1	0	0	0

4.2.3 Current and Planned Studies

In each of the five mangrove subsystems a $100m^2$ nested quadrat is placed, and plants measured for ht., FPC, GBH, and evidence of dieback. In addition, 5 x $0.125m^2$ ground quadrats are placed at the four corners of the large quadrat, and at its centre, in which are scored the number and height of seedlings, pneumatophores, and as part of the assessment of health status, evidence of macrofauna including numbers of crab holes and gastropods. From adjacent to the ground quadrats soil samples will be taken for routine sediment analysis and heavy metal levels.

From these data a detailed picture can be derived of the current status and performance of the mangrove communities. Sampling at reference sites, namely at Kitty's creek on the Lane Cove River, and Ermington on the opposite bank of the Parramatta River from Newington, are currently in progress. The Kitty's Creek site represents a stand on a river with much less industrial development than the Parramatta River, and the one at Ermington, which looks more luxurious than the Newington stands, is fed from the same river, but has perhaps not been subjected to the bunding and draining of Newington. The history of any disturbances to the mangroves of Ermington is at present being checked.

4.3 Results and Discussion — Mangrove Studies

4.3.1 Historical Mapping Survey

The results of this survey are presented in Table 12. The Homebush Bay area in this case includes the present Newington wetlands, as well as what were the upper reaches of Haslams Creek and adjacent areas. The Bicentennial Park values include the original swamp land which has now been converted into lawns areas and the ornamental lake in the picnic ground.

Over the 60 year period, there has been an overall decline of about 25% in the area of mangroves, but a reduction of over 60% in the total saltmarsh area, despite the fact that the current saltmarsh in Bicentennial Park has developed anew during that period. The reduction at the Newington site has been mainly in the valley area at the top of Haslams Creek. Over the same period, the forest area of Newington appears to have been reduced in area by over 20% also, though the canopy in later photographs seems heavier now than at some earlier times.

Since 1965 the casuarinas have appeared. The general view is that these were part of the original vegetation of the area, but were cleared earlier in the century, and then allowed to regenerate from suckers.

Table 13 Current distribution of communities in Newington wetland

Community	% total wetland area
Mangroves	37
Saltmarsh*	22
Casuarinas	17
Water	13
Scald/ bare	11

* The three rare species occupy 2.5% of total wetland; less saline communities occupy 4.5%.

4.3.2 Current Distribution in Newington Wetland

Figure 2 is the detailed map of the current distribution of mangroves, saltmarsh and casuarinas in the Newington wetland, and their apparent health status, while the current proportions of the various components of the wetland community are shown in Table 13. The very limited distribution of the three rare saltmarsh species are highlighted by these figures.

4.3.3 Structure and Health of Mangroves

The detailed ground truthing that was carried out in the preparation of the map has led us to the view that the whole of the wetland system at Newington is showing signs of stress, as indicated by dieback, loss of canopy density, and stunted growth, in all three component plant communities, namely mangroves, saltmarsh and casuarinas. This is exemplified by the data for mangroves in particular (Table 14), which indicate that 'healthy' trees, defined here as having a foliage projective cover of greater than 50%, account for only 15% of the total mangrove community. Part of this will have been the result of four years drought in the Sydney area, from which the saltmarsh has responded most quickly with the rains of January 1995. It will be interesting in future sampling to investigate the extent to which the mangroves recover canopy density and new growth over the next annual cycle.

As mentioned above, this study has just been commenced, and the reference sites are being investigated before the Newington sites, to ensure that comparative judgements can be made on the way (Plate 14). Similar studies carried out by this laboratory in other areas show that this approach is a powerful method for elucidating the performance of mangrove communities.

Table 14 Distribution of apparent health status among mangrove communities of Newington wetland

Community type	% total mangrove area
Healthy (> 50% FPC)	15
Dieback-affected (< 50% FPC)	45
Stunted shrubs	20.5
Dying/ dead stumps	19.5

5 OUTCOMES AND FUTURE STUDIES

The studies have provided a better understanding of the species composition, structure, sediment characteristics and seasonal dynamics of the saltmarsh communities, and the historical and current distribution of both saltmarsh and mangrove communities in the Newington wetlands and adjacent areas of Homebush Bay. Specific findings of the study include the following:

5.1 SALTMARSH STUDIES

5.1.1 Distribution

The ecological and transplant studies have revealed something of the climatic and edaphic factors that affect the survival and growth of the local saltmarsh species. The results clearly confirm the pattern of zonation of the saltmarsh species, as well as providing new information on the micro-distribution of the three rare species. As observed by Clarke and Hannon (1967), soil type does not appear to be an important factor in the distribution or zonation of saltmarshes. Saltmarsh species have been found to be prone to dying back under conditions of drought, but recover rapidly after rain. As with much vegetation in the Sydney area, therefore, the seasonal patterns of growth within the saltmarsh, or any sub-community within it, is likely to be as dependent on water availability, and hence the water/ salinity balance, as it is on seasonal changes in temperature.

5.1.2 The Three Rare Species

It is interesting to note that, while the transplant studies show that H. *pergranulata* is capable of growth and survival at any level within the marsh, in the Homebush Bay area it is commonly found mainly at the top of the marsh, or in non-tidal areas with a saline substrate.

Wilsonia backhousei appears to favour a position in the low to mid-marsh, as evidenced by its natural distribution in patches through the Newington wetland. It seems to favour areas of lower pH than S. quinqueflora, as evidenced by its distributions in Sites 1 and 3. Where the distributions overlap, it may be a poor competitor with S. *quinqueflora* where their ranges meet, which may help account for its scarcity. Its dispersal mechanisms remain to be investigated.

Lampranthus tegens is less common again, but is found in some swards (not included in the transect areas) at the edges of the casuarina stands. This species seems from general field observation to be particularly susceptible to drought, that is, to dieback.

The current investigation include no physiological studies of any of the wetland species. Controlled laboratory studies would complement field studies in helping to elucidatie the factors determining field distribution, survival, growth and reproduction of the three rare species, and their horticultural cultivation as a means of conserving the biodiversity which they represent.

5.1.3 Transplantation

The transplant studies show quite clearly that it is feasible and practical to propagate and cultivate the saltmarsh species from cuttings, given the correct growth conditions of salinity and hydrology. From a management point of view this would be an efficient way to achieve the rapid colonisation of an area to be regenerated, since if carried out carefully, it is not destructive of the parent stock. The project has shown that the commoner species will start to colonise the area within two or three seasons, provided salinity and hydrology are appropriate. In future transplantantion programs, therefore, attention could be concentrated more on the three rare species, with minimal planting of the remainder, unless an instant sward is needed by management.

5.2 Mangrove and Whole Wetland Studies

The historical mapping project has allowed us to detail specifically the decline in wetland areas of Homebush Bay and the upper reaches of the southern shore of Parramatta River over the last 60 years. There has been a 30% decline in mangrove areas and an over 60% decline in saltmarsh areas. The value of the remainder, which still constitute the largest area in the Port Jackson estuary, is concomitantly raised, and the need for adequate restoration and management reinforced.

The mapping of the current distribution and condition of the wetlands of the Newington Depot has allowed an appraisal of the system as a whole. This has revealed that the whole wetland area is showing symptoms of stress, perhaps the result of a four year drought, but evidently aggravated by the bunding and drainage blocking that have stopped the normal tidal flushing of such an area.

The detailed structural analysis of the mangrove areas has just been commenced, the aim of the study being to elucidate with more detail and accuracy the status and performance of the mangrove community and the interrelationships of mangrove and saltmarsh areas.

All of the projects reported above are continuing, to throw light on the structure and performance of the mangrove communities, and longer term influences on the seasonal growth of all of the wetland communities. Investigations are also planned for monitoring other scattered, isolated patches in the Newington wetlands, that are not part of the intensive study sites, but contain one or other of the rare species, and sometimes other species of uncommon growth forms.

The information derived from this study, together with the continued studies of the seasonal dynamics of the saltmarsh, will assist in determining strategies for the successful restoration and management of the wetland systems of the Homebush Bay area.

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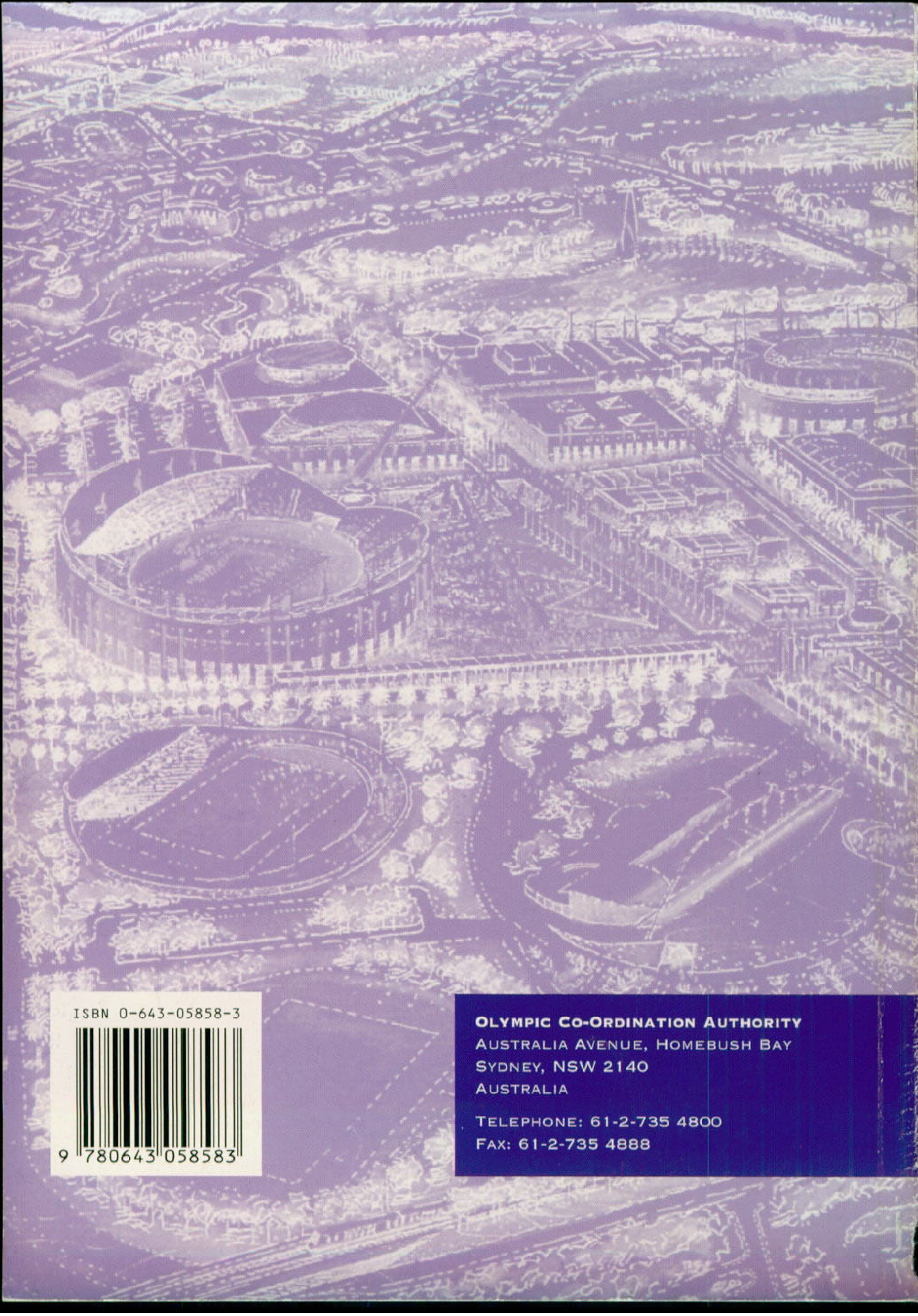

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Olympic Co-ordination Authority
Australia Avenue, Homebush Bay
Sydney, NSW 2140
Australia

Telephone: 61-2-735 4800
Fax: 61-2-735 4888