Report to:

Sydney Ports Corporation

Port Botany Expansion

Aquatic Ecology, Conservation & Fisheries

VOLUME 1: Main Report

Final

May 2003

Report prepared by:

The Ecology Lab Pty Ltd

Port Botany Expansion

Aquatic Ecology, Conservation & Fisheries

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Volume 1: Main Report

Report Prepared for:

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SUMMARY

S.1 Background, Aims and Scope

Sydney Ports Corporation (SPC) is proposing to upgrade the port facilities in Botany Bay, by expanding the existing container terminal at Port Botany. The expansion will require reclamation over about 60 ha and dredging over about 75 ha between the existing sea port and the airport. The changes proposed would alter the aquatic environment on the northern side of Botany Bay between the Parallel Runway and Molineux Point, whilst the potential for changes in other parts of Botany Bay must be considered also.

The Ecology Lab Pty Limited was engaged by SPC as part of the study team assembled to prepare the EIS and associated specialists' reports upon which the assessment of environmental impacts will be made. The team is being led by URS Australia, who is also writing the EIS.

The broad aims of The Ecology Lab's study are to:

1. Provide a description of the habitats, flora and fauna of aquatic environments and of fishing activities that may be affected by the proposed port expansion that provides a suitable basis for predicting and assessing the significance of the impacts of the proposed expansion.
2. Use the description of the aquatic environment, detailed assessments by other specialists on other aspects of the aquatic environment (e.g. water quality and wave climate) and detailed descriptions of the proposal itself to predict and assess the significance of the impacts of the proposed expansion.
3. Recommend ways in which negative impacts on aquatic flora and fauna or fishing activities might be removed or mitigated and ways in which positive impacts might be enhanced.
4. Recommend broad programs for environmental management during construction and operation, including monitoring and suggest if any baseline monitoring is required (i.e. sampling before construction begins at impact and reference locations).
5. Recommend, where appropriate, strategies for developing compensatory aquatic habitats.

S.2 The Existing Aquatic Environment

The study area focuses on the northern side of Botany Bay, which extends from the mouth of the Cooks River to La Perouse. The "core study area" included that part of the bay between the Parallel Runway and Molineux Point. In addition, issues were considered in relation to wetland habitats in the catchment of the Mill Stream, some elevated areas within the current navigation channel for Port Botany and the whole of Botany Bay to the extent that the proposed works may affect important physical or ecological processes. The Aquatic Reserve at Towra Point was also considered due to its high conservation value.

Habitats

Botany Bay has been the subject of a number of major studies on topics that include contamination and pollution, effects of multiple airport expansions and port construction, beach nourishment and the installation of beach groynes, maintenance dredging, commercial fishing, introduction of alien species and a variety of government and university research. The available information on aquatic habitats and biota were summarised and supplemented by detailed mapping of seagrass habitats, wetland habitats in Penrhyn Estuary, surveys of benthic communities in intertidal and subtidal soft sediment habitats and recent water quality data undertaken as part of the preparation of this report.

Aquatic habitats in Botany Bay are diverse, extensive and some have undergone significant changes in nature and extent as a result of development activities. Major habitats considered include the water column, soft, unvegetated sediments (intertidal, shallow and in deeper areas), natural and artificial hard surfaces, seagrass and algae, saltmarsh and mangroves and freshwater habitats, including wetlands within the catchment of the Mill Stream.

<u>Water Column</u>

Little information is available on the ecology of the water column, despite its importance in linking other aquatic habitats within the bay. Tidal fronts and eddies have been identified as key means by which larvae of commercially important fish can be transported and concentrated into larval fish "hot spots". Some information is available for areas near Foreshore Beach regarding the attenuation of light in the water column, in relation to the suitability of newly created habitats for seagrass transplantation.

<u>Soft Sediments</u>

Soft, unvegetated sediments provide habitat for mainly invertebrate animals, which in turn are a supply of prey for wading birds and food for fish in deeper water. Relatively few surveys of the fauna of sandy intertidal sediments relevant to the proposal exist and sandy intertidal fauna are incompletely known despite the accessibility of the habitat for sampling. A previous study on Foreshore Beach revealed a fauna dominated by polychaete worms, with amphipods and a few molluscs also present. No studies of fish and mobile invertebrates in unvegetated sandy habitats have been done near Foreshore Beach, although similar habitats have been sampled in other parts of Botany Bay (Lady Robinsons Beach and Towra Point) and in other estuaries (Batemans Bay, Port Hacking and Jervis Bay). The available information suggests that the species using these habitats are generally found in other habitats within the bay. Shallow, soft-sediment habitats provide habitat for transient fish species of commercial value (tailor, southern herring, sand mullet, flat-tailed mullet and sea mullet) and non-commercial species including bait fish, gobies, hardyheads, perchlets, sprats and toad fish.

The fauna of subtidal soft sediments are relatively better known, due mainly to studies on the effects of dredging on benthic and fish communities. The total numbers of species collected in three such studies ranged from 56 to 303, with communities usually dominated by polychaete worms, crustaceans and molluscs. Comparison of species found in Botany Bay to those from similar habitats in other estuaries lead to the conclusion that the benthic fauna of the bay are not unique and are probably drawn from the same pool of species within the mid-coast biogeographical region. No previous studies of benthic communities in Penrhyn Estuary were available.

Studies in Botany Bay that attempted to examine the effects of dredging tend to be complex in design because of the need to differentiate the effects of water depth and sediment type, two factors known to be important in the structuring of benthic communities. Benthos recolonised dredged holes within a periods of months, but the faunal composition had changed by approximately 20%, suggesting that recovery to the pre-dredging community had not occurred by the end of the two year study.

Fish and mobile invertebrates of deeper habitats were sampled as part of a larger study of fish in Botany Bay, and two sites near the proposal were sampled. Thirty-three of the 87 fish species caught at these sites were of economic importance, none were considered to be permanent residents of this habitat but were common in adjacent coastal habitats. Some non-commercial species including stingaree, crested flounder and bar-tailed goatfish were considered to be resident in the deeper habitat. Another study sampled using a prawn trawler and found larger catches of fish on the western side of the bay but higher numbers of prawns and cephalopods (octopus, squid) on the eastern side (near the Parallel Runway) and their abundances varied greatly through time.

Due to limited information on benthic invertebrates in Penrhyn Estuary, additional surveys were undertaken as part of this study in sandy intertidal and shallow subtidal habitats. Benthic samples were taken at five locations along the intertidal portion of Foreshore Beach. Locations were selected approximately 300 m apart and within each location, 3 sites were sampled at intervals of about 50 m. This approach enabled an evaluation of variation at different spatial scales. In the second survey, subtidal samples were collected from Penrhyn Estuary, Quibray Bay and near Towra Point, with 3 sites sampled in each position. Samples were collected in October, 2002

The fauna collected from the intertidal habitat along Foreshore Beach showed an expected range of types and numbers of invertebrate animals. Included in the dominant fauna were burrowing worms (Orbiniidae), shallow burrowing crustacean amphipods (Exodicerotidae), tube-building worms (*Australonereis*) and free crawling worms (*Ceratonereis* and Phyllodocidae). The range and numbers of types present indicate that the current community is diverse and functions as an ecological unit. From the perspective of the current proposal, the habitat supports a diverse community compared to other similar habitats and likely provides links to other parts of the ecosystem in Botany Bay by providing food for wading birds and fish. Although the food items of wading birds in this habitat are not known in detail, it is likely that some wading birds feed on at least the larger and more visible components of this fauna, for example the bright orange or green coloured crawling worms of the family Phyllodocidae, which can reach up to 20 cm in length.

Locations along Foreshore Beach differed from one another, with the outer area of Penrhyn Estuary notably different from other locations. While the range of animals found at this location was similar to the others, the composition of the assemblage varied. The factors responsible for this differences are not known, but may include subtle differences in the composition of sediment particles, differences in the behaviour of tidal currents at that location or some combination of these and other factors.

Larger numbers of animals and a greater diversity of animals were found in subtidal habitats compared to the intertidal habitats. This habitat was dominated by capitellid worms at all locations (i.e. within Penrhyn Estuary and at the reference locations). The presence of a diversity of feeding types and life styles in the subtidal benthic communities in Penrhyn Estuary indicates a functioning ecological unit, which contrasts with what may be predicted given the levels of contamination recorded there.

<u>Hard Substratum</u>

The amount of hard substratum in the bay has increased through time with the development and expansion of the port and airport facilities, respectively, replacing sections of natural sandy shoreline with artificial hard structures. Limited information is available on the ecology of hard-substrata communities within the bay, although much is known about the ecology of rocky intertidal and subtidal habitats at the entrance to the bay (Cape Banks). Species lists available for these habitats suggest that communities on artificial surfaces are similar to those on natural rocky reefs, but often differ in the structure of the assemblage. A survey of hard substrata communities near the Parallel Runway found a small diversity of animals that tended to increase along the wall with distance away from the entrance to the Mill Stream.

In subtidal habitats a range of reef-dwelling fish have been observed associated with hard surfaces, although very few fish were associated with the vertical walls of the Parallel Runway, probably due to the lack of topographical complexity of the structure. A recent study suggested that the presence of a reef structure, whether natural or artificial, altered the sediments near the reefs, resulting in different benthic assemblages. The results suggest that artificial structures placed in soft-sediment habitats will have a significant influence on the surrounding sediments.

<u>Algae and Seagrasses</u>

A variety of algae occur in the bay, including larger plants such as kelp and sargassum, smaller forms that attach to other algae or seagrass, weakly attached or drifting forms and forms that grow in soft sediments. The latter includes some introduced species, including the pest species, *Caulerpa taxifolia*.

Seagrasses are flowering plants adapted for subaquatic life and are considered of ecological importance. The most common seagrass in the study area is *Zostera capricorni*, while two species of *Halophila* and *Posidonia australis* are present but less common. The ecological functions of seagrasses include a significant contribution to the productivity of the ecosystem, stabilising sediments, providing food and habitat for fish and invertebrates and providing "nursery habitats" for recreationally and commercially important species of fish and invertebrates such as prawns and crabs. The presence of seagrass influences the faunal assemblages found there, both the mobile components (fish and mobile invertebrates such as prawns, crabs and octopus) and relatively sedentary components such as the benthic infauna and epifauna. Fauna associated with seagrass beds can be influenced by the physical conditions within beds, including water movement, temperature, oxygen concentration, morphology of seagrass blades, proximity of the bed to other habitats and biological conditions such as the supply of larvae, availability of food and predation.

Some information is available on the fauna associated with *Zostera* seagrass beds in the northern section of the bay. Fish and mobile invertebrates in *Zostera* beds are more abundant and diverse compared to mangrove habitats and unvegetated hard or soft substrata habitats. This may be in part due to the large number of species that are temporary residents, in particular juveniles of species that later move to other habitats. Nineteen species of commercially important fish and 15 species of non-commercial fish species have been recorded from *Zostera* beds in the northern section of Botany Bay, including sand whiting, yellowfin bream, tarwhine, luderick, sand mullet and yellow-finned leatherjacket. Invertebrates included king prawns, blue swimmer and other crabs, octopi, cuttlefish, squid and shrimp. Research done since the construction of the Parallel Runway found that blue groper recruited to northern *Zostera* beds in pulses each year with peaks in abundance in September and October. Juvenile tarwhine and trumpeter were found to have higher abundances in northern seagrass beds compared to other locations in the bay. In the most recent work, tarwhine, blue groper and eastern king prawns were found to be more abundant in seagrass off Foreshore Beach compared to more southern sites, but fewer palaemonid prawns were found. Overall, the seagrass beds off Foreshore Beach had consistently greater abundances of commercially important species, but fewer species than other sites in the bay.

Little is known about the benthic fauna of seagrass beds in the study area. Research on *Zostera* beds in other estuaries suggests that while seagrass faunas rarely associate with a particular species of seagrass, *Zostera* beds support a more diverse and abundant infauna than *Posidonia*. Infauna assemblages are dominated by polychaete worms, followed by crustaceans including amphipods, snapping shrimp, prawns and crabs, and bivalve and gastropod molluscs.

The distribution of seagrass beds in the bay has undergone natural and man-induced changes over the last 100 years. The earliest estimates of the total extent of seagrass beds in Botany Bay are based on aerial photographs from the 1940's, but there is some information from the northern side of the bay (i.e. extending for the mouth of the Cooks River to La Perouse) from 1930. The largest area of seagrass was estimated to be 761 ha, based on aerial photos from 1942. The smallest estimate was a total of 340 ha, based on aerial photos from 1977-1979. Considerable changes in the extent of the seagrass beds along the entire northern shore of the bay (i.e. including the shoreline from the mouth of the Cooks River to La Perouse) can be attributed largely to two expansions of the airport and the development of port facilities and access, although there appears to have been extensive natural variation in the seagrasses from 1930 to 1961 (i.e. 35, 93, 22, and 49 ha in 1930, 1942, 1951 and 1961, respectively). Prior to the construction of the Parallel Runway the seagrass beds in the core study area were estimated to cover 32 ha, decreasing to 16.4 ha after construction was completed. More recent research estimated *Zostera* to occupy 7.5 ha, while a second estimate based on aerial photos taken a year later concluded that 16 ha were present, in the form of a main bed parallel to Foreshore Beach and patches on either side of the main bed. Discrepancies between the latter two estimates may be due to actual changes in extent, differences in methodology and differences in the study areas. The composition of the seagrass bed along the northern shore of the bay may have also changed through time. The 1942 estimate did not distinguish between *Zostera* and *Posidonia*; the 1995 study found no *Posidonia*; but *Posidonia* was recorded in small patches in 1996. Sediment cores have detected subsurface parts of *Posidonia* (e.g. roots) at several locations, including the entrance to Cooks River, Foreshore Beach (Banksmeadow), Frenchmans Bay and Yarra Bay.

As part of this study, The Ecology Lab undertook mapping of seagrasses off Foreshore Beach from the entrance of the Mill Stream to Penrhyn Estuary, and along the eastern edge of the Parallel Runway to determine their present composition and extent. The aim of the study was to provide an estimate of the area of seagrasses that could be compared to the footprint of the proposed port expansion.

Aerial photos taken in April 2001 were used as the basis of mapping. Areas interpreted to contain seagrass were drawn on computer-based digitised aerial photographs with an average resolution of approximately 3.5 m^2. For areas where the aerial photos could not be resolved, ground truthing was done in the field using divers and differential GPS equipment. The species composition and depths of seagrass at the margins of beds and patches were also recorded.

The total area of seagrass in the study area was estimated to be 9.67 ha. The majority of this area was comprised of *Zostera capricorni* that varied in coverage from sparse to dense. Patches of *Posidonia* were also present on the seaward edge of the main bed toward the entrance to the Mill Stream. *Halophila ovalis* was frequently present mixed with *Zostera* in the main bed, and *Caulerpa filiformis* and *Caulerpa taxifolia* were also present toward the southern end of the main bed. Seagrasses were observed to grow in depths ranging from 0.72 m LAT to -2.65 m LAT. The deepest beds measured were those along the seaward edge of the main bed, while the shallowest were patches of seagrass growing between the main bed and Foreshore Beach.

The extent of seagrass measured in the core study area was intermediate between the estimates obtained by other researchers and based on 1995 aerial photos (7.5 ha) and 1996 aerial photos (16 ha).

The area of seagrass that would be removed as a result of the proposal was calculated to be approximately 4 ha. In the south eastern section of the study area approximately half of the main seagrass bed would be removed, along with all patches between the main bed and Foreshore Beach. In the north western section, mainly patches of seagrass between the main bed and Foreshore Beach would be removed. The area between the proposed port terminal and Foreshore Beach has been identified as potential seagrass habitat following alteration to provide appropriate bottom depth and profile. To compensate for this loss, replacement seagrass habitat of up to 8 ha would be made available as a result of the proposed expansion.

<u>Mangrove and Saltmarshes</u>

Mangroves and saltmarshes once occurred at several places on the northern shoreline of Botany Bay, particularly at the entrance to the Mill Stream. With the diversion of the Mill Stream during construction of the Parallel Runway, these mangroves and saltmarshes were removed. Currently, mangroves and saltmarshes are most common at Towra Point and Woolooware Bay. Saltmarsh and mangrove habitats occur within Penrhyn Estuary, but not within the Mill Stream as its estuarine portion has been formed into a channel with vertical walls. Anecdotal and pictorial evidence suggests that the mangroves within Penrhyn Estuary are currently expanding into areas of saltmarsh.

Within Penrhyn Estuary, site inspection revealed that there were areas of mangroves ranging from juvenile seedlings to mature mangrove trees growing towards the back of Springvale Drain. The salt marsh plants *Sarcornia* and *Suaeda* were also abundant on the shore fringing the more stable rush grasses (*Juncus kraussii* and *Isolepis nodosus*). Further up the shore Bitou bush (*Chrysanthemoides monilifera*) and *Acacia* spp. became more prevalent as well as coastal she-oak (*Casuarina equisetifolia*).

S3. Threatened Species Issues

Several species of aquatic fauna scheduled as threatened or protected under the NSW *Fisheries Management Act* (1994), NSW *Threatened Species Conservation Act* (1996) and the *Commonwealth Environment Protection and Biodiversity Conservation Act* (1999) may occur within or around the area proposed for the port expansion. These include marine mammals, fish and waterbirds, such as penguins. It is concluded that no Species Impact Statements are required for any species, populations or communities considered in this report. Notwithstanding this, some issues related to the fauna considered should be incorporated into the design of the project or management plans for the construction and/or operational phases of the project, subject to its approval. For example, there should be an appropriate management initiative for commercial shipping to cope with movement of southern right whales into Botany Bay.

S4. Effects of Previous Human Activities

It is important to understand the extent to which previous human activities have affected the areas in which the proposed expansion would operate to allow, where possible, impacts from a variety of sources to be differentiated and to evaluate potential cumulative effects. The broad issues related to previous human activities include:

- Creation and removal of habitats, particularly creation of habitats comprising hard surfaces (e.g. seawalls) and deep holes (from dredging) and partial removal of seagrass beds and shallow, unvegetated sediments.
- Water quality and contamination. This includes catchment wide processes as well as specific issues related to industrial contamination.
- Introduction of alien species, some of which are associated with commercial shipping (e.g. dinoflagellates), others whose origin is less clear (e.g. aquarium weed – *Caulerpa taxifolia*).
- Fishing activities, including exploitation of stocks and habitat modification
- Existing port operations, including spillages (and emergency responses) and antifouling issues.

S5. Assessment of Impacts

From the perspective of aquatic ecology, the major components of the proposed port expansion include dredging, reclamation, creation of a public recreation area, enhancement and restoration of aquatic habitat, and operational activities. Mitigative measures have been built into the proposal in anticipation of some impacts; for example a silt curtain would be deployed around the works to inhibit the spread of any turbid water. Work done by other specialists suggests that impacts would be confined to the area between the Parallel Runway and Molineux Point, with negligible physical changes occurring in other parts of Botany Bay, such as at Towra Point Aquatic Reserve.

A major component of the proposed port expansion is the enhancement of aquatic habitat within Penrhyn Estuary and the access channel to this area. The estuary would cover approximately 27 ha and would be made up of constructed saltmarsh habitat, sand and mud intertidal flats and an area of up to 8 ha of seagrass habitat (to be established by a combination of transplanting and natural colonisation).

Within the core study area, there would be no increase in wave height on the sandy terrace adjacent to the Parallel Runway which has been used in the past as a site for transplanted seagrasses. There has also been natural colonisation of the terrace by seagrasses.

On Foreshore Beach, there would be movement of sand from the west of the proposed boat ramp towards the mouth of the Mill Stream. This westerly transport of sand already occurs and would require ongoing maintenance with or without the proposed port expansion.

<u>The Water Column and Fish Passage</u>

Following the proposed port expansion, all estuarine habitats within the core study area would have access to tidal waters, enabling exchange between these habitats, Botany Bay and the coastal environment. Springvale and Floodvale Drains would flow into Botany Bay via access channels within Penrhyn Estuary and via the main channel into Botany Bay. Similarly, there are no structures proposed that are likely to impede fish passage within the area.

Soft, Unvegetated Habitats

Under the proposal, Foreshore Beach would be divided into two beaches at the location of the new boat ramp and recreation area. There would be a small loss of sandy habitat at the ramp, but the amount of similar habitat created in Penrhyn Estuary would be far greater than the small amount lost. It is expected that the western portion of the beach would contain similar types of benthic organisms as currently occurs there, however the eastern portion would become much more sheltered and a different assemblage would probably develop there.

Subtidally, the dredging and reclamation would remove a large area of shallow sandy habitat (the reclamation) and replace it with deeper, soft sediments (dredging). Dredging would cause a temporary loss of benthic productivity but the dredged area, which is connected to the main navigation channel (and not isolated) would be colonised over time scales of months. Longer term establishment of a fauna typical of such deep areas may take two or more years. In the longer term, fish assemblages within the dredge hole would also differ from the shallow habitat it replaced.

New assemblages of benthic fauna would also develop on the slopes of the dredge hole and within the flats created in Penrhyn Estuary.

Hard Substrata

Under the preferred embankment design, the amount of hard substrata would increase substantially as a result of the port expansion and would include additional wharf face, steel pilings and rubble seawall. These areas would be colonised by a wide variety of algae and invertebrates, which fish would shelter and feed around these structures. Opportunities also exist to enhance some of the structures to increase their biodiversity.

Seagrasses, Algae and Associated Assemblages

Within the area of the proposed port expansion, an area of up to 4 ha of seagrass would be potentially lost as a result of dredging and reclamation. There are also areas of drift algae (e.g. *Gracilaria*) that may occur intermittently. The seagrasses beneath the construction footprint would be transplanted to Penrhyn Estuary. Some of these seagrasses may need to be transplanted to the terrace to allow the new habitat to be prepared. Most of the seagrasses to be transplanted would be *Zostera*, although a small patch of *Posidonia* would also need to be moved. *Zostera* has been transplanted previously in Botany Bay with some success, while small-scale transplanting of *Posidonia* within Port Hacking has also shown success.

There are large areas of seagrass (including some *Posidonia*) that should not be affected by the proposed expansion. Seagrasses close to the edge of the works would need to be protected as part of the environmental management of the project.

It is difficult to predict the assemblages of fish and invertebrates that would colonise the compensatory seagrasses because such assemblages are highly variable in nature. Notwithstanding this, it is predicted that these seagrasses would support a diverse and abundant fauna.

Saltmarshes and Mangroves

Under the proposal mangroves would be removed from Penrhyn Estuary as part of the habitat enhancement. This loss would represent about 0.1% of the mangroves within Botany Bay, most of which occur at Towra Point, Cooks River and Georges River. A saltmarsh habitat of approximately 6 ha would be created by a combination of transplanting and natural colonisation. This establishment represents an increase of almost 4% in the area of saltmarshes in Botany Bay.

Freshwater Ecosystems

Freshwater habitats associated with the Mill Stream and Sir Joseph Banks Park would not be subject to any change in hydrology or groundwater as a result of the proposal. There would be some short term disturbance to Floodvale and Springvale Drains due to emplacement of culverts and gross pollution traps, but these disturbances can be minimised by proper environmental management.

Introduced Species and Threatened Species

Two classes of introduced species, toxic dinoflagellates and aquarium weed (*C. taxifolia*) can be managed appropriately as part of the project and hence should not be problematic. Generally, threatened species would be unaffected by the proposal. Creation of compensatory seagrass habitat should also provide habitat for Syngnathidae (sea horses and pipefish), while appropriate management plans should be able to address the possibility of marine mammals (particularly humpback whales and southern right whales) entering the waters around the port.

Fishing and Aquaculture

Commercial fishing is now banned in Botany Bay, hence it would not be directly affected by the proposal. Recreational fishers would potentially lose approximately 1.5% of the bay waters and may encounter some inconvenience during construction and operation of the terminal. On the other hand, a new boat ramp and recreational area would be made available which would enhance the fishing amenity.

Greenhouse Issues, Cumulative Effects and ESD

Changes in sea level could cause changes to aquatic flora and fauna by affecting biota with depth limitations (e.g. seagrasses need suitable growth for photosynthesis), inundating saltmarsh and causing changes to the energy regime of an area. Similarly, increases in temperature could affect assemblages by favouring species generally more common further to the north of Botany Bay. An increase in water level would have significant consequences for the enhanced habitat within Penrhyn Estuary. In particular seagrasses may advance further into the estuary while landward extension of saltmarshes would be limited by the topography surrounding the water body.

These following issues are relevant to potential cumulative effects:

1. Continued loss of seagrass for the northern parts of Botany Bay. Existing information indicates that there has been a large loss of seagrass from the core study area and that the decrease is continuing well after completion of the last major capital works, the Parallel Runway. This may be due to erosion occurring along Foreshore Beach or other, unknown factors. The present proposal provides an opportunity to arrest this decline and, hopefully, promote an increase in the seagrasses by providing a stable habitat.

2. Increased amounts of artificial structure in the area. The additional structure provided by the new terminal would continue the increase in this type of habitat and presumably the plants and animals associated with it. These organisms have their own potential benefits, both ecologically (by enhancing biodiversity), socially and economically (as some of these biota are utilised by humans).
3. Continued contamination of Penrhyn Estuary and the effect of habitat enhancement on the ability of the system to discharge, dilute and neutralise the contaminants. The expansion would change the hydrodynamic processes within Penrhyn Estuary and that there is likely to be an increase in volatile hydrocarbons due to the migration of groundwater plumes – this latter issue will occur irrespective of the expansion. A risk assessment analysis has concluded that the expansion would not significantly alter the risks to aquatic organisms as a result of changes to the hydrodynamic regime. Notwithstanding this, there remain concerns that the habitat enhancement proposed for Penrhyn Estuary may place an otherwise thriving assemblage of fish and invertebrates associated with these new habitats at risk due to their relatively close proximity to the point of groundwater, with its associated contamination into Botany Bay.

Whilst the proposed port expansion would affect the aquatic environment of the core study area, it has been designed with the aim of minimising damage to habitats and in several cases, enhancing habitats. Apart from the loss of mangroves, the same habitats would be present in the area following construction, but the relative amounts of these habitats would change. On a broader scale, the loss of mangroves should not be a concern, given the small size of the loss and the aim of enhancing saltmarshes. On balance, it would appear that the proposal would help to maintain biological diversity. The design of the project also addresses the precautionary principle, by initiating measures to prevent harm to the environment. This is evident in the design of dredging and commitment to seagrass transplanting. Finally, the creation of additional aquatic habitat (e.g. saltmarshes and seagrass beds) is consistent with principles of inter-and intra-generational equity.

S6. Environmental Management

Management of environmental issues would be developed within environmental management plans (EMPs) for the construction (CEMP) and operational (OEMP) phases of the project. These would incorporate additional mitigative measures, appropriate training of personnel in terms of protecting the aquatic environment, monitoring of selected environmental indicators and feedback to managers so that the results of monitoring could be incorporated into ongoing management or adjustments made to construction or operational activities.

The major indicators suggested for monitoring include: water quality during construction and operation; benthic fauna inhabiting intertidal, shallow subtidal areas and dredged areas; biota colonising hard surfaces; and seagrasses, algae and associated fauna, such as fish and mobile invertebrates.

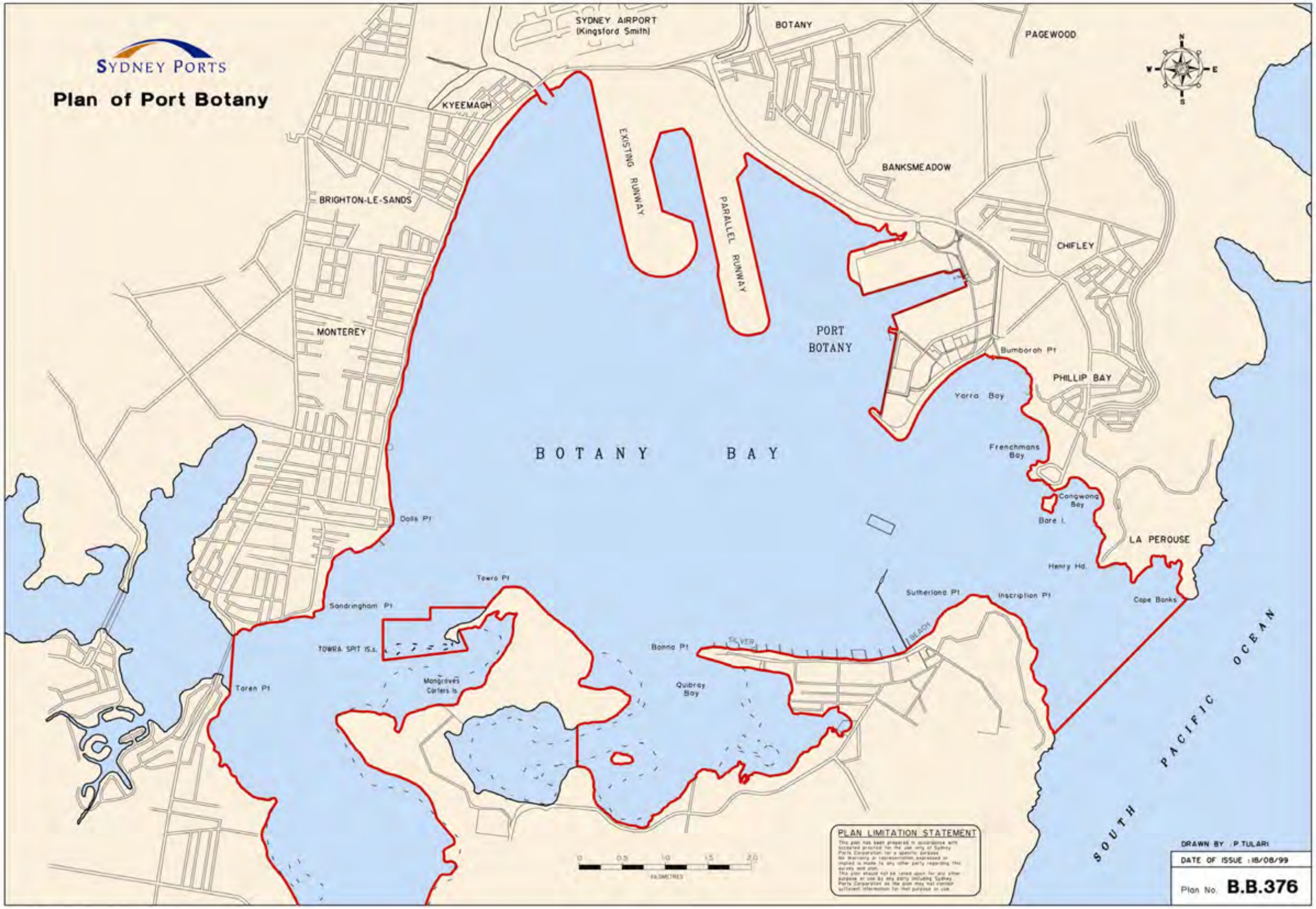


Figure S1: Study area for proposed Port Botany Expansion. Source: Sydney Ports Corporation Survey Section.

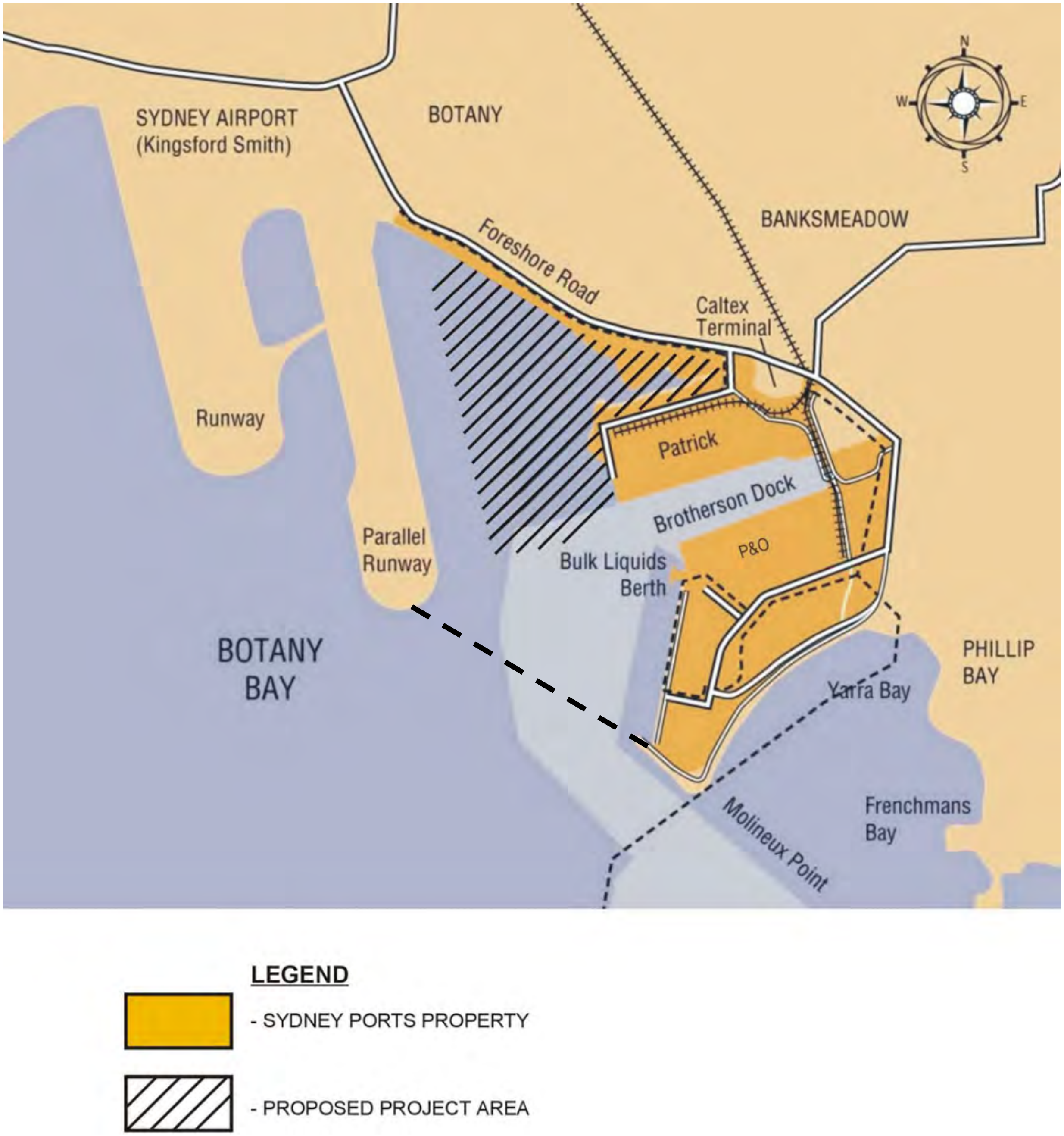


Figure S2. Core study area for investigations of aquatic ecology for Port Botany EIS by The Ecology Lab Pty Ltd. Area is north of dashed line between Parallel Runway & Molineux Pt. Source: Sydney Ports Corporation.

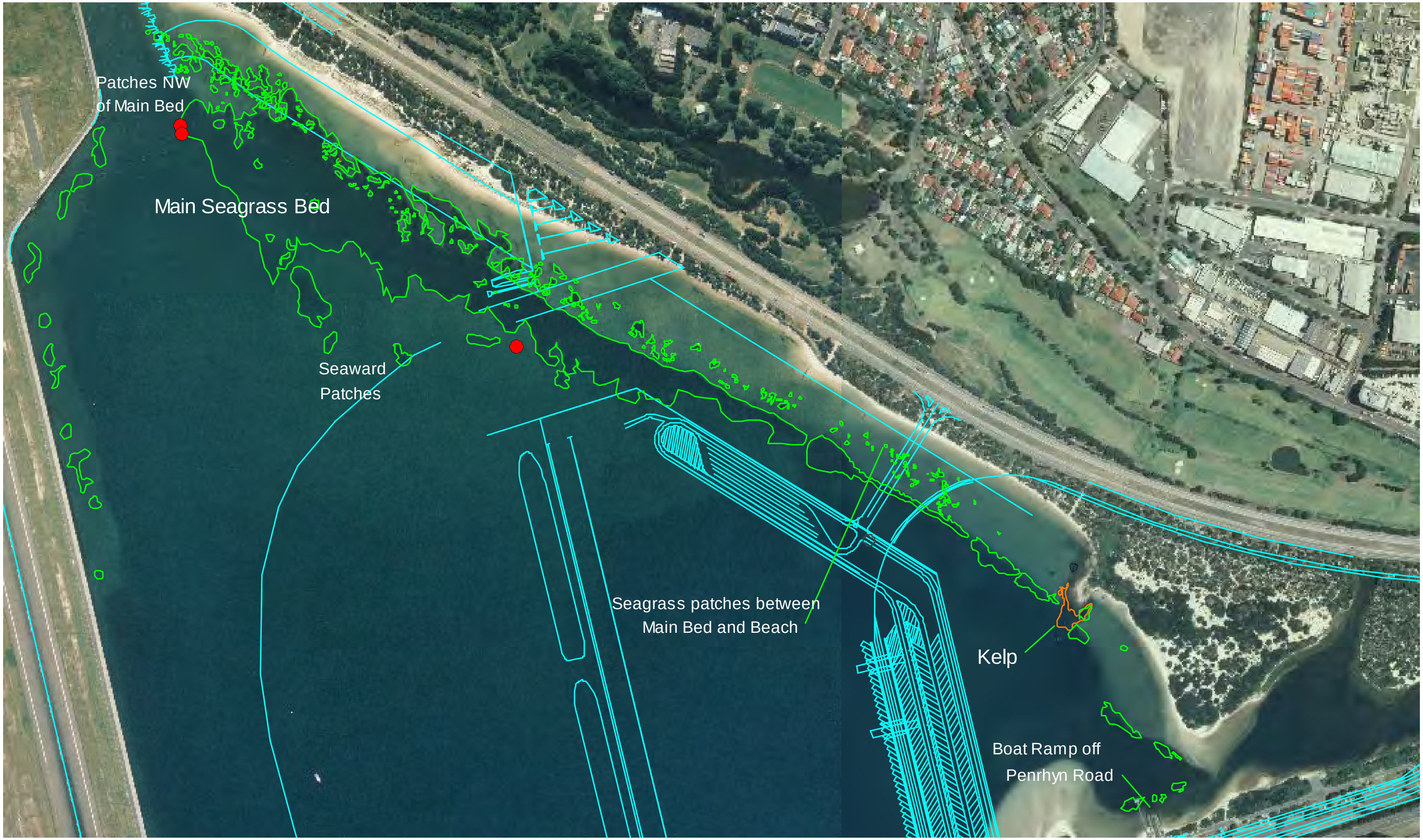


Figure S3. Areas of seagrass derived from interpretation of aerial photographs taken in April 2001 and verified with ground truthing. Areas of mainly *Zostera* are enclosed in green lines; red dots indicate presence of *Posidonia australis*.

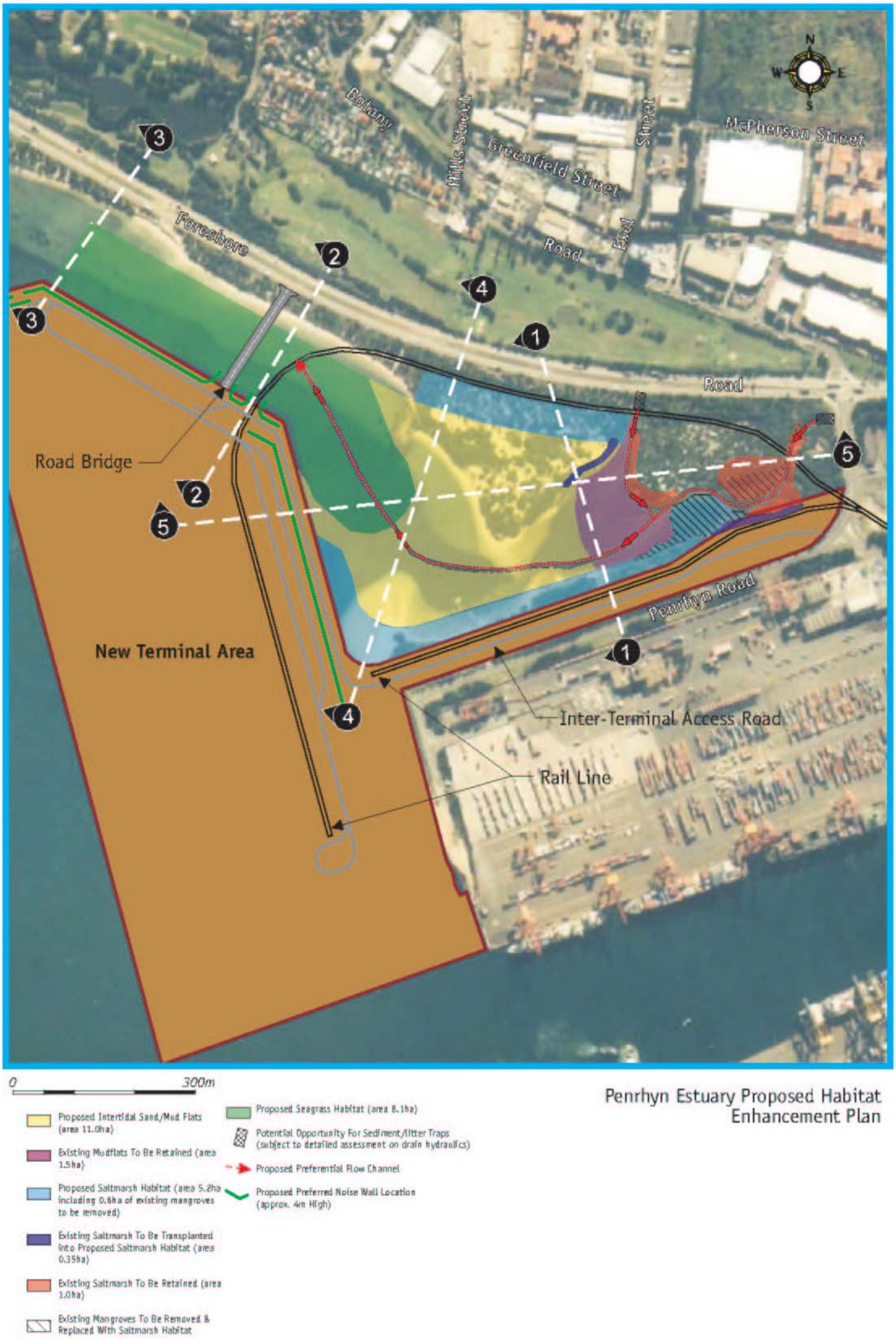
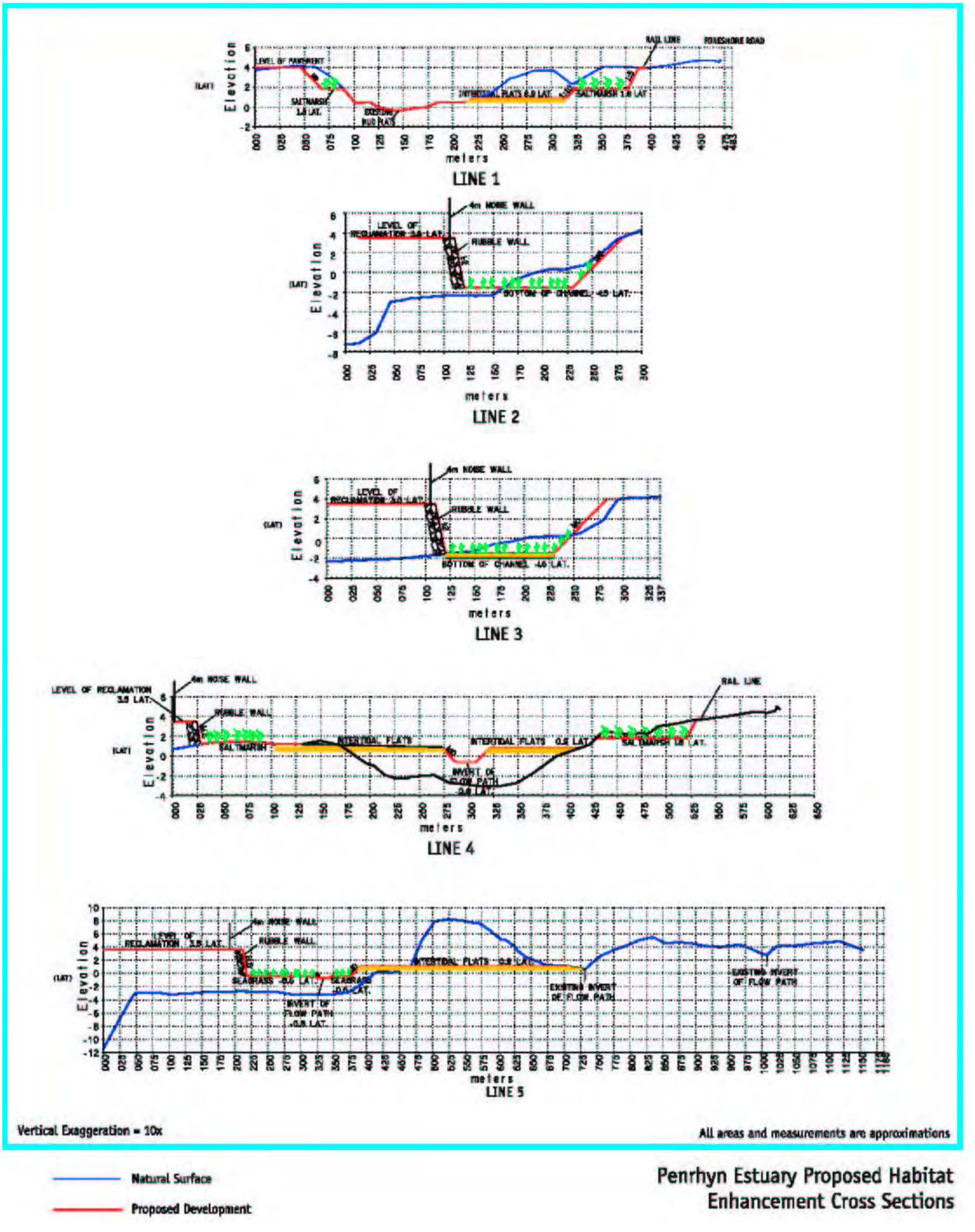


Figure S4a. Proposed habitat enhancement for Penrhyn Estuary. Source: Sydney Ports Corporation, 14/5/2003.



Penrhyn Estuary Proposed Habitat Enhancement Cross Sections

Figure S4b. Proposed habitat enhancement for Penrhyn Estuary. Preliminary Cross Section. Source: Sydney Ports Corporation, 14/5/ 2003.

1.0 INTRODUCTION

This chapter identifies the aims of the study, outlines major issues for investigation and describes the structure of the report.

1.1 Background and Aims

Sydney Ports Corporation (SPC) is proposing to upgrade the port facilities in Botany Bay, by expanding the existing container terminal at Port Botany. The expansion will require reclamation over about 60 ha and dredging over about 75 ha between the existing sea port and the airport. The changes proposed would cause changes to the aquatic environment on the northern side of Botany Bay between the Parallel Runway and Molineux Point, whilst the potential for changes in other parts of Botany Bay must be considered also.

The Ecology Lab Pty Limited was engaged by SPC as part of the study team assembled to prepare the EIS and associated specialists' reports upon which the assessment of environmental impacts will be made. The team is being led by URS Australia, who is also writing the EIS.

The broad aims of The Ecology Lab's study are to:

1. Provide a description of the habitats, flora and fauna of aquatic environments and of fishing activities that may be affected by the proposed port expansion that provides a suitable basis for predicting and assessing the significance of the impacts of the proposed expansion.
2. Use the description of the aquatic environment, detailed assessments by other specialists on other aspects of the aquatic environment (e.g. water quality and wave climate) and detailed descriptions of the proposal itself to predict and assess the significance of the impacts of the proposed expansion.
3. Recommend ways in which negative impacts on aquatic flora and fauna or fishing activities might be removed or mitigated and ways in which positive impacts might be enhanced.
4. Recommend broad programs for environmental management during construction and operation, including monitoring and suggest if any baseline monitoring is required (i.e. sampling before construction begins at impact and reference locations).
5. Recommend, where appropriate, strategies for developing compensatory aquatic habitats.

1.2 Scoping the Aquatic Ecology Issues

The proposed Port Botany expansion involves complex environmental issues that have the potential to span a large area of Botany Bay over a relatively long time frame, both for construction and operation. Dredging and reclamation alone would span more than one year and the new terminal would not be developed to its full operational capacity until at least 2025. Within this context, the process of environmental impact assessment (EIA) will require detailed scoping initially and recognition that any additional issues arising during the assessment process will need to be accommodated.

The proposed expansion will be determined at both the Commonwealth (Environment Australia) and State (PlanningNSW) levels. Both groups have provided requirements regarding issues that are to be addressed. In addition, NSW Fisheries and NSW National Parks and Wildlife Service have provided input into scoping for the proposal. Details of the consultation process, including the outcome of planning focus meetings, are presented in the EIS (URS 2003). Finally, SPC have engaged a peer reviewer, Professor A. J. Underwood, to evaluate the work being done on aquatic ecology for the EIS. Professor Underwood has been involved with the project during the preparation phase and has had input into the design of studies that have been done.

Based on the initial scoping of the project, there are six broad categories of issues related to aquatic flora and fauna that need to be addressed as part of the EIS. These are summarised as follow:

1. **Loss, addition and/or alteration of habitats.** The proposed expansion would affect a variety of aquatic habitats in Botany Bay. These need to be considered in relation to existing habitats and how habitats have been, or are being, altered by previous development such as the Parallel Runway (i.e. cumulative effects). The most important habitats requiring consideration include the following:

   - The water environment itself (e.g. plankton and pelagic fish).
   - Sandy beach habitat, which would be modified (but remain a beach) near the entrance to the Mill Stream, and part of which that would be reclaimed for a new boat ramp and tug boat berths.
   - Subtidal sedimentary habitats, including shallow areas and basins dredged to provide sand for Parallel Runway reclamation.
   - Rocky shores, including artificial structures such as the parallel runway, Molineux Point and existing port facilities.
   - Seagrasses, which include mainly eelgrass (*Zostera capricorni*) and paddle weed (*Halophila* spp.), but may also include some strapweed (*Posidonia australis*), considered to be of high conservation value.
   - Penrhyn Estuary, including intertidal flats, subtidal sediments, saltmarsh and mangroves. Of particular importance is the use of flats around Penrhyn Estuary by bird waders, which include species that are considered to be threatened and/or subject to protection under state, national and international agreements. Further to this, there are opportunities to enhance existing or replace habitats and these are considered as part of the environmental assessment and management of the project.

     The issue of birds is not directly part of the scope-of-works contained within the engagement of The Ecology Lab, and this is being addressed by other specialists (Avifauna Research and Services (ARS) and URS Australia). Notwithstanding this, The Ecology Lab has provided advice regarding the presence of prey species within Penrhyn Estuary and on the effects of enhancement of bird habitat on aquatic flora and fauna.

- Freshwater ecosystems, such as the Mill Stream and Lachlan Swamps, which could be affected if changes to groundwater occur as a result of the proposed port expansion.
- Potential changes to other parts of Botany Bay (e.g. by changes in wave climate). Of particular importance is the Towra Point Aquatic Reserve, which contains a rich diversity of aquatic habitats, including the largest amounts of seagrass, mangrove and saltmarsh in Botany Bay.

2. **Threatened species**, potentially including a variety of fish species, as well as endangered marine mammals and marine reptiles. Our scope-of-works includes an evaluation of fish, aquatic invertebrates, aquatic plants, marine mammals, marine reptiles and penguins. Bird waders and migratory seabirds (e.g. little terns) have been considered by ARS (2002) and URS Australia (2003).
3. **Contamination and Pollution issues.** These will need to be considered in terms of existing sources of contaminants (i.e. cumulative effects) and in terms of construction and operation of the proposed facility. Here it is important to distinguish between contamination, that is, the presence of a potentially harmful chemical and pollution, which has a measurable effect caused by the contaminant. For example, heavy metals derived from industry and occurring within sediments are contaminants, but they may not cause pollution if they are bonded strongly to sediment particles. If conditions change so that the metals are released, then they may cause pollution. Specific issues that need to be considered include:
    - Water quality during construction:
        - Physical measures, particularly turbidity, dissolved oxygen and pH
        - Mobilisation of nutrients and contaminants, such as heavy metals and organics
    - Water quality during operation:
        - Potential for algal blooms in Penrhyn Estuary
        - Spillages, environmental accidents, leachate from antifouling paints
        - Management of runoff from the terminal and surrounds, including sewage overflows from the Mill Stream and within the channels of Springvale and Floodvale Drains. This also extends to effects on groundwater and subsurface movement of contaminants, particularly within the aquifers of Springvale and Floodvale Drains. Whilst this catchment contamination has not been caused by SPC, its implications and management strategies will form part of the assessment of cumulative impacts.
        - Hydraulic efficiency of Penrhyn Estuary and the entrance to the Millstream and how this would affect local aquatic ecology.
4. **Increased potential for introduction of exotic species.** With increasing shipping associated with a new terminal, there may be a potential for increased introductions of exotic species, which has become a major issue of concern regarding shipping worldwide. Specific areas include:
    - Exotic species associated with ballast water and ships' hulls

- Secondary movement of exotic species – e.g. mobilisation of sediments with spores of toxic dinoflagellates (this may occur due to dredging or turbulence from ships' propellers).

5. **Commercial and recreational fishing.** Botany Bay was closed to commercial fishing in 2002, in the expectation that this will lead to improved amenity for recreational fishing. The impacts of the proposal on fishing will need to be assessed in terms of present and future management of fishing within the bay and in terms of opportunities that may be identified to provide adequate compensatory fish habitat where required.

6. **Environmental management.** This would include habitat restoration and compensation (e.g. habitat enhancement, seagrass transplanting), minimising the effects of runoff, etc., where required. It would also include a program for monitoring selected environmental indicators where appropriate.

1.3 Structure of this Report

The next Chapter of this report (**Chapter 2**) defines the study area for this investigation and provides a description of the existing aquatic environment relevant to the proposed port expansion. This description is based on existing information supplemented with new field studies.

Chapter 3 addresses threatened species issues at both the Commonwealth and State levels. Operating under instruction from Environment Australia the assessment of threatened species follows the State protocol and involves the use of 8 part tests to determine the level of management required for selected species and species groups.

Chapter 4 discusses existing and historical effects of human activities in the study area and other parts of Botany Bay. Part of this chapter evaluates the effects of existing port operations and describes a small field experiment undertaken as part of this assessment examining wild populations of Sydney rock oysters (*Saccostrea glomerata*) as an indicator of the present impact of antifouling paints on the aquatic environment.

Chapter 5 presents a description of the proposed development as described in the EIS (URS 2003), but with emphasis on those features most relevant to the aquatic environment. This includes measures for enhancing habitats, including those present in Penrhyn Estuary, seagrasses and artificial surfaces created by the new terminal. It then discusses physical, chemical and biological stressors and their predicted effects on the aquatic environment, both within the study area and in other parts of Botany Bay.

Chapter 6 describes mitigative measures and outlines monitoring programs and a range of feedback mechanisms to management, including triggers for response and horizons for monitoring.

Chapters 7 & 8 present acknowledgements and references cited, respectively. These are followed by **Tables**, **Figures** and **Appendices** of raw or summarised data.

2.0 THE AQUATIC ENVIRONMENT

This chapter defines the study area for this investigation and provides a description of the existing aquatic environment relevant to the proposed port expansion. This description is based on existing information supplemented with new field studies, where appropriate.

2.1 The Study Area and Overview of Existing Information

The existing port and area of the proposed expansion are located at the northern side of Botany Bay, in the suburbs of Botany and Banksmeadow (Figure 2.1). The core study area has been defined as: that part of Botany Bay between the southern tip of the Parallel Runway and the south western tip of Molineux Point (Figure 2.2), because this is where most of the proposed works would occur. In addition to this study area, we also considered issues associated with wetlands in the catchment of the Mill Stream, some areas of elevated seabed within the current navigation channel for Port Botany that are proposed to be dredged, and more generally, the whole of Botany Bay as may be affected by changes in physical or ecological processes. In particular, Towra Point Aquatic Reserve was given special consideration due to its high conservation value.

The physical, chemical and biological attributes of Botany Bay have been studied extensively over the past four decades. Major research programmes have included the following:

- Studies co-ordinated by the State Pollution Control Commission (now NSW Environment Protection Authority, EPA) and funded by the Maritime Services Board spanning 1978 to 1980. These studies included surveys of a variety of indicators over a two year period. The focus was on Botany Bay, but studies extended to catchment processes.
- Studies done in relation to the environmental impact assessment and construction monitoring of the Parallel Runway. The studies were co-ordinated initially by Kinhill Engineers and then by the Federal Airports Corporation, who also funded the work. The studies extended from 1989 to the mid 1990's. The focus of this work was on the northern parts of Botany Bay, but work also extended to Towra Point and, in some cases, to the use of external references selected in other estuaries in the Sydney region.
- Jervis Bay Baseline Studies. A major study on the marine ecology of Jervis Bay used sites selected within and at the entrance to Botany Bay as external reference areas. Work included studies of fish and invertebrates associated with seagrass beds and rocky reefs. Some of this information was used in the EIA for the Parallel Runway.
- Contamination issues in Penrhyn Estuary. The movement of contaminants from the ORICA (formerly ICI) Banksmeadow site towards Botany Bay via ground water and surface water associated with Springvale and Floodvale Drains has triggered a series of environmental investigations. Of relevance here was the collection and analysis of fish and invertebrates from Botany Bay for a series of organic contaminants and heavy metals.
- Beach nourishment and groyne installation at Lady Robinsons Beach. As a result of changes to the shoreline and bathymetry of Botany Bay, patterns of wave energy

Figure 2.1. Study area for proposed Port Botany Expansion. Source: Sydney Ports Corporation Survey Section.

have also changed at several beaches in Botany Bay. At Lady Robinsons Beach, on the western side of the bay, a programme of beach nourishment and groyne installation was initiated in the mid 1990's. An important component of environmental management for this programme was transplanting of the seagrass *Zostera capricorni* from Lady Robinsons Beach to two locations on the northern side of Botany Bay.

- Proposed maintenance dredging at the Mill Stream. Sediments at Foreshore Beach have tended to migrate along the beach from the east towards the mouth of the Mill Stream. This had reduced the efficiency of the stream channel and blocks stormwater drains at the entrance to the stream (The Ecology Lab 2001). Work done for this project included seagrass mapping and analysis of data on flora and fauna of seagrasses.
- University and Government Research. There have been many field experiments on the flora and fauna of Botany Bay, including studies of plankton, seagrasses, invertebrates living in soft sediments, fish, etc. These provide both specific and general information on ecological issues.
- Environmental Impact Statements on Commercial Fishing in NSW. NSW Fisheries is in the process of preparing EISs for major fisheries in NSW. Whilst commercial fishing has now been closed in Botany Bay, the EISs on the Estuary General Fishery (NSW Fisheries 2001) and the Estuary Prawn Trawl Fishery (NSW Fisheries 2002) provide useful compilations of information on the fisheries resources of Botany Bay (and other estuaries in NSW).
- Previous studies for the Port Botany expansion. There have been two previous investigations of aquatic ecology in relation to the proposed port expansion. The Ecology Lab (1995) reviewed existing information and identified issues that would need to be considered for the port expansion. Marine Pollution Research (MPR 1998) provided a review of literature and undertook some limited field surveys.

It is not the aim of this report to review all these studies, but rather to draw on information within them as required to assist with describing the aquatic environment for the purposes of assessing the effects of the proposed port expansion. It should also be noted that, while there are a great many articles and reports available on the ecology of Botany Bay, it is important to recognise that a) often source data are repeated in multiple documents, hence there is often an impression of there being more data available than is actually the case; and b) often the data collected suffer from faults in sampling design or sampling techniques, hence are of limited value (McGuinness 1988).

2.2 Aquatic Habitats

The study area contains a diverse array of aquatic habitats which potentially could be affected by the proposed port expansion. The major habitats that need to be considered include:

- The water column,
- Soft, unvegetated sediments, including intertidal beach habitat, shallow subtidal habitat and deeper, silty areas created as a result of dredging,

Figure 2.2. Core study area for investigations of aquatic ecology for Port Botany EIS by The Ecology Lab Pty Ltd. Area is north of dashed line between Parallel Runway & Molineux Pt. Source: Sydney Ports Corporation.

- Hard surfaces, including artificial and natural substrata,
- Seagrasses and algae,
- Saltmarshes and Mangroves,
- Freshwater habitat, including wetlands within the catchment of the Mill Stream and parts of Springvale and Floodvale Drains.

In describing these habitats, it is important to consider not only patterns and processes within habitats, but also linkages among them.

2.3 The Water Column

The water column provides a habitat for a highly diverse assemblage of plants and animals within Botany Bay. Plants include the seeds of seagrasses and mangroves, spores of macroalgae and phytoplankton, which can vary dramatically in response to climatic conditions (e.g. sunlight) and levels of nutrients. Zooplankton includes permanent inhabitants of the water column (called holoplankton) and transient forms, such as fish and prawn eggs and larvae (called meroplankton). In addition to planktonic forms, there are also larger pelagic biota, including rafts of drift algae (typically dislodged from coastal reefs), large jellyfish (e.g. *Catostylus mosaicus*), highly mobile invertebrates, such as squid and a large variety of pelagic fish.

Important studies of planktonic organisms within Botany Bay included work on larval fishes in water off Foreshore Beach (Steffe 1989, 1991), studies on the ecology of *Catostylus mosaicus* (Pitt and Kingsford 2000a, b, Pitt, 2000, Kingsford *et al.* 2000) and studies of larval fishes associated with tidal fronts near the entrance to Botany Bay (Kingsford and Suthers 1994, 1996). Steffe's work focused on how larval fishes maintain position or move to more favourable positions within the water column. The diversity of larval fishes was found to be very large possibly reflecting numerous habitats from which larval fishes were derived. Kingsford and Suthers (1994, 1996) identified the importance of tidal fronts for concentrating and then dispersing larval fishes. Most of their work was done to the east of Molineux Point.

Emplacement of the original North-South Runway is believed to have created an eddy of currents offshore from Foreshore Beach. This eddy has been attributed to directing large numbers of fish larvae onto seagrass beds at the Pilot Station at the north western end of Foreshore Beach (McNeill *et al.* 1992). With the construction of the Parallel Runway, the Pilot Station and seagrasses were reclaimed, but it is not known if this habitat loss has affected the overall populations of fish and invertebrates within the bay.

Catostylus mosaicus is a large, conspicuous member of the planktonic community in estuaries and saline lagoons (e.g. Lake Woolooweyah) of NSW. The large, bell-shaped medusa is the reproductive stage, while larval jellyfish settle onto hard surfaces on the estuarine floor. In Botany Bay, medusae were found to aggregate near the mouths of freshwater input, such as the Georges River and Cooks River (Pitt and Kingsford 2000a). This pattern was also observed in other NSW estuaries. *C. mosaicus* is of commercial significance in some NSW estuaries. It is not harvested in Botany Bay and is unlikely to be harvested in future due to the closure on commercial fishing (see Chapter 4). Medusae of *C. mosaicus* are capable of swimming and hence can move independently of water currents.

Apart from supporting a large variety of plants and animals, the water column is responsible for transporting essential items, such as food and oxygen to various habitats and for transporting wastes away from habitats. The clarity of the water column also determines the depth to which attached plants, such as seagrasses and macroalgae, can grow. Where the water contains contaminants or excess suspended sediment or nutrients, water quality is diminished, potentially affecting the way aquatic ecosystems function. Issues related to water quality are considered in Chapter 4 of this report.

2.4 Unvegetated Soft Sediments

Soft, unvegetated sediments have often been considered to be somewhat of an ecological desert, as they appear to be relatively depauperate compared to more structurally complex habitats, such as rocky reefs, seagrass beds and mangrove forests. However, soft sediments can be very diverse and, because they can occupy a very large proportion of an estuary, they collectively have a major influence on estuarine assemblages. Indeed, soft sediments comprise the largest and most widespread habitat type within Botany Bay. Furthermore, different areas of soft sediment can have highly distinctive assemblages of animals, depending on the type of sediments (e.g. sand or mud), location, depth, proximity to other habitats and degree of contamination.

The soft sediments of Botany Bay have been greatly affected by human activities, through loss of habitat (e.g. for land reclamation), changes in depth (through dredging) and changes in composition. Furthermore, the invertebrates living in soft sediments (often called "benthos") are often used as an indicator of environmental change. These issues are discussed further in Chapter 4; here an overview of relevant studies is presented.

2.4.1 Existing Information

Soft sediment habitats often appear to be very homogeneous, however, the benthic fauna that live there can vary at quite small spatial and temporal scales (Morrisey *et al.* 1992a, b, c, 1994), which has implications for the way in which field studies are designed and interpreted. Soft sediments of the intertidal zone, including Foreshore Beach and the edge of Penrhyn Estuary, would be physically altered by the proposed port expansion. Subtidal sediments would also be affected by dredging and reclamation.

2.4.1.1 Intertidal and Shallow Subtidal Habitats

Beaches provide important habitat for aquatic organisms and are popular recreational areas. Within the northern parts of Botany Bay there are recognised sites for wading birds. Many of these birds prey on benthic organisms, including polychaete worms and molluscs.

2.4.1.1.1 Intertidal Benthos

There have been relatively few surveys of the sandy intertidal habitats of Botany Bay. Dexter (1983, 1984, 1985) surveyed intertidal invertebrates at Dolls Point and Towra Point. She sought to relate benthic assemblages to different characteristics of beaches, particularly exposure, but limitations in the sampling design limited interpretation of results.

As part of supplementary work for the Parallel Runway, Kinhill (1991) commissioned a survey of beach fauna at Foreshore Beach (denoted as Botany Beach in that study) and at two reference beaches, Towra Point and Runway Beach (on the eastern side of the original north-south runway, but now removed – Figure 2.4.1). At each beach 3 sites were sampled at 2 heights on the shore, 0.3 to 0.5 m and 0.5 to 0.7 m LAT. Five replicates were taken at each site/height, but these samples were combined to obtain a bulk sample for each of the 3 sites. Samples were collected by coring and sieved through a 1 mm mesh.

Foreshore Beach was dominated by the nereid polychaete *Australonereis ehlersi*, which was also abundant at Runway Beach (Kinhill 1991). The fauna was quite distinctive compared to Towra Point, being dominated numerically by the amphipod *Urohaustorius metungi* and the polychaete *Scolopsis simplex*.

Kinhill (1991) concluded that there was a distinctive gradient in abundance of benthos along Foreshore Beach. The northern part was relatively sheltered, with an abundance of benthic invertebrates of 4,835 (± 419 SE) individuals per m^2; the central area supported and average of 1,190 (± 109) individuals per m^2 while the southern, most exposed site sampled had an average abundance of 854 (± 53) individuals per m^2. These differences were attributed mainly to a change in abundance of *A. ehlersi*.

Much of the section of Foreshore Beach surveyed by Kinhill (1991) was lost as a result of the construction of the Parallel Runway. The middle site sampled was close to the present mouth of the Mill Stream, whilst the southern most site (A) was northwest of Penrhyn Estuary (Figure 2.3). As far as is known, there are no data on the intertidal benthos of the current southern portion of Foreshore Beach, or of Penrhyn Estuary. Since this area would be affected by the proposed port expansion, it was considered useful to obtain data on biota of the beach. Moreover, the method of compositing samples used by Kinhill (1991) limits the way in which data can be evaluated. Hence, a supplementary survey of intertidal benthos was done as part of the studies for the proposed port expansion. This supplementary work is described below in Section 2.4.2.

2.4.1.1.2 Fish and Mobile Invertebrates of Intertidal and Shallow Subtidal Habitats

NSW Fisheries surveyed fish occurring off sandy beaches along Lady Robinsons Beach and at Towra Spit. The only samples taken off Foreshore Beach were from beds of *Zostera capricorni* (SPCC 1981a, b). As part of the studies for the Parallel Runway EIS, The Ecology Lab sampled fish along Runway Beach (Kinhill 1990). Apart from these studies, no other work on fishes using shallow, unvegetated sediments in Botany Bay were found. Apart from Botany Bay, CSIRO surveyed fish and mobile invertebrates off sandy beaches in Jervis Bay over two years. They also sampled sandy beaches in Batemans Bay and Port Hacking over a shorter period as references for Jervis Bay (CSIRO 1994). The CSIRO study, while not done in Botany Bay, provides some indication of assemblages occurring within this type of habitat.

SPCC (1981a, b) used a variety of seine nets to collect a total of 68 species of fish from two shallow sandy sites in Botany Bay, 32 of which are economically important. Most of the commercial species were regarded as being transient in this habitat, with the exception of sand whiting (*Sillago ciliata*). Transient species of commercial value included tailor (*Pomatomus saltatrix*), southern herring (*Herklotsichthys castelnaui*), sand mullet (*Myxus elongatus*), flat-tail mullet (*Liza argentea*) and sea mullet (*Mugil cephalus*). All these species are common in other habitats. Species of limited economic value occurring as residents in the shallow sandy habitat included gobies and flounder (e.g. *Ammotretis rostratus*), while there were also several types of schooling bait fishes, including hardyheads (*Atherinosoma ogilbyi*), perchlets (*Ambassis jacksoniensis*), sandy sprats (*Hyperlophus vittatus*) and several species of toad fishes (Tetraodontidae) occurred in small schools in this habitat.

The Ecology Lab used a seine net (25 m long x 2 m deep, with 6 mm mesh) to sample fish at 3 sites along the Runway Beach on 3 occasions from November to December 1989 (Kinhill 2000). Two replicate hauls were done at each site and time. Forty-eight species of fish and mobile invertebrates were collected, totalling approximately 34,000 individuals. The species composition was similar to that reported for other sandy beaches in Botany Bay by SPCC (1981a, b), with sandy sprats and perchlets dominating the catch numerically. Other common species included three species of gobies, sand whiting, sand mullet and tarwhine.

CSIRO (1994) sampled fish and mobile invertebrates at 6 beaches around Jervis Bay and at 2 sites each in Batemans Bay and Port Hacking. A seine net similar to the one used by The Ecology Lab was used. Ninety-seven species were collected, 41 of which are economically significant. As in Botany Bay, the catches were numerically dominated by schooling baitfish and there were no clear seasonal patterns (cf. SPCC 1981b). Moreover, changes in tidal height appeared to have little effect on abundance of fish and invertebrates off the sandy beaches in Jervis Bay.

2.4.1.2 Subtidal Habitats

There has been far more work done on the benthos associated with subtidal than intertidal habitats in Botany Bay. Much of this work has been directed at measuring the effects of dredging on benthos (e.g. Jones and Candy 1981, Kinhill 1991, AMBS 1993, 1998) or fish (SPCC 1981a, b, AMBS 1993).

2.4.1.2.1 Subtidal Benthos

Jones and Candy (1981) investigated the effects of dredging on benthos in Botany Bay by examining faunal composition and community structure of dredged and undredged areas within the bay. Four dredged and four nearby undredged sites were sampled from November 1976 to January 1977. The dredged areas included:

- The navigation channel at the entrance to Botany Bay;
- Two separate parts of the navigation channel around Port Botany (i.e. two locations with matching undredged sites); and
- The basin dredged for fill for the original North-South airport runway.

A fifth undredged site, comprising muddy sediments, was sampled at Ramsgate, on the western side of the bay.

At each site, 10 sediment cores were collected by divers for examination of benthos. Sediments were sieved through a 1 mm mesh. t-tests were used to compare species richness and abundance for each pair of dredged and undredged sites. Multivariate analyses using the Bray Curtis measure of dissimilarity and Euclidean distances were performed.

A total of 225 species were recorded, with an average of 17 species per sample. T-tests comparing dredged and undredged sites were generally non-significant, indicating that the numbers of species were similar between the two treatments. There was a trend, however, for dredged sites to have a muddier substratum than their adjacent site and to have a slightly reduced number of species. The exception was at the entrance to Botany Bay, where the dredged channel was much richer than the adjacent undredged channel. This difference was attributed to the greater depth of the dredged area relative to the surrounding seabed and hence was less subject to disturbance from wave activity.

Kinhill (1991) sampled 6 sites in the northern portion of Botany Bay in July 1991, including 4 sites within the study area (Sites 1 – 4) for the proposed port expansion (Figure 2.3). At each site, 5 replicate samples were collected. The sieved mesh size was not reported. Three of the sites (1, 2 & 3) were in areas proposed to be dredged; the other 3 were not to be dredged. Sites 1 and 4 were at depths < 4 m, Sites 2 and 5 at a depth of 5 m and Sites 3 and 6 were at depths > 8 m (Table 18.6 in Kinhill 1991,). Sediments were described as sandy mud (sites 1 & 6) or muddy sand (Sites 2, 3, 4 & 5).

Fifty-six species of invertebrates were collected, including 35, 12 and 9 species of polychaetes, molluscs and crustaceans (Kinhill 1991). The most abundant organisms found in the samples were deposit feeding polychaetes, including *Chaetozone setosa*, *Notomastus chrysosetus*, *Heteromastus filiformis*, *Mediomastus* sp. and *Augeneria verdis*. A polychaete not recorded previously in Australia, *Notocirrus* sp., was collected at Site 5, to the south of the original North-South Runway. It was suggested that the creation of deep, isolated holes through dredging would be undesirable in areas that would experience high levels of sedimentation or constant local disturbance of fine sediments (Kinhill 1991).

The Australian Museum sampled benthos and benthic scavengers as part of preliminary sampling for monitoring the recovery of areas to be dredged for obtaining fill for the Parallel Runway (AMBS 1993). Six sites were sampled in Botany Bay in April and July 1992 (Figure 2.4). Three of the sites were to the east of the original North-South Runway in areas proposed for dredging; the other 3 were to the west of the runway and were considered as references. Samples were collected using grab samplers.

A total of 303 species were collected comprising 128, 99, 76 and 1 species of polychaetes, crustaceans, molluscs and an echinoderm, respectively (AMBS 1993). In addition, specimens of the phyla or classes Sipuncula, Oligochaeta, Nemertea, Phoronida and Nematoda were collected. The average number of taxa per grab ranged from 22 to 41 in April and from 14 to 48 in July. Sediments were typically sandy (> 80% for each sample, on average), although Site 6, a reference, had a relatively high percentage of mud.

It was concluded that the benthic fauna consisted of species that also occurred in other shallow, protected embayments of the Sydney region. Spatial patterns tended to be more pronounced than temporal ones, however, there was only a small gap of time between the two surveys. It was also found that the reference sites tended to differ from the future dredge sites and this was attributed to longitudinal differences (i.e. references were west of the N-S Runway; dredge sites to the east) and to differences in sediment and possibly salinity characteristics (AMBS 1993). It was also suggested that the temporal differences may be linked to recovery of benthic habitats following the end of the trawling season, which occurred at the end of April.

In addition to grab sampling, small baited traps were deployed during the night time to sample invertebrate scavengers (AMBS 1993). At each of the six sites, three traps were deployed at two sub-sites. Forty-seven species were collected, 22 of which were recognised as scavengers; the other were considered to be vagrants. The main scavenging guild consisted of cirolanid isopods, cypridinid isopods, lysianassoid amphipods and nassariid gastropods. An average of 4 species was collected per trap, but abundance was highly variable. There were also large differences between the two times, but it is difficult to attribute the causes of this pattern.

AMBS (1998) undertook a comparison of data on benthos from Botany Bay with Pittwater and Jervis Bay, based on existing information. It was concluded that none of the species from Botany Bay was endemic to the bay; hence the fauna of Botany Bay is probably drawn from the same pool of species within the Sydney (or mid-coast) region as would be other local estuaries and embayments.

Following the completion of dredging for the Parallel Runway, the Australian Museum undertook a further field investigation of benthos in relation to dredging AMBS (1998). The broad aim of this work was to measure recolonisation within the dredged areas and to assess recovery. Recovery was considered to occur when the assemblages of the dredged areas varied in a similar manner to assemblages in deep, undredged areas. It was assumed that the biota of the dredged areas would be very different to those of the shallow habitat prior to dredging. Furthermore, no deep holes were available within Botany Bay to serve as reference areas against which the new assemblages could be compared.

On this basis, no further sampling was done at shallow sites (cf. sites 4, 5 and 6 in AMBS 1993), rather, 3 reference sites were selected, one each within two deep holes in Pittwater and one deep hole in Port Hacking. This design does not allow a valid comparison of assemblages among estuaries, only of deep sites affected by the dredging in Botany Bay with similar sites not affected by the dredging.

Benthos was sampled 12 times over approximately 2 years at 4 sites in Bot 1, Bot 2, Bot 3 and Bot 4 (Figure 2.4), 2 in Pittwater (PIT 1 and PIT 2) and 1 site in Port Hacking (HAC) (AMBS 1998). All sites were 12 to 20 m deep. Three sub-sites were sampled in each site, except at BOT 4, where 2 sub-sites were sampled, yielding a total of 20 sub-sites. At each sub-site, 2 replicate grabs were obtained for benthos and 1 for sediment analysis at each time.

All sites differed in their sedimentary composition, with BOT 1 & 2 showing the large range of variation. BOT 1 & 2 sediments consisted of muddy sand and had large deposits of black organic material on the surface, probably consisting of ancient wood exposed by dredging (AMBS 1998). BOT 3 & 4 consisted of mostly mud over the entire study period. Sediment composition was less variable at the reference sites and was generally sandy.

During the first 4 months or so after dredging (April to July 1994), the abundance of benthos was very low at all sites (AMBS 1998). By period 5 there was a large settlement of polychaetes, but abundance declined after August and was then quite variable for the remainder of the study.

Compared with AMBS (1994), there were 70 species recorded in the earlier study that did not occur in the dredge holes, and there were several species in the dredge holes not recorded in the earlier study, suggesting a change of > 20% in the fauna (AMBS 1998). It was concluded that recolonisation of the dredged holes had occurred within the period of the study, as numerous taxa had established large populations. Notwithstanding this, it was concluded that recovery had not occurred by the end of the two year study (as compared to assemblages within the reference sites). It was also suggested that the seabed at BOT 3 & 4 had very limited flushing as these holes were relatively isolated. As a consequence, diversity and abundance of benthos was reduced compared to BOT 1 & 2, which were connected to the main navigation channel for Port Botany.

Figure 2.3. Sampling Sites for invertebrate animals from Kinhill (1991) study. Source: Figure 18.2 In Proposed Third Runway - Supplement to the Draft Environmental Impact Statement, Volume One, Kinhill 1991.

2.4.1.2.2 *Fish and Mobile Invertebrates of Deeper Habitats*

SPCC (1981a, b) surveyed fish and mobile invertebrates of deeper habitats in Botany Bay, including the following:

- A dredged area in the main navigation channel at the south eastern end of Molineux Point denoted in SPCC 1981a, b as "ED").
- An undredged area off the southern end of the original North-South Runway (EU).
- A dredged area used as a borrow pit for fill for the N-S Runway, on the western side of that runway (WD).
- An undredged area offshore from Ramsgate, on the western side of Botany Bay (WU)
- An undredged site at the mouth of the Georges River (RM).

EU and ED are the sites closest to the study area for the proposed port expansion and were denoted "eastern deep soft substrate" (SPCC 1981a). WD, WU and RM were considered to form a distinct habitat, denoted the "western deep soft substrate". Surveys were done bimonthly in 1977 and 1978. At each site, two replicate trawls were done each during the day and night.

The sites constituting the eastern deep soft substrate yielded 87 species of fish, including 33 of economic importance. None of the dominant commercial species was considered to be a permanent resident of this habitat. Many of the species were considered to be common in adjacent coastal habitats, using these deeper areas of the bay as an extension of the coastline. Several non-commercial species were considered to be resident in this habitat. They included the stingaree (*Trigonoptera testacea*), crested flounder (*Lophonectes gallus*) and bar-tailed goatfish (*Upeneus tragula*).

Sites constituting the western deep soft substrate yielded 102 species of fish, including 35 species of economic importance (SPCC 1981a). As in the deep sites, none of the commercial species was considered to be a permanent resident, but several species were considered to be temporary residents (e.g. juvenile snapper, *Pagrus auratus*, large juvenile dusky flathead, *Platycephalus fuscus*, adult trumpeter whiting, *Sillago maculata* and adult silver biddies, *Gerres subfasciatus*).

As part of surveys done prior to the construction of the Parallel Runway, AMBS (1993) used a prawn trawler to sample fish and mobile invertebrates at 6 sites within Botany Bay, 3 within the area of construction of the Parallel Runway and 3 reference sites to the west of the original North - South Runway (Figure 2.4). Four, 2-minute hauls were done at each site during the evening in April and July, 1992. Catches of fish on the western side of the bay (i.e. the references) yielded the largest biomass, due to large catches of yellowfin bream (*Acanthopagrus australis*). Catches of invertebrates (prawns and cephalopods) were high on the eastern side of the bay and showed strong temporal differences (fewer in July than April).

NSW Fisheries studied the catches of prawn trawlers in Botany Bay compared to Sydney Harbour, as part of monitoring the effects of the Parallel Runway. Results of this work are presented in Kennelly (1993) and Liggins *et al.* (1996), and are summarised in NSW Fisheries (2002). The study yields limited data on specific sites within Botany Bay, because surveys were structured around the commercial trawling activity. Generally, by-catch from Botany Bay (particularly octopus and blue swimmer crabs) was up to nearly 4 times greater than Sydney Harbour during the same period and in both estuaries the quantity of by-catch was

Figure 1. Botany Bay, distribution of sampling sites before (large numbers; see Australian Museum, 1993) and after (polygons) dredging for the parallel runway. Sites BOT3 and BOT4 are equivalent to dredged area A3. Site BOT1 is equivalent to dredged area B. Site BOT2 is equivalent to dredged area C. Also shown are dredged Areas F and G, which were not investigated by this study. Area F was investigated by Australian Museum (1994). North is toward the top of the page.

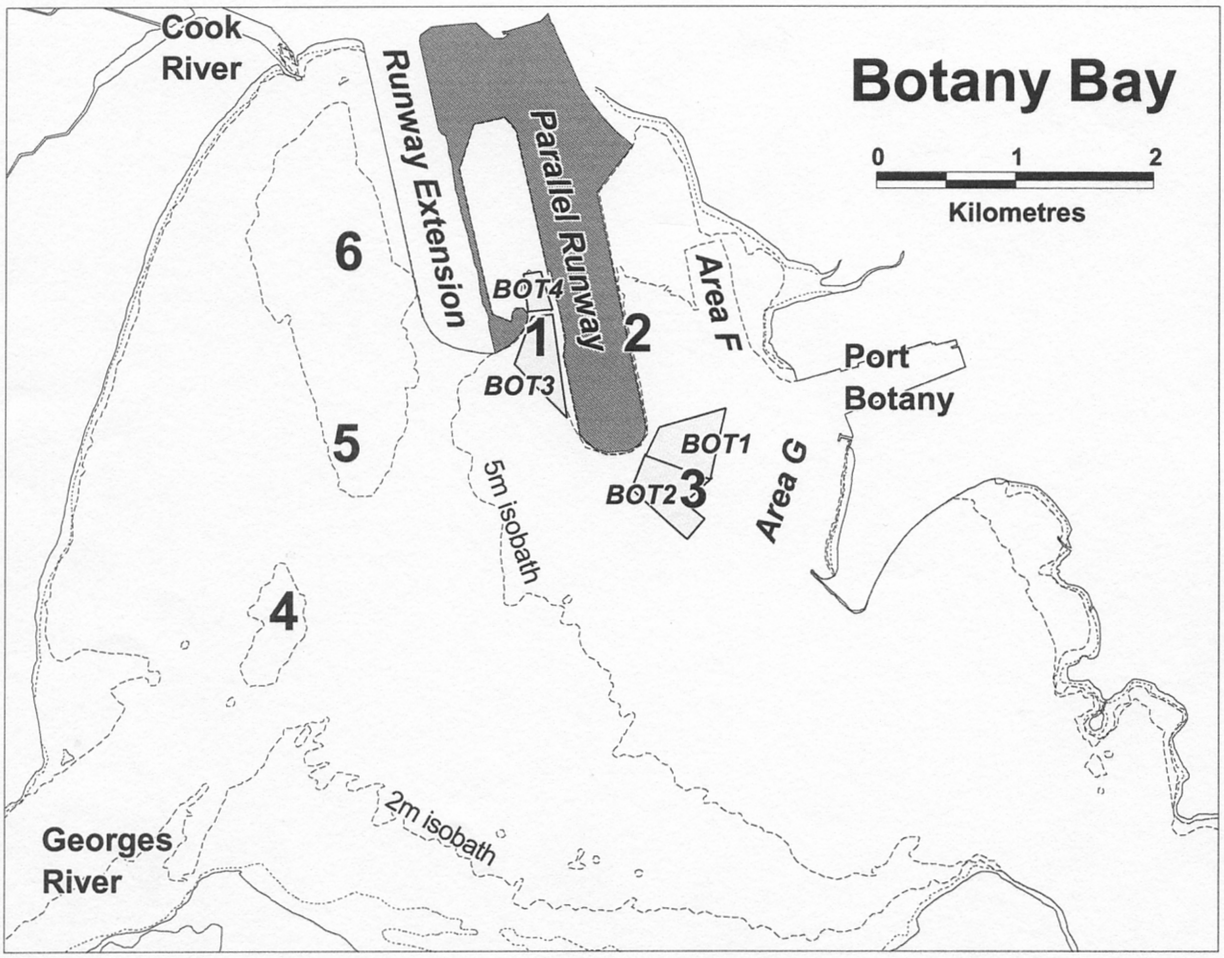


Figure 2.4. Sampling sites for soft sediment benthic samples from The Australian Museum study, 1993. Source: AMBS 1993.

larger, by weight, than the prawn catch. The 10 most abundant species consisted of species that would not have been retained by fishers as by-product because they were either too small or not accepted by the market (NSW Fisheries, 2002). This suggests that the trawlers were removing considerable biomass from Botany Bay that were not being utilised.

It was concluded that no effects on the trawl catch from construction of the Parallel Runway could be discriminated based on the trawl data (Kennelly 1993, Liggins *et al.* 1996). However, it was acknowledged that limitations in the sampling design would have reduced the ability to detect an effect. Moreover, there was no comparison of trawling in specific areas that would have become difficult to trawl following dredging and reclamation.

2.4.2 Supplementary Intertidal Investigations

2.4.2.1 Aims

There is very little information on the occurrence of benthic invertebrates within Penrhyn Estuary and limited information on these animals along Foreshore Beach. According to ARS (2003) Penrhyn Estuary is an important area for waders in Botany Bay, being used for feeding and roosting. A former roosting site within the estuary, which comprised saltmarsh has now become overgrown with mangroves. As far as is known, there has been virtually no work done on soft-sediment macrofauna of the estuary. It is known that large crabs (blue swimmer and mud crabs) and prawns occur in the estuary seasonally (The Ecology Lab 1995) and casual observations indicate that there is a colony of soldier crabs occurring on intertidal flats.

As part of the studies being done for SPC, The Ecology Lab collected sediment samples from intertidal areas for analysis of infauna. This study was done to improve the description of the existing environment for the EIS, to assist in the bird studies (by indicating presence and abundance of prey taxa) and contribute to the baseline of information for monitoring the effects of the proposed port expansion. A full report on the study is presented in Appendix 1 of this report, a summary of the methods, results and conclusions is provided in the next two sections.

2.4.2.2 Methods

Intertidal benthic habitats were sampled at five locations along the length of Foreshore Beach in October 2002 (Figure 2.5). At each location, three sites approximately 50 m apart were sampled. Six replicate core samples of sandy substrata were taken at each site at the water-sand interface at low tide so that the benthic invertebrate community could be examined. In addition, two replicate core samples were taken at each site for analysing the distribution of particle size.

In the laboratory, the samples of benthic invertebrates were rinsed through a 1.0 mm mesh size sieve and then the invertebrates were identified and counted at the taxonomic level of family (with the exception of a few groups). Samples of grain size were wet sieved through a number of different sieve mesh sizes, and the fraction of the sample retained on each sieve size was recorded. Benthic data were analysed using a variety of statistical procedures (Appendix 1). The grain size analyses focused on the percentage of 0.151 – 0.3 mm grains (fine-to-medium sand).

Figure 2.5. Positions of sampling sites (orange dots) for intertidal benthos along Foreshore Beach and Penrhyn Estuary, Botany Bay sampled 8 October, 2002 by The Ecology Lab Pty Ltd.

2.4.2.3 Results and Conclusions

The dominant taxa found in this study of the intertidal benthos were similar to those reported by AMBS (1993), including the polychaete worm *Australonereis* (family Nereididae) and amphipods from the family Exoedicerotidae .

The intertidal locations, particularly Penrhyn Outer, differed significantly from each other with respect to their assemblages of benthic invertebrates. Although differences between locations were significant, there was substantial overlap in the structure of the assemblages at each location. Most of the differences amongst the locations were attributed to only a few taxa, particularly polychaete worms in the family nereid polychaetes and exoedicerotid amphipods. Differences among sites within locations were significant and more apparent than differences among locations.

The intertidal locations significantly differed with respect to their numbers of taxa, however specifically which locations differed could not be differentiated statistically. None of the other variables examined showed significant differences at the scale of location. Site-scaled differences were present for several of the variables (including nereids and exoedicerotids), but not in any particular pattern.

The intertidal locations were primarily composed of sand, which was mostly fine-to-medium grade (0.15 – 0.3 mm). The percentages of fine-to-medium sand grains were similar among locations. At the scale of sites, however, there were significant differences within all locations except of sites at the Penrhyn Inner location. The factors that may have caused the differences among locations in the benthic communities are not known.

2.4.3 Supplementary Subtidal Investigations

2.4.3.1 Aims

As part of the studies being done for SPC, The Ecology Lab also collected sediment samples from intertidal areas for analysis of infauna. This study was done to improve the description of the existing environment for the EIS and contribute to the baseline of information for monitoring the effects of the proposed port expansion. A full report on the study is presented in Appendix 1 and summary of the methods, results and conclusions is provided in the next two sections.

2.4.3.2 Methods

Subtidal benthic habitats were sampled at six locations, two each at Penrhyn Estuary, Towra Bay and Quibray Bay on 24 and 28 October 2002 (Figure 2.6). Quibray Bay and Towra Point were selected to provide a spatial comparison for assemblages in Penrhyn Estuary and they may be used as a reference for future monitoring. At each location, three sites were sampled at similar depths. Six replicate van Veen grab samples were collected at each site for examining the benthic invertebrate community. In addition, two grab samples were collected at each site for analysing the distribution of particle grain size. Whilst the use of divers to collect cores has been common in Botany Bay (e.g. Morrisey et al. 1992a) and is probably a more rigorous approach, the presence of contaminated sediments meant that the use of a grab was safer for field staff. The laboratory and statistical methods used for the subtidal samples of benthic invertebrates and particle grain sizes were the similar as those used for the intertidal samples.

Figure 2.6. Sampling locations for subtidal benthos sampled in Botany Bay on 24 and 28 October, 2002. Each orange dot represents a location where three sites were sampled, each with five replicate grabs.

2.4.3.2 Results and Conclusions

The dominant taxon found in the subtidal benthos was the family of polychaete worms, Capitellidae. Although care was taken to control for factors known to influence benthic communities such as water depth, exposure to currents and tides and composition of sediments, differences were detected between locations. The subtidal locations all significantly differed from each other with respect to their assemblages of benthic invertebrates. The assemblages of invertebrates were distinctive in Penrhyn Outer, Penrhyn Inner and Quibray Outer compared to Towra Inner, Towra Outer and Quibray Inner, which were all quite similar to each other. The exception to this was that Quibray Outer showed substantial overlap in its assemblages with Quibray Inner. The dissimilarity of the locations was not strongly attributed to any taxon in particular; rather the contribution of each taxon was moderately even. Differences between sites were significant, but less apparent than differences among locations.

The subtidal locations significantly differed in their numbers of taxa and polychaete taxa, such that Penrhyn Outer contained significantly more than the other locations. The locations differed significantly in their numbers of individuals and polychaete individuals, with Penrhyn Inner containing significantly more than the other locations. These differences in the number of individuals at Penrhyn Inner were mostly due to polychaete worms (Nereididae) and round worms (Nematoda). Small-scale differences (i.e. among sites within locations) occurred at many different levels, but not in any particular pattern.

The subtidal locations were primarily composed of sand, which was mostly very fine-to-medium grade. However, some sites contained substantial amounts of mud. With the exception of Quibray Outer, all locations showed statistically significant differences in their percentages of fine-to-medium sand grains, but the magnitude of these differences was relatively small.

2.5 Hard Substrata

Originally, most of the northern shoreline of Botany Bay consisted of sandy substratum. This has changed dramatically with the construction of training walls at Cooks River and with the development of the airport and Port Botany. According to MPR (1998) there was a shoreline length of 24.9 km of rocky habitat within Botany Bay at the time of that report, made up of 6.1 km of natural shoreline and 18.8 km of artificial surface (e.g. breakwaters, revetments). This represents 28% of the total shoreline of Botany Bay (all habitats). Within the northern portion of Botany Bay (which approximates the present study area) there was a shoreline length of 2.6 km, all of which was artificial (MPR 1998; see also Figure 2.1). The amount of artificial habitat would increase substantially as a result of the proposed port expansion (considered in Chapter 5).

There have been numerous studies of the ecology of rocky intertidal and subtidal habitats at the entrance to Botany Bay, especially at Cape Banks, but there has been far less work done within the bay. Work done previously within the study area has been limited mostly to compilation of species lists and qualitative comparisons. As part of the investigations for the Parallel Runway, The Ecology Lab did limited sampling of intertidal and subtidal flora and fauna of the original North-South Runway (The Ecology Lab 1990; Kinhill 1990; 1991). As part of the earlier investigations for the proposed port expansion, MPR (1998) recorded species of algae, invertebrates and fish occurring around the Parallel Runway, structures at

Penrhyn Estuary and at the south western end of the Patrick Terminal at Brotherson Dock. The Ecology Lab (2001) recorded algae, invertebrates and fish occurring around the derelict groyne at Penrhyn Estuary.

The findings of these studies indicated that organisms associated with artificial surfaces are similar to those found on natural rocky reef, but the structure of assemblages is often quite different (see also Barros 2001). Intertidally, the artificial shores of the study area were dominated by oysters (*Saccostrea glomerata*) and several species of barnacles in the mid levels, whilst habitats were often dominated by tubeworms (*Galeolaria caespitosa*) and solitary ascidians known as cunjevoi (*Pyura stolonifera*). Subtidally, habitats were often dominated by macroalgae, including kelp (*Ecklonia radiata*) and sargassum (*Sargassum* spp.). MPR (1998) stated that the diversity of intertidal biota was generally small at sites on the Parallel Runway and attributed this to the type of surface, which was a vertical wall with very few crevices that could be used by invertebrates, such as gastropods, for shelter. It was also suggested that diversity tended to increase along the runway wall with distance away from the entrance to the Mill Stream.

A range of reef-dwelling fishes was often seen associated with the artificial surfaces. Burchmore *et al.* (1985) surveyed fish associated with the outer (eastern) shore of the revetment wall at Molineux Point and at a natural reef at Inscription Point, on the southern headland of Botany Bay, over a two year period. They reported a large range of reef fishes representing major groups, such as the wrasses (Labridae), blackfish (Girellidae), mado and sweep (Scorpididae), yellowtail and trevally (Carangidae) and bream (Sparidae). Many of the fish sheltered in the deep caves created by the dolus concrete blocks used to construct the revetment. Lincoln Smith *et al.* (1993) surveyed reef fish at artificial breakwaters and natural reefs in Jervis Bay, on the NSW south coast. They recorded similar taxa associated with the breakwaters, but generally there were more species present on the artificial habitat than natural reef at any one time. As with the invertebrates, MPR (1998) reported very few fish associated with the vertical walls of the Parallel Runway; again, this was probably due to the lack of topographic complexity associated with this structure.

Apart from the assemblages that occur on artificial reefs, it has been shown that the presence of reef structure can influence ecological patterns and processes in adjacent soft sediments (e.g. Randall 1965; Barros *et al.* 2001). Randall (1965) recorded effects of herbivorous reef fish on adjacent seagrass beds in the Caribbean. Barros *et al.* (2001) studied benthic invertebrates at increasing distances from four reef structures (3 natural reefs and 1 artificial breakwater) in Botany Bay. All the locations were to the east of the present study area. They found that sediments tended to be coarser near the reef structures and that benthic assemblages were generally different closer to the reefs. More species occurred closer to reefs, but some groups, such as syllid polychaetes, were more abundant further away. The results of these studies suggest that when a new artificial structure is placed within a habitat dominated by soft sediments, that the structure will have a significant influence on the surrounding sediments.

2.6 Seagrasses and Algae

Four species of seagrass have been identified in Botany Bay: *Posidonia australis* (mainly along the southern shoreline), *Zostera capricorni* and *Halophila ovalis* along both the northern and southern shore and some *Halophila decipiens* in the deeper water (1-3 m) of Quibray Bay. Algal species reported from the northern shoreline include *Sargassum* spp. and *Ecklonia* spp.

(Watford and Williams, 1998). In addition, there are numerous species of algae within the bay and around its entrance. These include:

- Algae, such as kelp (*Ecklonia radiata*) and sargassum (*Sargassum* spp.) that attach to hard surfaces including reefs, breakwaters, pylons, marker buoys and even shells.
- Algae that attach to other algae or seagrasses (commonly called epiphytes).
- Algae that are either unattached or weakly attached to the seabed, forms known as drift algae. Examples include *Gracilaria*, *Colpomenia*, *Chaetomorpha*, *Enteromorpha* and *Polysiphonia*.
- Algae that attach to soft or hard sediments and includes an important group of introduced species - *Caulerpa fillifomis*, *Caulerpa scapelliformis* and *Caulerpa taxifolia*.

Seagrasses are flowering plants that have evolved to live under the water. Like terrestrial grasses, they are attached to the substratum by a root system (known as rhizomes). They obtain nutrients from either the sediment or the water column. Algae are usually attached by holdfasts to solid objects. The holdfasts are an organ of attachment and nutrients are obtained from the water column. Both seagrasses and algae photosynthesise and their depth distribution is limited by light availability. Similarly, if they become shaded (e.g. by a wharf structure) or the water medium become less clear (e.g. by an increase in suspended sediments, or by blooms of phytoplankton) then growth can be inhibited or the plants die.

2.6.1 Ecological Functions

Seagrasses are considered ecologically important components of the aquatic environment and in NSW they are given a high conservation value (Smith and Pollard 1999). They fulfil a range of ecological functions, and they are considered to:

- be highly productive (King 1981; Zieman and Wetzel 1980),
- stabilise sediments (Keough and Jenkins 1995),
- provide food and habitat for fish and macroinvertebrates (Zieman and Wetzel 1980; Bell and Westoby 1987),
- provide "nursery habitats" for recreationally and commercially important species (Pollard 1984; Bell and Pollard 1989; Larkum *et al*. 1989; Smith and Pollard 1999)

Faunal assemblages associated with seagrass may be influenced by:

- supply of larvae (Worthington *et al.* 1992; Jenkins *et al*. 1997),
- physical conditions (temperature, salinity, turbidity, oxygen concentration, water movement)(Howard *et al.* 1989; Keough and Jenkins 1995),
- morphology of seagrass (Bell *et al*. 1987; Sogard *et al.* 1987; Worthington *et al.* 1992; Edgar and Robinson 1992),
- availability of food (Edgar 1992),
- predation (Ryer 1988),
- proximity to other habitats (Harris *et al.* 1995; Sogard 1989).

Several studies have focused on the importance of the seagrass beds in the vicinity of the proposed port expansion, particularly the beds of seagrass offshore from Foreshore Beach. The following is a summary of this work, extracted from The Ecology Lab (2001).

Bell and Westoby (1986a, 1986b) manipulated shoot density within the northern *Zostera* beds and found that macrofauna tended to inhabit dense seagrass in preference to sparse, and that predation was not the proximate cause of the pattern. An alternative model, the preference of individuals for dense seagrass, was proposed to explain the patterns of species abundance (Bell and Westoby 1986b). At the larger scale between seagrass beds, structure of the seagrass canopy (density of shoots) did not explain variations in faunal assemblages in natural beds (Bell and Westoby 1986c; Worthington *et al.* 1992a) or artificial beds (Bell *et al.* 1987; Worthington *et al.* 1991). Other environmental factors (e.g. sediment grain size, area of seagrass bed and distance from the ocean) did not explain differences in abundances of dominant small fish and macroinvertebrates (Bell and Westoby 1986c). An alternative model in which stochastic settlement of fish and invertebrates to seagrass beds, followed by post-settlement movement within beds to favoured microhabitats was proposed to explain differences in faunal abundances at the larger scale (Bell and Westoby 1986c; Worthington *et al,* 1991, 1992). Sogard (1989) and Jenkins *et al.* (1998) modified the model to include post-settlement movement of some species between seagrass beds.

Other studies examined the effects of hydrological processes on fish distribution and abundance. Kingsford and Suthers (1994; 1996) found larvae of several species of fish (e.g. members of the Sparidae (bream), Girellidae (luderick), Monacanthidae (leatherjackets) in waters adjacent to tidal fronts near the entrance to the bay. They proposed that larvae were transported along topographically stable fronts on flood tides to areas favouring retention of larvae (recruitment 'hot spots'). Although there are no direct studies on the supply of larvae to seagrasses adjacent to Foreshore Beach, Steffe and Pease (1988) found a greater proportion of larvae derived from pelagic eggs (i.e. spawned in the ocean) adjacent to the entrance compared to other sites in the estuary. In a separate study Steffe (1991) reported a greater abundance of larvae of commercially valuable species at a site near the entrance, adjacent to the port, relative to another site in the main tidal stream near Towra Point. It was proposed that reduced water flow at the Port site (caused by eddies) enhanced the survival of larvae and resulted in greater numbers of juveniles settling in habitats adjacent to Foreshore Beach (Steffe, 1991).

2.6.2 Fauna of Seagrass Beds

2.6.2.1 Fish and Mobile Invertebrates

In a comprehensive study spanning a variety of habitats and sampling over two years, the State Pollution Control Commission (1981a, b) used a variety of techniques including rotenone, beam trawls and seine nets to sample fish and mobile invertebrates. Abundance and biomass of fish were highest in *Zostera* habitats compared to other habitats sampled (mangroves, shallow sand, shallow mud, deep soft and hard substrata). Species richness in *Zostera* habitat may be partially due to large numbers of temporary residents, in particular the juveniles of a variety of species that later move to other habitats. Nineteen commercial fish species were recorded in the study, of which 16 were juveniles of either temporary residents or transient species. Most of the commercial species collected spawn in the ocean, with the major species such as sand whiting (*Sillago ciliata*), yellowfin bream (*Acanthopagrus australis*), tarwhine (*Rhabdosargus sarba*), luderick (*Girella tricuspidata*), sand mullet (*Myxus* *elongatus*) and yellow-finned leatherjacket (*Meuschenia trachylepis*) believed to spawn in inshore habitats close to the entrance of the bay. The large numbers of juveniles of these commercial species caught within the *Zostera* habitat in this and subsequent studies reinforce the view that seagrass habitats serve important functions as nursery grounds. McNeill *et al.* (1992) found that five species of commercially important fish consistently recruited in greater numbers over a period of 2.5 years to a bed of *Zostera* in Botany Bay (i.e. the Pilot Harbour, a constructed site reclaimed during the construction of the parallel runway) compared to other beds within Botany Bay and to *Zostera* beds in three other estuaries. The authors suggested that oceanographic features such as eddies may have caused large numbers of recruits to arrive and be retained at the site, and that the quality of the seagrass could not explain the consistently higher larval recruitment to the site. They emphasized that identifying such recruitment "hotspots" was an important element in the management of the commercial fisheries of the bay (McNeill *et al*. 1992).

The SPCC study (1981a, b) also collected 15 species of non-commercial fish, 6 of which were temporary residents or transient species. These included four species of gobies (Gobiidae), four species of pipefish (Syngnathidae), three species of toadfish (Tetraodontidae), perchlet (*Velambassis jacksoniensis*), six-lined trumpeter (*Pelates sexlineatus*) and fortesque (*Centropogon australis*).

Juvenile king prawns (*Penaeus plebejus*) and juvenile blue swimmer crabs (*Portunus pelagicus*) recruited predominately to *Zostera* habitats, while mud crabs (*Scylla serrata*) were widespread throughout the bay (SPCC 1981a, b). Three-spot crabs (*Portunus sanguinolentus*), coral crabs (*Charybdis feriata*), octopus (*Octopus* spp.), cuttlefish and two species of squid (*Sepiolenthis australis* and *Notodarus gouldii*) were also collected in low densities (SPCC, 1981). Wading birds have been identified as significant predators on shrimps (*Macrobrachium intermedium*) in *Heterozostera* beds in Western Port Bay, Victoria (Lowe 1982). The interactions of wading birds with seagrass fauna will be considered in more detail in another specialist report.

The majority of studies on the fish and macroinvertebrates associated with seagrass beds were done prior to the reclamation of seagrass habitats and construction of the parallel runway. In a post-construction study Gillanders (1997) found that blue groper recruited to northern *Zostera* beds in pulses each year with peak abundance in September and October. Smith (1999) found higher abundances of juvenile tarwhine (*Rhabdosargus sarba*) and trumpeter (*Pelates sexlineatus*) in northern *Zostera* beds compared to sites near Kurnell. Upston (2001) investigated the spatial and temporal patterns in the abundance of juvenile fish and mobile macroinvertebrates associated with the seagrass beds off Foreshore Beach and three other locations. She found a greater abundance of three species (tarwhine, blue groper and eastern king prawns) in the beds off Foreshore Beach compared to other locations on the southern side of the bay, and a lesser abundance of palaemonid prawns (*Macrobrachium intermedium*). Overall, the seagrass beds off Foreshore Beach had fewer species than other sites but had consistently greater abundances of commercially important species than in other seagrass beds sampled (Upston 2001).

2.6.2.2 Other Seagrass Fauna

A wide range of mainly invertebrate animals are found in seagrass habitats and are grouped according to where they live. Animals living within the sediment and among the matts formed by the rhizomes of seagrass plants are termed infauna, and include invertebrate forms that are specialised for a burrowing life style. Infauna include burrowing crustaceans such as snapping shrimp and small, burrow-dwelling fish such as gobies. Invertebrates living at the surface of the sediment are called epifauna and include crawling forms such as gastropod snails, mobile worms and small crustaceans. The term epiphyte is used to describe the plants and animals that live directly attached to the seagrass blades. This group include single-celled plants such as diatoms, small filamentous algae, plant-like animals such as bryozoans that can cover the seagrass blades by reproducing like plants, small, sessile worms that filter food from the water, and a group of small, specialised grazers and predators such as caprellid amphipods and isopods (crustaceans).

Compared to studies of fish in seagrass beds, relatively few studies have focused on the benthic fauna of seagrasses, and no studies have examined the benthos of seagrass beds in the vicinity of the proposed port expansion (Howard *et al*. 1989). Much of the information available for benthic community structure is derived from comparative studies of *Zostera* and *Posidonia* beds (Young and Wadley 1979; Young 1981; Middleton *et al*. 1984), and many of the studies have been done in smaller coastal lagoons and estuaries, some of which are intermittently closed to the ocean (Powis and Robinson 1980; Hutchings 1982; Fitzharding 1983).

While a large number of environmental factors have been shown to influence the distribution of seagrass faunal assemblages, seagrass faunas rarely associate with a particular seagrass species but rather to a restricted set of local environmental parameters (Howard *et al*. 1989).

In Careel Bay Hutchings and Recher (1974) found that *Zostera* beds supported more diverse infauna than *Posidonia*, both in terms of overall abundance and numbers of species. Other studies demonstrated that infauna from sediment in seagrass beds are more diverse and abundant compared to unvegetated sediments (Harris 1977; Stoner 1980). Within seagrass beds polychaete worms dominated the infaunal community (51%), followed by crustaceans (33%) including amphipods, snapping shrimp, prawns and crabs and bivalve and gastropod molluscs (11%) (Poiner 1980). The polychaete worm component of infaunal communities in *Zostera* beds in NSW have some common features: they usually include at least one nereid species and one capitellid species (Hutchings 1982). Fourteen species of polychaetes were recorded from *Posidonia* beds near Towra Point (Australian Littoral Society, 1978).

Hutchings and Recher (1974) reported strong seasonality in the infauna of *Zostera* and *Posidonia* beds with maximum number of species in June and a maximum abundance in November in *Zostera*. Mass settlement of the polychaetes *Scoloplos* sp. (a burrowing species) and *Ceratonereis erythraeensis (*now *C. aequisetis)* (a mobile, presumably omnivorous species) and the bivalve *Macoma deltoidalis* was recorded between June and November (Hutchings and Recher 1974).

2.6.3 Effects of Developments on Seagrass Beds in Botany Bay

As a result of the long history of development in Botany Bay, there is considerable information on the distribution and characteristics of seagrass and algal beds in Botany Bay. An extensive summary of development events within Botany Bay was prepared by McGuinness (1988). The most recent summary of historical changes in seagrass beds can be found in Watford and Williams (1998) and is summarised below.

Of the four species of seagrass reported from Botany Bay: *Posidonia australis* occurs along the southern shoreline, *Zostera capricorni* and *Halophila ovalis* occur along both the northern and southern shore and some *Halophila decipiens* is found in deeper waters of Quibray Bay (West *et al*., 1989). Larkum and West (1990) used aerial photographs to document changes in the distribution of seagrasses in the bay between 1942 and 1985. Among their observations were the following:

- *Posidonia* had disappeared from the northern shore,
- Over the study period a single, large bed of *P. australis* was fragmented and decreased in cover by 58% on the southern shore.
- The area covered by *Zostera* fluctuated on the northern and southern shores,
- In many places *Zostera* became established where *Posidonia* declined.

Some changes were natural, attributed to grazing by sea urchins (*Heliocidaris erythrogramma*), but most losses were due to residential and industrial development, relocation of the mouth of the Cooks River and dredging to allow passage of large ships to and from the oil refinery, which affected seagrasses by altering wave climate.

Further historical developments and activities that affected seagrass distribution included:

- The construction of rocky groynes along Silver Beach to control erosion,
- Further extension of the airport runway,
- Dredging designed to direct wave energy away from the port the revetment wall,
- An increase in wave energy, height and direction at Towra Point and Dolls Point due to changes in bottom topography from dredging,
- Construction of the Parallel Runway from November 1992 to October 1994, causing a direct loss of 13.73 ha of *Zostera* on the northern shoreline (The Ecology Lab, 1994), and an increase in cover of *Posidonia* in deeper water at Towra Point (The Ecology Lab, 1995).

Comparative data from 1942 to 1995 showed fluctuations in the total area of seagrass beds in Botany Bay through time. The maximum cover recorded was 761 ha (Larkum and West, 1990), which may be an underestimate due to differences in analytical techniques and source material (aerial photographs). The minimum cover in the study period was 340 ha and was recorded from aerial photos taken from 1977 to 1979 and field checked in 1981 (West *et al.*, 1985).

2.6.4 Changes in Seagrasses Along the Northern Shoreline

Estimates of changes in the area of seagrasses within the study area over the past 70 years are summarised as follow:

- Larkum and West (1990) estimated the area of seagrasses in Botany Bay from aerial photographs (APs) from 1930 to 1985. Seagrasses were generally not discriminated into species and the quality of the photographs was variable. A summary of results for the northern side of Botany Bay (i.e. from the Cooks River to Frenchmans Bay and hence extending beyond the core study are for this investigation) is as follows:
  - 1930 – area: 35 ha, based on poor quality black and white APs
  - 1942 – area: 93 ha, based on fair quality black and white APs
  - 1951 – area: 22 ha, based on good quality black and white APs

    - 1961 – area: 49 ha, based on good quality black and white APs
    - 1975 (or 1977; unclear from paper) – area 16 ha, based on good quality black and white APs
    - 1985 – area: 27 ha, based on excellent quality colour APs.

    These estimates are likely to have been affected to some extent by the quality of the APs, but they do suggest considerable variability in the amount of seagrass on the northern side of the bay. Some of the differences from 1930 to 1961 are likely to reflect natural variability, given that the major airport and port infrastructure affecting the bay had not been built at that time.

    Analysis of sediment cores also indicated that beds of *Posidonia* had existed at several locations on the northern side of the bay (Larkum and West 1990).

- West *et al.* (1985) recorded a total of 27 ha based on aerial photos from 1977 to 1979 and field checked in 1981.
- Prior to the construction of the parallel runway MPR (1992) and The Ecology Lab (1994) estimated that the northern shoreline between the existing runway and westward off Foreshore Beach consisted of 32 ha of *Zostera*, distributed in a large (22.2 ha) bed and in patches totalling 8.2 ha adjacent to deeper water.
- MPR (1994b) estimated that the construction of the Parallel Runway led to a loss of 15.7 ha of *Zostera* with 16.4 ha remaining, distributed in a shallow bed (7.4 ha) and in patches totalling 9 ha adjacent to the main bed.
- Seagrasses were transplanted in April 1995, August 1995 and April 1997 from donor sites off Lady Robinsons Beach to newly created shallow habitats between the two runways and to the east of the parallel runway (Gibbs 2001). Various methods of transplants were trialled, but overall the long-term survival of the transplanted plugs was poor. Natural recolonisation of the new habitats was also monitored and while rates of colonisation overall were low, there was greater long term survival of naturally colonised plants (dominated by *Halophila ovalis*) along the eastern side of the parallel runway compared to between the runways (Gibbs, 2001). While the created habitat was considered to be suitable for seagrass growth in terms of depth and light availability, it was concluded that wave action between the runways were a deterrent to growth, while the habitat along the parallel runway was too far away from the nearest seagrass bed (off Foreshore Beach) to sustain the processes of natural recolonisation.
- Watford and Williams (1998) indicated that the total area between the parallel runway and Brotherson Dock contain 7.5 ha of *Zostera*, based on aerial photos from 1995. This figure represented 1.2% of all seagrasses present in the whole of Botany Bay at that time and 21.5% of all seagrass in the northern sections of the bay. Their figures appear to represent only the main *Zostera* bed, and do not include seagrass in Penrhyn Estuary. Watford and Williams note the absence of *Posidonia* in this northern region in 1995 (Watford and Williams, 1998).
- Based on aerial photos from April 1996 and field checking in Oct 1997, MPR (1998) estimated that the total seagrass areas off Foreshore Beach was 16 ha, comprised mainly of *Zostera capricorni* , with a small clump of *Posidonia australis* at the Mill

Stream end of the main bed. Their figures included the sparse patches of *Zostera* located along the eastern side of the parallel runway (MPR 1977c), comprised of naturally colonised *Zostera* and *Halophila* and transplanted *Zostera*. They estimated that the actual net decrease in *Zostera* in the main bed was 1.7 ha (0.4 ha of dense seagrass and 1.3 ha of *Zostera* in patches). Their figures included the seagrass in Penrhyn Estuary.

The apparently large discrepancy between the latter two estimates based on aerial photos taken only one year apart is likely to be due to differences in methodology used. Seagrass in Penrhyn Estuary were not included in the Williams and Watford (1998) study, neither were the patches of *Zostera* and *Halophila* seagrass located along the edge of the Parallel Runway. However, together these could account for no more than 1.3 ha of the seagrass total area (1 ha for patches along the Parallel Runway and 0.3 ha for seagrass in Penrhyn Estuary (Marine Pollution Research, 1998).

MPR used a planimeter to determine the boundaries of seagrass beds, a method likely to result in less accurate results than the digital methodology based on raster images used by Watford and Williams (1998). In addition, the field checking undertaken by the latter was done two years after the aerial photos were taken, introducing another potential source of error. Hence we consider that while the estimate of the total area of 7.5 ha (Watford and Williams, 1998) may slightly underestimate the seagrass area present along the northern shoreline in 1995-69. The estimate of 16 ha by MPR (1998) is considered likely to be an over estimate.

As part of the present study The Ecology Lab mapped seagrasses along the northern shoreline based on aerial photos taken in 2001 and field checked in April and July 2002. The section below details the methodology and results of this mapping.

2.6.5 Supplementary Mapping of Seagrasses

2.6.5.1 Aims

The review of information in the previous section indicates that the area of seagrass within the northern parts of Botany Bay has changed significantly during the last 60 years or so. Moreover, there is some doubt regarding the present distribution and area of seagrass. The main aim of the supplementary mapping of seagrasses was to provide estimates of area that could be compared against the footprint of the proposed port expansion. This would allow the calculation of the area of seagrass likely to be affected and assist in developing plans for habitat compensation, if required.

A secondary aim of the mapping was to use ground truthing to confirm which species of seagrass were present and to measure the depth distribution of seagrasses. This would also assist with habitat compensation.

2.6.5.2 Methods

2.6.5.2.1 Resources

Resources used to determine the extent of seagrass in the vicinity of the proposed Port Expansion included:

- Aerial Photographs dated April, 2001, supplied to The Ecology Lab by SPC.
- Ground truthing using DGPS position fixing system undertaken on 1 - 2/05/02 and 09/07/02.
- NSW Fisheries digital maps of estuarine vegetation in Botany Bay. These were based on aerial photographs at 1:16,000 taken in 24/04/1995. These data may have been ground truthed in 1998. The data were extracted from Watford and R. J. Williams (1998) and were provided by Mr Gregory West (NSW Fisheries) in a format suitable for import to MapInfo. All maps and aerial photographs were analysed and areas calculated using MapInfo Professional Version 7 (Figure 2.7).
- Maps of seagrasses produced for this study were compared to that presented in MP R (1998). No digital version of these data were available for detailed comparison of calculated seagrass areas.

2.6.5.2.2 Measuring Area of Seagrasses

Digitized aerial photographs were examined and polygons drawn by computer around areas interpreted to contain seagrass. The boundaries of seagrass beds and patches were adjusted to accommodate the findings of ground truthing. In the case of seagrass beds near Penrhyn Estuary mapping was done from ground truthing data only, as the aerial photograph in that area was too dark to be interpreted reliably. This area also contained patches of marine algae which were difficult to distinguish from seagrass due to the dark quality of the aerial photograph. All patches of seagrass along the eastern side of the Parallel Runway, to the landward edge of the main bed adjacent to Foreshore Road, and patches to the seaward side of the main bed were drawn and their size recorded. Due to time constraints, the seagrass beds in the shallow area along the eastern edge of the parallel runway were not ground truthed.

The size of each area was calculated by the MapInfo program and recorded on a spreadsheet. The main bed was traced, as were patches that appeared to be "holes" (i.e. gaps interpreted to be bare sediment) in the main seagrass bed. The cumulative area of the latter was subtracted from the former to determine the net area of the main seagrass bed.

The smallest area for which we could efficiently detect seagrass was approximately 3.5 m^2. In the section of the study area between the main seagrass bed and the beach, it was possible to detect patches as small as 3.5 m^2 because the patches were easily distinguished from the light-coloured sand background. However, for the section of the study area to the seaward side of the main bed, it was far more difficult to resolve patches of seagrass from the darker background of the deeper water. Similarly, "holes" in the main seagrass bed (areas without seagrass) were more difficult to resolve due to the darker background colour caused by deeper water and, as we discovered from ground truthing (see below), the presence of detritus on the sea bed. In these sections of the study area, it is estimated that the smallest discernible patch or "hole" area was approximately 8 to 10 m^2.

To determine the area of seagrass that would be reclaimed under the proposed Port Expansion, a drawing of the proposed Port Expansion supplied by Sydney Ports was over - laid on the mapped seagrass. Areas of seagrass lying within and at the margins of the proposed structures were calculated.

2.6.5.2.3 Ground Truthing

Ground truthing was done on 1 and 2 April, 2002 and 9 July 2002 by wading and snorkeling from a boat. The edges of beds and patches of seagrass were established by divers. Critical points were marked with buoys and co-ordinates for each point were taken from the boat using a Differential Global Positioning System (DGPS). Data were recorded in AMG 94 (GDA Zone 56) datum. A description of each point, including type of vegetation present, density and depth (measured using a weighted tape measure) were recorded with each datum. Data for water depth were later corrected to Lowest Astronomical Tides (LAT, which approximates Indian Spring Low Water, ISLW, and is at about -0.92 Australian Height Datum, AHD) using charts based on tides at Fort Dennison, Sydney.

Data recorded on the DGPS unit were downloaded to an Excel spreadsheet and the data format was modified for input into MapInfo. Field observation points were overlaid on the registered aerial photo, including identifying labels. This information was used to adjust the boundaries of the seagrass bed that were drawn based on interpretation of the aerial photograph.

2.6.5.2.4 Comparison to Previous Mapping

The seagrass map resulting from the combination of aerial photograph interpretation and ground truthing in April and July 2002 was compared to marine vegetation maps produced by NSW Fisheries based on 1995 aerial photographs and to a hard copy of the seagrass map in MPR (1998) which was based on aerial photographs taken in 1996. The NSW Fisheries map layer containing records for *Zostera capricorni* was examined. This layer also included records of three patches of algae (kelp) located off a derelict groyne and jetty to the northwest of Penrhyn Estuary.

2.6.5.3 Results and Conclusions

2.6.5.3.1 Areas of Seagrass Recorded

The area of seagrass determined from the combined interpretations of aerial photographs and ground truthing is shown in Figure 2.8 and quantified in Table 2.1. The area of seagrass calculated on the basis of Figure 2.8 does not include the area of kelp located around the derelict groyne and jetty, which was identified by NSW Fisheries and verified by the field observations. It includes seagrasses growing in the shallow habitat along the eastern edge of the parallel runway.

The total area of seagrass beds in the study was calculated to be 96,715 m^2 (i.e. 9.67 ha, Table 2.1). Most of this area consisted of the seagrass *Zostera capricorni* that varied from sparse to dense coverage. In patches near the boat ramp off Penrhyn Road *Zostera* was found in mixed beds containing the seagrass *Halophila ovalis* and the algae *Caulerpa filiformis* and *Caulerpa taxifolia*. Apart from qualitative observations of leaf density (e.g. "sparse" or "dense") morphological characteristics of the seagrasses and associated biota were not quantified. However, observations made while ground truthing within the area proposed for port expansion and surrounding beds within the core study area suggest that the beds were often quite sparse and did not contain large numbers of fish.

The largest contiguous area of seagrass is contained in the "Main Bed" off Foreshore Beach, accounting for 7.5 ha out of the total 9.6 ha (Table 2.1). In many places in this large bed,

Figure 2.7. Areas of seagrass as mapped by NSW Fisheries (1998). Mapping based on aerial photos taken in 1995. Overlaid on aerial photo taken April, 2001.

Halophila ovalis was also observed. Small patches of *Posidonia australis* were noted along the seaward edge of the bed, which were not reported by Watford and Williams (1998). Finally, in several places small growths of *Caulerpa taxifolia* were observed.

Table 2.1. Areas of seagrass beds along the Botany Foreshore and in Penrhyn Estuary. Areas of seagrass calculated were calculated from aerial photographs, while the presence of seagrass habitat was checked by ground truthing (April and July 2002).

Seagrass Bed	Description	Net Area (m^2)
Main Bed off Foreshore Beach	*Zostera capricorni*. Varies from dense to sparse. Mixed in places with *Halophila* and *Caulerpa filiformis*. Two patches of *Posidonia* along seaward edge.	75,350
Patch south east of Main Bed	*Zostera capricorni*	611
Patch further south east of Main Bed	*Zostera capricorni*	1,230
Patch at south end of Main Bed	*Zostera capricorni*	3,487
Patches at north west end of Main Bed	Sparse *Zostera*	3,186
Patches between the Main Bed and Foreshore beach	*Zostera*	3,278
Patches seaward of the Main Bed	*Zostera*	3,272
Sum of four patches near point of land opposite boat ramp	*Zostera.* Some kelp in area (not included in area measured).	874
Sum of four patches off beach near mouth of Penrhyn Estuary	*Zostera*	1,046
Sum of four patches near boat ramp off Penrhyn Road	Sparse to moderately dense *Zostera* mixed with *Halophila* and *Caulerpa filiformis.*	559
Sum of *Zostera and Halophila* along eastern side of parallel runway	Very sparse beds of *Zostera* and *Halophila* including naturally colonised and transplanted plants	3,824
Sum of all seagrass beds in study area, m^2		**96,715**
Sum of all seagrass beds in study area, ha		**9.67**

The remaining seagrasses measured were distributed in discreet beds located along the eastern side of the parallel runway, to the deeper, seaward side of the main bed and between the main bed and the Foreshore Beach (Figure 2.8). In general, the patches located seaward of the main bed were fewer in number, larger in extent and appeared to contain more dense seagrasses than those located between the main bed and Foreshore Beach.

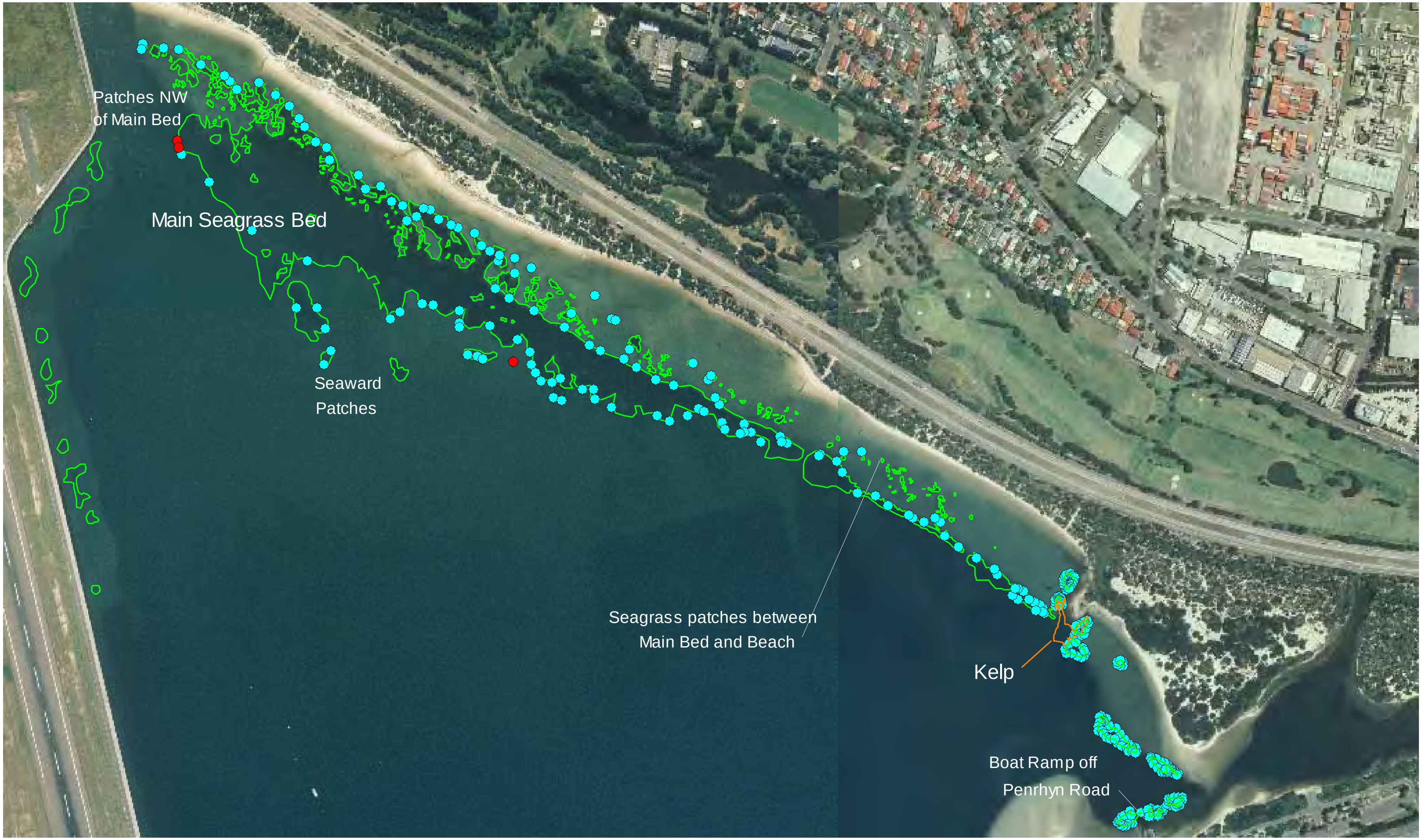


Figure 2.8. Areas of seagrass off Foreshore Beach as derived from field DGPS readings (blue dots), by The Ecology Lab, May 2002. Points overlaid on aerial photo taken April, 2001. Red dots indicate presence of *Posidonia australis*.

2.6.5.3.2 Comparison to Previous Data

The area of *Zostera* calculated from the map supplied by NSW Fisheries was 74,752 m^2 (i.e. 7.48 ha) (Watford and Williams, 1998) (Figure 2.7), compared to 9.67 ha calculated in the current study. This estimate made by NSW Fisheries was based on interpretation of aerial photographs taken in 1995. When the data supplied by NSW Fisheries is overlaid on the aerial photo on which the current mapping is based (April 2001) (Figure 2.7), some reasons for the difference in the two estimates became apparent. The average width of the main bed appears wider in the 2001 aerial photo, and the patches between the main bed and Foreshore Beach appear to be larger than in 1995. The patches seaward of the main bed appear more fragmented and smaller in size than in the 2001 photo. In summary, the differences between the estimate made from 1995 photos and that made in the present study could be due to a number of factors. Some of factors that could influence the real or apparent changes in seagrass area include:

- Actual differences in the extent of seagrass cover. Seagrass are known to vary naturally on the scale of seasons, years and decades. Factors influencing natural changes in seagrass beds include seasonal growth patterns, storm frequency, large-scale water circulation, temperature patterns and changes in local nutrient inputs from terrestrial sources such as those entering Botany Bay via Penrhyn Estuary. For example, MPR (1998) reported "a more or less continuous and narrow strip of *Zostera* seagrass bed lining the mouth of Penrhyn Estuary, west of the entrance shoal (i.e., between the old and new boat ramps). This study found no seagrass inside the entrance shoal and outside the entrance shoal the *Zostera* occurred in a series of distinct patches on either side of the entrance shoal, consisting of sparse to moderately dense *Zostera* mixed in some patches with *Halophila* and *Caulerpa filiformis*.
- Quality of aerial photographs. As evident in the present study, reliable interpretation of the extent of seagrass beds depends greatly on the quality of the aerial photographs analysed. In the present study, the presence of all beds in the vicinity of the mouth of Penrhyn Estuary were determined by field inspection, as that section of the aerial photograph was too dark for accurate interpretation. In addition, the scale at which the aerial photographs were taken may influence the ability to resolve areas of seagrass.
- Coverage of the entire study area. The data provided by NSW Fisheries did not include the sparse seagrasses growing along the eastern edge of the Parallel Runway. While these were estimated to occupy approximately 1 ha (Marine Pollution Research 1998), the present mapping detected a total area of 0.2 ha (Table 2.6.1). This result is consistent with the findings of Gibbs (2001), which indicated very low rates of natural recolonisation in this habitat and very poor survival of transplanted seagrass plugs monitored until mid 2000 (Gibbs, 2001).

NSW Fisheries found no *Posidonia australis* in the study area. MPR (1998) reported "A small clump" of this species toward the Mill Stream end of the main bed. The current study found a larger patch of *Posidonia* along the seaward edge of the main bed at the Mill Stream end of the main bed and another patch on the seaward edge near the middle of the main bed, in an area that would be dredged under the port expansion proposal (Figure 2.8).

2.6.5.3.3 Depth Distribution of Seagrasses

In order to gain a more detailed view of the depth distribution of seagrasses within the study area the depths recorded for the boundaries of seagrass beds and patches during ground truthing were sorted according to the location and type of seagrass bed. Depth at each observation point was recorded on the DGPS unit and was determined by using a weighted tape measure with gradations of 5 mm. The time of each observation was recorded. In the laboratory the tidal height at the time of each observation was determined using a tidal chart. LAT (m) was determined by subtracting the charted tidal height from the measured water depth. Table 2.2 presents the depths according to location and type of bed or patch, and give the maximum, minimum and mean depths for each category.

The overall range of water depth in which seagrasses were present was 0.72 m to -2.65 m LAT. The patches of seagrass located between the main bed and the beach had the shallowest average depth (0.13 ± 0.04 m LAT), while those along the outer edge of the main bed were the deepest (average -1.48 ± 0.07 m LAT). The average depth of the inner edge of the main bed off Foreshore Beach ranged from 0.72 m LAT to -1.22 m LAT, with an average value over 60 measurements of -0.33 ± 0.07 m LAT. The average depth of the seaward edge of the main bed ranged from -0.9 to -2.65 m LAT, with an average over 42 measurements of - 1.48 m LAT. Seagrass beds near Penrhyn Estuary had an average depth of -0.48 ±- 0.06 m LAT, but had a wide depth range from -2.26 m (deepest) to 0.51 m LAT (shallowest). The depth of the seagrass patch along the parallel runway was not recorded during ground truthing.

2.6.5.3.4 Seagrass Depth: Comparison to Previous Data

MPR (1998) did not detail the field methodology used to determine depth of seagrass beds and patches, the number of measurements made for each category of seagrass, or the method used to derive LAT. They reported that the inner edge of the main bed was "delineated approximately by the -0.2 m LAT contour". This value is slightly shallower than our average value of -0.33 m LAT. MPR (1998) reported that the outer edge of the main bed was delineated more or less by the 1 m LAT contour, but that near the Mill Stream end a portion of the main widened out to the 2.0 m LAT contour. This assumes that 1 m LAT in the MPR (1998) report actually refers to -1 m LAT. Our finding of a mean depth of -1.48 m is within the range estimated by Marine Pollution Research; however the deepest depth we recorded was -2.65 m LAT. Similarly, our mean value of 0.13 ± 0.04 m LAT for the depth of seagrass patches between the main bed and Foreshore Beach falls within the range of the estimate by MPR (1998) of "about the 0.0 m LAT contour to the edge of the dense bed". This study's estimate of the range of depth of the seagrass near the mouth of Penrhyn Estuary falls within the range of the 0.0 m to 2.0 m LAT (equal to -2.0 m LAT) contours reported by MPR, but, as noted previously, these beds appear to have decreased in extent significantly since the mapping done by MPR (1998).

The Ecology Lab (2001) inspected sections of the main bed off Foreshore Beach as part of a Review of Environmental Factors for the Sydney Airport Corporation for maintenance dredging at the mouth of the Mill Stream. Field inspections were done on 15/3/2001 and depths were recorded using a diver's depth gauge and later corrected to AHD. For the purpose of this comparison AHD depths recorded by The Ecology Lab (2001) were translated to LAT. The number of readings taken to establish to depth of seagrass beds was not recorded, but was small compared to the number taken for the present study. The

Ecology Lab (2001) recorded a depth of -0.68 m LAT for the inner edge of the main bed, close to the mean of -0.33 m LAT recorded for the present study. The depth of the outer edge of the main bed was -2.08 m LAT, again close to the mean value of -1.48 m LAT derived from our 42 measurements. The Ecology Lab (2001) recorded the deepest depth observed for any seagrass as -3.18 m LAT, whereas this study recorded a maximum depth of -2.65 m LAT. Given the differences in the equipment used, the intensity of the field effort, the results of the present study are in good agreement with those of The Ecology Lab (2001).

Table 2.2. Depths of seagrass beds (LAT, m) derived from ground truthing data, 2/5/02 and 9/7/02.

Parameter	Patches between Main Bed and beach	Inner edge of Main Bed	Outer (seaward) edge of Main Bed
Deepest	-0.33	-1.22	-2.65
Shallowest	0.43	0.72	-0.9
Number of measurements	25	60	42
Mean	0.13	-0.33	-1.48
SE	0.04	0.07	0.07

Parameter	Seaward patches	Patches near shore at SE end of Main Bed	Patches near Penrhyn Estuary
Deepest	-1.55	-0.38	-2.26
Shallowest	-1	0.45	0.51
Number of measurements	9	28	137
Mean	-1.30	0.17	-0.48
SE	0.06	0.04	0.06

2.6.5.3.5 Calculation of Area of Reclaimed Seagrass

The area of seagrass that would be removed as a result of the proposal was calculated to be 3.95 ha (Table 2.3), based on construction plans supplied by Sydney Ports (Drawing: B-Pd-P-048A). In the western section of the study area, there would be beach replenishment and construction of a breakwater at the mouth of the Mill Stream. It is understood that sand deposed in this area would be placed on the existing beach and should not, therefore, directly smother any seagrasses. In the eastern section of the study area, approximately half of the main seagrass bed would be removed during dredging and construction, along with all patches between the main bed and Foreshore Beach.

Table 2.3. Area of seagrass to be resumed based on plans supplied by Sydney Ports. Areas of seagrass based on aerial photograph dated April 2001, verified by DGPS and ground truthing (April and July 2002).

Seagrass Bed	Description	Location with respect to proposed Port Expansion	Area (m^2)
Patches at north west end of Main Bed	*Zostera capricorni*. Varies from dense to sparse.	Northern section of reclaimed area near Mill Stream. Seagrass patches affected by sand infill between main seagrass bed and beach	2,636.95
Western section of Main Bed off Foreshore Beach and patches between Main Bed and beach	Sparse to moderately dense *Zostera*.	Breakwall, boatramp, smaller breakwall, reclaimed area near carpark and sand-filled area north of boat ramp	3,511.14
Part of Main Bed and patches affected by reclamation for boat ramp	Moderate to dense *Zostera*.	Near boat ramp, to be reclaimed	3,450.16
Eastern sections of Main Bed, patches south-east of Main Bed and patches between Main Bed and beach	Moderate to dense *Zostera*. Patch of *Posidonia* near corner of port island structure.	Area of dredging and foreshore enhancement works	27,376.87
Beds at mouth of Penrhyn Estuary	Sparse to moderately dense *Zostera,* some *Halophila* and *Caulerpa*.	Area to be come new seagrass habitat	2,478.13
Sum of seagrass area to be resumed, m^2			**39,453.25**
Sum of seagrass area to be resumed, ha			**3.95**

The section of the core study area between the proposed port terminal and Foreshore Beach has been identified as potential seagrass habitat, following alteration to the bottom profile to produce a water depth suitable for seagrass growth. This area represents at least 4 ha available for potential seagrass habitat (Figure 2.9).

2.7 Saltmarshes and Mangroves

Mangroves and saltmarshes once occurred at several places on the northern shoreline of Botany Bay, particularly at the entrance to the Mill Stream. With the diversion of the Mill Stream during construction of the Parallel Runway, these mangroves and saltmarshes were removed. Currently, mangroves and saltmarshes are most common at Towra Point and Woolooware Bay. There are also several large stands of mangroves and some small saltmarsh areas within Cooks River. Within the core study area, saltmarsh and mangrove habitats are confined to Penrhyn Estuary. They do not occur within the Mill Stream as its estuarine portion has been formed into a channel with vertical walls. Anecdotal and

Figure 2.9. Areas of seagrass derived from interpretation of aerial photographs taken in April 2001 and verified with ground truthing. Areas of mainly *Zostera* are enclosed in green lines; red dots indicate presence of *Posidonia australis*.

pictorial evidence suggests that the mangroves within Penrhyn Estuary are currently expanding into areas of saltmarsh (ARS, 2003). Further details on the habitats of Penrhyn Estuary are presented in Section 2.9.

2.8 Freshwater Ecosystems

The main flow of surface freshwater into Botany Bay is via the Georges River, of which the Woronora River is a large tributary. Most of the catchment of these rivers is well to the west of the proposed port expansion and would not be affected by the proposal. Similarly, Cooks River and its current entrance is to the west of the airport runways and effectively isolated from the proposed development. The current entrance to the Mill Stream is to the north east of the Parallel Runway. The mouth of the stream is subject to sedimentation from sand transported westwards along Foreshore Beach (The Ecology Lab 2001). The "estuarine" portion of the Mill Stream is effectively restricted to the main stream channel; further upstream a barrage greatly inhibits penetration of saline water. This barrage also prevents movement of most biota, with the likely exception of eels (F: Anguillidae). The study of biota of the Mill Stream is not within the scope-of-works for The Ecology Lab – issues here relate to effects of the proposed port expansion on ground water, discussed in Chapter 5.

The two creeks that flow into Penrhyn Estuary (Floodvale Drain and Springvale Drain) have freshwater habitat in their upper catchments. These drains are highly disturbed by surrounding development and contaminants from industry and their value as freshwater habitat is considered to be very limited.

2.9 Supplementary Site Inspections

During the investigations for this study, several sites were inspected with the objective of providing a description of the presence and current distribution of habitats. These inspections helped to focus on particular, site-related issues for the environmental impact assessment. All but one of the areas were within or very close to the core study area (Figure 2.2). The exception was within Quibray Bay, which was considered to have some of the ecological features that might develop in Penrhyn Estuary as a result of the proposed port expansion. In particular, there is a small lagoon of similar size to Penrhyn Estuary that occurs on the eastern side of Quibray Bay, between Bonna Point and Captain Cook Drive.

Each site was visited in a boat by staff of The Ecology Lab between April and June, 2002. Notes were made of aquatic habitats present. Water quality was measured at some locations using a Yeo-Kal 611 water quality meter to provide a snapshot indication of variables at some locations. Variables included dissolved oxygen, pH, salinity, temperature, turbidity and redox potential. Replicate readings were taken at the surface and, where deep enough at the seabed and one or two intermediate depths. Differences in indicators of water quality between different depths can indicate the occurrence of "stratification" due to differences in water density (caused by differences in water temperature and/or salinity). Stratification can be significant in aquatic ecology, as it can affect ecological processes, such as oxygen consumption, mobilisation of contaminants or nutrients; and physiological processes, such as tolerance by biota to reduced oxygen. It is recognised that the water quality indicators can vary greatly over small scales in space and time. The data collected here are not intended as a thorough description of conditions within the areas sampled, but as a snapshot to supplement the more detailed descriptions of water quality prepared by other specialists (Lawson and Treloar 2003, Volume 2).

Water quality was sampled on 9 May and 14 June 2002. On both occasions conditions were dry with winds from the south west to northwest. On 9 May sampling was done on a falling tide, with the low tide at 12:22 PM (0.46 m). On 14 June sampling was done during a rising tide, with a high tide at 10:47 AM (1.24 m) and as the tide began to ebb. A more detailed and comprehensive assessment of water quality was compiled by Lawson and Treloar (2003) as part of their engagement for the proposed port expansion. Water quality results were compared to the ranges of default trigger values recommended in the ANZECC Water Quality Guidelines (2000).

Water depths were measured with a hand-held depth meter, accurate to about 0.1 m and positions were recorded for sampling stations using a hand-held GPS (Garmin 12 channel). The additional site inspections are described as follows.

2.9.1 Penrhyn Estuary

2.9.1.1 Background Information

Penrhyn Estuary is a small waterway of approximately 30 ha to the west of Brotherson Dock. It receives freshwater from two drains (Springvale and Floodvale) that run through Banksmeadow and Matraville and opens out to northern expanse of Botany Bay. Penrhyn Estuary was not originally a natural feature of Botany Bay, it was constructed during the process of reclamation of the Botany Foreshore from 1975-1978.

Since its construction, the estuary has been filling with sediments, a proportion of which is contaminated (AGC Woodward- Clyde 1990). Previous studies have revealed that contaminants drain into the estuary from ground water and adjoining drains from a nearby industrial area (AGC Woodward- Clyde 1990). This is considered further in Chapter 4. Sediments in the estuary range from sand to mud and silts further up the estuary.

Seagrass beds (*Zostera capricorni*) occur at the mouth of the estuary and extend into the estuary parallel to the shoreline. MPR (1998) reported that there were approximately 0.3 ha of *Zostera* within Penrhyn Estuary. Seagrass mapping for the current study, however, recorded only half that amount, and none within the inner estuary (Table 2.1). Areas of seagrass have recently been found surrounding the two rocky structures in the estuary, the boat ramp on the eastern side of the estuary and derelict groin structure on the western side of the estuary. In addition to seagrasses, there are also saltmarshes, mangroves and algal beds within the estuary.

As far as is known, there have been no quantitative surveys of fish living in Penrhyn Estuary, although a survey of contamination in fishes yielded 14 fourteen species of commercially important fish in the estuary (The Ecology Lab 1995).

Penrhyn Estuary was visited by staff of the Ecology Lab on several occasions from April to June, 2002. General characteristics and ecologically important habitats of the estuary were recorded along with prominent species. Seagrass habitats and vegetation were mapped onto aerial photographs. Water quality was measured on 9 May 2002.

2.9.1.2 Description of the Estuary

2.9.1.2.1 Inner Estuary

The inner estuary comprises a small, shallow lagoon (~ 1.4 m deep) with the two drains (Floodvale and Springvale) flowing into the estuary from industrial and residential catchments from Banksmeadow and Matraville and forming two distinct deltas (Figure 2.10). Sand and mud flats covered most of the shore and in some areas there were oysters on the mud flats. Sediments in the creeks were fine and black with a distinct sulphurous smell. There is a derelict boat ramp on the eastern side of the inner estuary, with some rock rubble at the base of the ramp.

Towards the back of Springvale Drain, there were areas of mangroves ranging from juvenile seedlings to mature mangrove trees (Figure 2.11). The salt marsh plants *Sarcornia* and *Suaeda* were also abundant on the shore fringing the more stable rush grasses (*Juncus kraussii* and *Isolepis nodosus*). Further up the shore Bitou bush (*Chrysanthemoides monilifera*) and *Acacia* spp. became more prevalent as well as coastal she-oak (*Casuarina equisetifolia*). No seagrasses were recorded in the inner estuary.

2.9.1.2.2 Outer Estuary

The inner and outer estuaries are connected via a channel which has reduced in width in recent years due to accretion of sand from Botany Bay. Although apparently stable at present, in the absence of the proposed expansion the channel could close up from time to time. The outer estuary comprises four habitats (Figure 2.10):

- Sand and silty intertidal flats on both sides of the estuary
- Unvegetated subtidal habitats ranging from sand in the shallows to dark, silty mud in deeper areas, down to at least -3 m LAT.
- Vegetated subtidal habitats, including seagrasses and some algae, occurring from about the low tide mark around the edges of the estuary (see below).
- Artificial substratum, including the new boat ramp and jetty on the eastern side of the outer estuary, and a derelict rock groyne and wharf pilings at the western end of the estuary.

2.9.1.2.3 Water Quality

Water quality was measured at 4 sites with the estuary – in the inner lagoon, adjacent to the existing boat ramp and at the mouths of Springvale and Floodvale drains (Figure 2.12, Table 2.4). Measurements were taken at the surface and bottom at the first two sites, but only at the surface (due to shallow conditions) at the drains. pH ranged from 7.48 to 8.46, which is within the ANZECC (2000) guideline. Temperature ranged from 19.61 to 21.09 and showed little sign of thermal stratification between the surface and bottom samples.

The water entering the estuary from the drains was a similar temperature to rest of the estuary, but was far less saline. There was also reduced salinity in the surface samples from the inner estuary and the boat ramp compared to the bottom samples from the same sites, indicating saline stratification. Turbidity was highly variable within the estuary (Table 2.4). The bottom samples tended to have low turbidity and were within ANZECC (2000)

Figure 2.10. Areas of seagrass in Penrhyn Estuary as derived from field DGPS readings, May 2002, overlaid on aerial photo taken in April 2001.

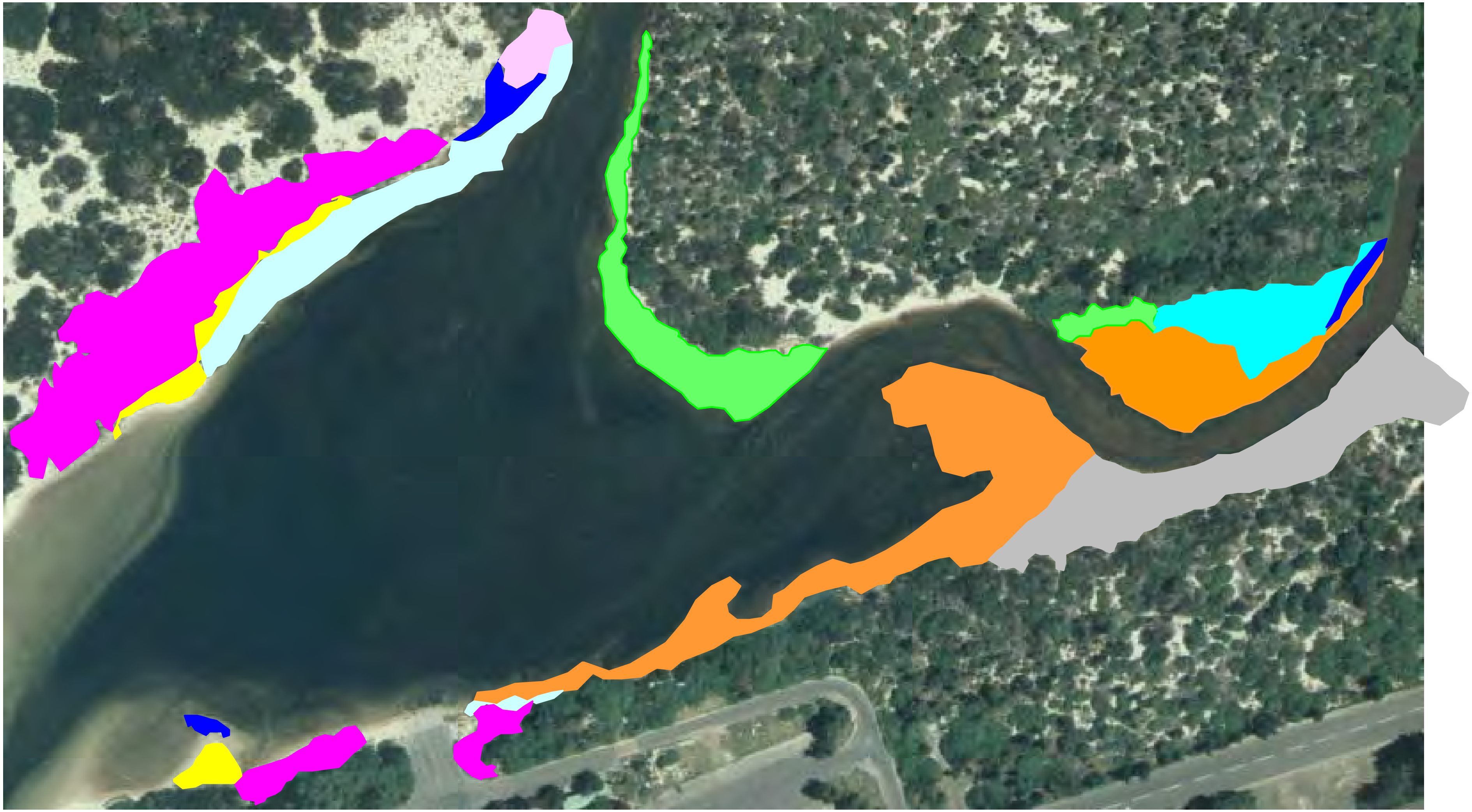


Figure 2.11. Penrhyn Estuary major vegetation and habitats. Based on ground truthing by The Ecology Lab on 9 May 2002. Overlaid on aerial photo taken 2001.

Mangroves | Mixed salt marsh | Beach Spinifex | Bitou bush & Acacias | *Sarcornia* spp.

Mixed salt marsh & rush grass | *Suaeda australis* | Kikuyu grass | *Suaeda australis & Juncus krausii* guidelines. The turbidity of water from Springvale Drain was extremely high (> 10 x the upper value of the guideline) while turbidity from Floodvale Drain was about twice the upper vale of the guideline. Other surface samples were also relatively high. Dissolved oxygen levels were low at all sampling positions and lowest from the Springvale Drain samples.

The water quality data from Penrhyn Estuary indicates some conditions "typical" of an estuary, in that there is a mixing zone of saline and fresh water. The dry conditions at the time suggest that the water in the drains may have come from local industrial sources, which may also reflect the high turbidity of water from Springvale Drain. The relatively low DO levels are difficult to interpret, as similar levels (apart from those in Springvale Drain) were recorded outside the estuary (see below).

Table 2.4. Geographical position (WGS 84; decimal degrees), replicate, Rep, sample depth, D, pH, temperature, T (C), salinity, S (ppt), turbidity, Tu (NTU) & dissolved oxygen, DO (%) in Penrhyn Estuary, 9/5/02. S=surface, B=bottom. Bracketed values are ANZECC (2000) guidelines, where available.

Location & Site Code	Latitude	Longitude	Rep	Depth Position	Depth (m)	pH (7.0 - 8.5)	T	S	Tu (0.5 - 10)	DO (80 - 110)
Inner Estuary (13)	33.963633	151.209817	1	S	<0.3	7.73	20.11	19.75	26.1	42
			2	S	<0.3	7.80	19.82	26.30	15.3	42
			1	B	0.8	8.31	19.81	34.25	8.7	45
			2	B	1.3	8.35	19.89	35.30	5.2	43
Boat ramp (14)	33.964017	151.209850	1	S	<0.3	7.98	21.09	23.17	15.1	55
			2	S	<0.3	8.25	20.35	29.95	12.0	53
			1	B	1.5	8.46	19.91	35.31	4.6	43
			2	B	2.7	8.46	19.61	35.51	3.1	47
Springvale Drain (15)	33.964000	151.211000	1	S	<0.3	7.59	19.73	2.93	131.8	26
			2	S	<0.3	7.58	19.61	2.97	124.8	22
Floodvale Drain (16)	33.963000	151.210000	1	S	<0.3	7.52	20.16	4.28	19.8	47
			2	S	<0.3	7.48	20.26	4.01	20.2	45

2.9.2 Mill Stream

The Mill Stream connects a large series of wetlands and ponds extending from Centennial Park to the Mill Pond (Lawson and Treloar 2003). The stream itself has been diverted as part of the development of the airport (Kinhill 1990) and has little resemblance to its original form. A weir several hundred metres upstream of the mouth forms a barrier to tidal exchange, hence the estuarine portion is extremely limited. The presence of sewer overflows leads to very poor water quality during periods of rainfall (The Ecology Lab 2001, Lawson and Treloar 2003).

The estuarine portion of the Mill Stream is completely channelised and contains soft sediments. There are no seagrasses, mangroves or saltmarshes within the channel, although

Figure 2.12. Positions of sampling sites (red dots) for water quality in Botany Bay sampled 5 May and 14 June, 2002 by The Ecology Lab Pty Ltd. Refer to Table 2.7.1 for names of sampling sites.

seagrasses occur offshore from its mouth. A sand bar has accumulated at the mouth of the stream due to movement of sediment westwards along Foreshore Beach. The presence of a weir upstream within the channel prevents movement of many species between Botany Bay and the wetlands further upstream. In essence, this habitat has been highly altered and is of limited ecological value.

Water quality was measured along a gradient extending from Botany Bay, beyond the mouth of the stream, to the mouth of the stream and extending up towards the weir (Figure 2.12, Table 2.5).

Table 2.5. Geographical position (WGS 84; decimal degrees), replicate, Rep, sample depth, pH, temperature, T (C), salinity (ppt), turbidity, Tu (NTU) & dissolved oxygen, DO (%) in and outside the Mill Stream Channel, 9/5/02. S=surface, B=bottom. Bracketed values are ANZECC (2000) guidelines.

Location & Site Code	Latitude	Longitude	Rep	Depth Position	Depth (m)	pH (7.0 - 8.5)	T	S	Tu (0.5 - 10)	DO (80 - 110)
Outer mouth (1)	33.956017	151.193900	1	S	<0.3	8.44	19.45	35.44	6.1	49
			2	S	<0.3	8.43	19.56	34.80	5.2	45
			1	B	1.8	8.46	19.65	36.09	5.9	49
			2	B	2.6	8.41	19.60	36.05	6.2	48
Mouth (2)	33.954733	151.192717	1	S	<0.3	8.34	19.71	34.09	4.8	37
			2	S	<0.3	8.32	19.37	32.02	4.7	36
			1	B	2.2	8.51	19.71	36.13	4.5	46
			2	B	1.0	8.48	19.98	35.89	3.8	39
Mid channel (3)	33.952967	151.191867	1	S	<0.3	8.24	19.67	31.78	4.0	28
			2	S	<0.3	8.10	19.77	30.59	4.3	21
			1	B	1.6	8.49	19.19	35.95	3.3	38
			2	B	1.5	8.50	20.01	35.95	3.0	39
Mid channel (4)	33.950717	151.190267	1	S	<0.3	8.09	20.26	32.50	5.5	18
			2	S	<0.3	8.08	20.72	32.49	6.7	17
			1	B	1.7	8.48	20.05	35.81	5.1	37
			2	B	1.5	8.48	20.12	35.79	10.7	38
Downstream of weir (5)	33.948150	151.188950	1	S	<0.3	7.99	20.26	29.70	9.9	14
			2	S	<0.3	7.90	20.55	27.20	7.1	20
			1	B	1.4	8.34	20.35	35.70	9.2	20
			2	B	1.2	8.35	20.42	35.69	11.2	17

Surface and bottom samples were taken at all sites. pH values were all within ANZECC (2000) guidelines. Temperature showed a slight increase with distance up the stream, possibly due to restricted exchange with bay waters. Salinity declined from the mouth of the Mill Steam towards the weir at the water surface, reflecting input of freshwater from the Mill Stream, but these values were much more saline than recorded at Floodvale and Springvale Drains (see above). Turbidity values were generally low, but two values within the channel slightly exceeded the guideline. DO levels were all below the guideline and tended to be smallest in the upper parts of the channel.

2.9.3 Foreshore Beach

Foreshore Beach is a major focus of the assessment process and has been described above in relation to seagrasses, algae and unvegetated sediments. The beach is currently eroding towards its eastern end, with sand migrating to the west and depositing at the mouth of the Mill Stream (The Ecology Lab 2001, Lawson and Treloar 2003). The beach is also significant in that groundwater from the surrounding aquifer enters the bay via the beach. There are no mangroves growing along the beach, presumably because it is relatively exposed to bay conditions (e.g. wind waves generated from the south east to south west).

Water quality was sampled at 3 sites along the beach (Figure 2.12, Table 2.6). Results for all sites were similar and were also similar to the "Outer Mouth" location described for the Mill Stream (previous section). There was no evidence of stratification between surface and bottom samples, which is not surprising given that the sites were quite shallow and exposed, suggesting the water would be well-mixed. Values for pH and turbidity were within ANZECC (2000) guidelines; DO was below the guideline.

Table 2.6. Geographical position (WGS 84; decimal degrees), replicate, Rep, sample depth, pH, temperature, T (C), salinity (ppt), turbidity, Tu (NTU) & dissolved oxygen, DO (%) off Foreshore Beach, 9/5/02. S=surface, B=bottom. Bracketed values are ANZECC (2000) guidelines.

Location & Site Code	Latitude	Longitude	Rep	Depth Position	Depth (m)	pH (7.0 - 8.5)	T	S	Tu (0.5 - 10)	DO (80 - 110)
West (6)	33.955950	151.194433	1	S	<0.3	8.47	19.72	35.24	5.5	46
			2	S	<0.3	8.44	19.76	35.21	5.1	45
			1	B	1.6	8.53	19.77	36.07	3.8	51
			2	B	1.3	8.51	19.85	36.07	3.6	49
Middle (7)	33.958350	151.198917	1	S	<0.3	8.46	19.44	35.69	5.5	51
			2	S	<0.3	8.47	19.39	35.55	5.2	52
			1	B	1.0	8.47	19.47	35.66	4.2	51
			2	B	1.0	8.48	19.38	35.53	3.6	52
East (8)	33.961467	151.204883	1	S	<0.3	8.47	19.59	35.83	5.3	56
			2	S	<0.3	8.47	19.53	35.81	4.6	56
			1	B	2.9	8.47	19.53	35.77	3.4	55
			2	B	2	8.48	19.52	35.81	3.1	56

2.9.4 Previous Dredged Areas and "High Spots" Within the Navigation Channel

As part of the investigations for the project, divers inspected a deep hole previously dredged to provide fill for the Parallel Runway and which would be reclaimed as part of the proposed port expansion. This hole is denoted as Area F, shown in Figure 2.4. Divers swam from the upper edge of the hole to a depth of about 10 m, as measured by a dive computer. The sediments around the drop-off to the hole were similar to the surrounding sediments, being sandy, pale-coloured and containing numerous burrows of invertebrates. The slope of the hole was very steep and was sandy, with numerous burrows to about 6 m depth. The sediments then appeared to become darker and finer, although numerous burrows were still evident. At about 10 m there was a narrow terrace with fine sediments. At this depth the water clarity was very poor and the inspection was discontinued.

Water quality was measured within areas dredged on 9 May and 14 June 2002 (Table 2.7). At this time samples were taken from the shallower parts of the Dredged Area F, and near

Table 2.7. Geographical position (WGS 84; decimal degrees), replicate, Rep, sample depth, pH, temperature, T (C), salinity (ppt), turbidity, Tu (NTU) & dissolved oxygen, DO (%) within former dredge basin (denoted "Basin") and around Brotherson Dock, May and June 2002. S=surface, M = Mid-depth, B=bottom. Bracketed values are ANZECC (2000) guidelines. ND = no data due to malfunctioning probe.

9 May 2002

Location & Site Code	Latitude	Longitude	Rep	Depth Position	Depth (m)	pH (7.0 – 8.5)	T	S	Tu (0.5 – 10)	DO (80 – 110)
Basin – NW corner (9)	33.960800	151.202983	1	S	<0.3	8.50	19.46	35.83	5.5	55
			2	S	<0.3	8.48	19.60	35.81	4.1	54
			1	M	3.7	8.50	19.34	35.77	3.8	54
			2	M	3.6	8.46	19.67	35.83	3.8	54
			1	B	7.3	8.47	19.92	36.06	5.7	49
			2	B	7.4	8.46	19.92	36.09	4.6	49
Basin – NE corner (10)	33.961800	151.203433	1	S	<0.3	8.48	19.68	35.83	4.9	55
			2	S	<0.3	8.46	19.67	35.86	5.1	55
			1	M	3.5	8.48	19.68	35.83	3.7	54
			2	M	3.6	8.46	19.67	35.83	3.8	54
			1	B	7.0	8.46	19.93	36.07	4.4	50
			2	B	6.8	8.43	19.92	36.09	3.7	49
Dock – outer mouth (11)	33.970933	151.207417	1	S	<0.3	8.46	19.73	35.82	5.4	57
			2	S	<0.3	8.45	19.72	35.85	2.2	57
			1	M	9.0	8.43	19.49	35.97	2.4	53
			2	M	10.9	8.45	19.36	36.08	1.5	52
			1	B	18.7	8.42	19.29	36.07	2.9	52
			2	B	18.9	8.44	19.23	36.11	2.1	52
Dock – mouth (12)	33.970633	151.209767	1	S	<0.3	8.45	19.63	35.82	4.0	57
			2	S	<0.3	8.44	19.59	35.69	4.0	57
			1	M	8.5	8.45	19.51	35.91	1.9	53
			2	M	8.9	8.45	19.50	35.83	1.8	54
			1	B	16.5	8.45	19.16	36.13	3.4	51
			2	B	17.9	8.45	19.18	36.15	4.0	51

…Continued

Table 2.7, Continued

14 June, 2002

Location & Site Code	Latitude	Longitude	Rep	Depth Position	Depth (m)	pH (7.0 – 8.5)	T	S	Tu (0.5 – 10)	DO (80 – 110)
Basin - centre (17)	33.964056	151.203273	1	S	0.0	8.45	16.16	38.39	ND	ND
			2	S	0.0	8.44	16.18	38.35	ND	ND
			1	M	4.0	8.44	16.17	38.29	ND	ND
			2	M	4.0	8.44	16.20	38.30	ND	ND
			1	D	8.0	8.44	16.13	38.28	ND	ND
			2	D	8.1	8.44	16.17	38.32	ND	ND
Basin - centre (18)	33.964966	151.203221	1	S	0.0	8.43	16.18	38.40	ND	ND
			2	S	0.0	8.43	16.21	38.39	ND	ND
			1	M	7.0	8.44	16.20	38.33	ND	ND
			2	M	7.9	8.45	16.15	38.36	ND	ND
			1	D	14.1	8.44	16.18	38.34	ND	ND
			2	D	15.8	8.44	16.22	38.34	ND	ND
Basin - SE (19)	33.966350	151.202922	1	S	0.0	8.43	16.20	38.39	ND	ND
			2	S	0.0	8.42	16.18	38.40	ND	ND
			1	M	9.0	8.42	16.12	38.30	ND	ND
			2	M	9.3	8.42	16.16	38.35	ND	ND
			1	D	19.0	8.42	16.20	38.34	ND	ND
			2	D	19.0	8.42	15.79	38.36	ND	ND
Basin - SE (20)	33.967166	151.202580	1	S	0.0	8.42	16.21	38.28	ND	ND
			2	S	0.0	8.41	16.17	38.24	ND	ND
			1	M	9.3	8.42	16.09	38.39	ND	ND
			2	M	9.3	8.42	16.17	38.33	ND	ND
			1	D	19.2	8.42	15.84	38.34	ND	ND
			2	D	19.4	8.41	16.17	38.39	ND	ND
Basin - SE (21)	33.968040	151.203178	1	S	0.0	8.39	15.02	37.91	ND	ND
			2	S	0.0	8.39	15.73	38.14	ND	ND
			1	M	9.3	8.39	16.15	38.34	ND	ND
			2	M	9.3	8.39	16.18	38.34	ND	ND
			1	D	19.5	8.38	15.12	38.37	ND	ND
			2	D	19.4	8.39	16.15	38.37	ND	ND

and at the entrance to Brotherson Dock. pH ranged from 8.42 to 8.50 and was therefore within or just at the upper boundary of the ANZECC (2000) guideline. Turbidity was also within the guidelines, whilst DO was relatively low as reported for other locations.

Temperature within the dredged basin was slightly greater at the bottom than the surface, whilst around Brotherson Dock it was slightly less at the bottom than the surface, possibly reflecting different patterns of circulation within these areas (or the different maximum depths sampled). Salinity was slightly greater at the bottom than the surface at all sites.

Sampling on 14 June focused on the deeper parts of the dredge basin (Table 2.7). At this time, temperature was about 3 C less than the samples taken in May and salinity was also greater, but neither indicator suggested any water stratification. pH values were all within the ANZECC (2000) guidelines. Unfortunately, the probe sensors for turbidity and DO malfunctioned and no data were available.

Under the proposed port expansion, part of the dredging would involve removing up to 400,000 m^3 of sediments from several "high spots" within the existing navigation channel and turning basin for the port (Figure 2.13). SPC requested that The Ecology Lab inspect some of these sites to determine if there were any particular features of ecological significance present (e.g. beds of seagrass or macroalgae). Divers from The Ecology Lab inspected several sites in the main shipping areas on 9 July 2002 to describe seabed characteristics. Water visibility ranged from about 6 m to 3 m. Water quality was not measured at this time. Dives were completed at Sites G, H, F and D as identified by SPC mapping and including the area known as the "Nob", which is south west of Molineux Point.

The seabed at the Nob consisted of fine, clean sand with extensive animal burrows. No seagrass, algal growth or reef was observed. Divers swam down the edge of the Nob from the top of the high spot, at a depth of about 8 m towards the north west to a depth of about 19 m. The slope was relatively steep and sediments became finer and darker with increasing depth. At a depth of about 10 to 12 m there was a small terrace which had accumulated a small amount of kelp (*Ecklonia radiata*). This kelp was not attached to the seabed, but had probably drifted into the bay from rocky reefs.

The other sites inspected were deeper, at about 12 to 13 m. The seabed consisted of fine sediments with animal burrows. No seagrass, algae (attached or drifting) or reef was observed.

2.9.5 Quibray Bay

Quibray Bay, which occurs within the Towra Point Aquatic Reserve (thus is outside the core study area), contains very extensive areas of mangroves and seagrasses, particularly *Posidonia australis*. To the north of the bay mangroves encroached on inactive oyster leases. The sediment on the bottom of the bay was generally heavily bioturbated (i.e. had invertebrate burrows and mounds) and covered in brown filamentous algae.

A small lagoon similar in size to the inner lagoon at Penrhyn Estuary was visited at the eastern end of Quibray Bay. Water depth in the lagoon ranged from about 0.4 to 1.7 m. At the mouth of the inlet to the lagoon there were extensive dense mangroves and the floor of the inlet contained beds of *Zostera capricorni* amongst mangrove pneumatophores. Large beds of *Posidonia australis* were found on the north side of the lagoon and in the mouth of the entrance to the lagoon. The *Posidonia* appeared dense and healthy with a small amount of epiphyte cover.

Water quality was determined at 5 sites in and around the lagoon entrance (Figure 2.12, Table 2.8). As noted above, no data on turbidity or DO could be obtained due to sensor

Figure 2.13. High spots in bottom profile requiring maintenance dredging as part of the port expansion proposal. Source: Sydney Ports Corporation.

problems. pH was within ANZECC (2000) guidelines. Temperature showed little evidence of stratification but was considerably less than the surface waters of Botany Bay on the same day (see Table 2.7). Given the shallow, sheltered nature of Quibray Bay, it is likely that water temperatures were affected by atmospheric conditions. Salinity was slightly less than in Botany Bay and showed no stratification.

Table 2.8. Geographical position (WGS 84; decimal degrees), replicate, Rep, sample depth, pH, temperature, T (C) and salinity (ppt) in eastern lagoon within Quibray Bay, 14/6/02. S=surface, B=bottom. Bracketed values are ANZECC (2000) guidelines.

Location & Site Code	Latitude	Longitude	Rep	Depth Position	Depth (m)	pH (7.0 - 8.5)	T	S
Lagoon - Middle (22)	34.018427	151.195078	1	S	<0.3	8.22	13.00	36.97
			2	S	<0.3	8.23	13.00	37.03
			1	B	1.0	8.29	13.14	37.14
			2	B	0.9	8.33	13.14	37.03
Lagoon - Inner (23)	34.018111	151.196298	1	S	<0.3	8.25	12.95	37.19
			2	S	<0.3	8.24	12.81	37.27
			1	B	1.7	8.31	12.99	37.04
			2	B	1.9	8.33	12.86	37.00
Lagoon - Outer (24)	34.017578	151.191923	1	S	<0.3	8.28	13.75	37.30
			2	S	<0.3	8.32	13.74	37.48
			1	B	0.7	8.30	13.73	37.52
			2	B	0.9	8.31	13.65	37.51
Lagoon - Middle (25)	34.017394	151.195338	1	S	<0.3	8.14	12.81	37.47
			2	S	<0.3	8.16	12.80	31.15
			1	B	0.9	8.22	12.88	37.03
			2	B	0.8	8.23	12.81	37.07
Lagoon - Outer (26)	34.016475	151.194751	1	S	<0.3	8.25	12.97	37.19
			2	S	<0.3	8.21	12.99	37.28
			1	B	0.7	8.24	12.96	37.32
			2	B	0.7	8.22	12.98	37.19

2.10 Aquatic Habitats of Significance Elsewhere in Botany Bay

Past capital works within Botany Bay have had effects well beyond the boundary of the works themselves, thus it is important to assess the impacts of the proposed port expansion beyond the core study area identified in Section 2.1.

Of particular interest is the Towra Point Aquatic Reserve, a marine protected area of 333 ha situated on the southern shores of Botany Bay. This reserve was declared in 1987 and contains most of the seagrasses, mangroves and saltmarshes within Botany Bay. It also contains refuge areas from fishing. Previous programs of capital works, especially dredging the entrance to Botany Bay, have affected patterns of erosion at Towra Point, leading to the loss of seagrass beds. Studies done by NSW Fisheries (Watford and Williams 1998) and The Ecology Lab (1995) have provided a good basis for understanding future changes in seagrass distribution at Towra Point Aquatic Reserve. In addition, it is understood that beach nourishment and other remediation works are proposed for Towra Point to control coastal processes. An important part of the assessment of the proposed port expansion will be to assess impacts of construction on Towra Point and the works proposed there.

To the east of Towra Point Aquatic Reserve is Silver Beach. This location also supports large areas of seagrasses, including *Zostera*, *Halophila* and *Posidonia.* In particular, there are large beds of *Posidonia* towards the western end of the beach. Another area of interest that needs to be considered is Lady Robinsons Beach, which has been subject to erosion/accretion as a result of previous capital works. Finally, the Cape Banks Scientific Marine Research Area is highly valued as an area of scientific research into intertidal and subtidal reef ecology.

2.11 Habitat Linkages

Whilst the various habitats have been considered separately within this Chapter, it is essential to recognise that many biophysical processes are linked among two or more habitats. The most obvious linkage of habitats is via the water column, as discussed in Section 2.2. It is also clear that some habitats can influence the flora and fauna in adjacent habitats. The examples discussed above were the influence of seagrass beds on adjacent unvegetated habitat (Ferrell and Bell 1991) and the influence of rocky reefs on unvegetated habitat (Barros *et al.* 2001).

The studies co-ordinated by the SPCC in the late 1970s identified that many species of fish and invertebrates were present in different habitats at different stages of their life cycle (SPCC 1981a; b; Middleton *et al.* 1981) and inferred that this was evidence of very strong habitat linkages. Thus, it was concluded that seagrass beds and mangrove creeks were important nursery areas for a variety of fish, while rocky reefs and bare substrata were frequented by adults. Furthermore, even with a habitat type such as *Zostera* compared to *Posidonia*, there were linkages between different life history stages.

There are at least two reasons why this concept of the importance of nursery habitats is questionable and this is important for assessing the effects of the proposed port expansion.

The first reason is that species can occur in several or even many different habitats at different age classes. For example, yellowfin bream (*Acanthopagrus australis*) occur as both adults and juveniles within seagrass habitats, although juveniles are not common on coastal rocky reefs (SPCC 1981b). Juveniles and adults are also commonly seen around sheltered rock and rubble habitats within estuaries (M. Lincoln Smith, pers. obs.), but this type of habitat was not sampled as part of the SPCC studies.

Often it is the presence of structure, which provides shelter that seems to be an important factor structuring distribution of fauna. Evidence of this was found by Bell *et al.* (1985) who found strong settlement to experimental artificial structures, including artificial seagrass and metal frames. In addition, juvenile bream are also seen occasionally in unvegetated habitats. If the density of these fish within the unvegetated habitat is small, but the amount of that habitat is large, then it may be just as important for the population as “nursery habitat” as other habitat types which are utilised in high densities but occupy a relatively small proportion of available space within an estuary.

The second reason comes from recent studies that "track" the relationship between adult and juvenile habitats using natural chemical markers in the otoliths (ear bones) of fish. Gillanders and Kingsford (1996) found that for one open coast species (*Achoerodus viridis*), a large proportion of adults came from recruits onto coastal reefs, where recruits occur in small densities compared to recruits into estuaries. Thus, whilst levels of settlement to seagrass "nursery" habitat may be high, subsequent recruitment to coastal habitats appears to be dominated by those fish that settle originally into the coastal habitats.

In terms of assessing the effects of human activities on the aquatic environment, it is important to recognise that there are linkages among habitats and that some habitats can fulfil more than one role for a given species. The importance for the proposed port expansion is to aim to seek diversity of habitats within the study area and to preserve connectivity among those habitats and with other parts of Botany Bay and the coastal ecosystem.

2.12 Conclusions

The study area for the proposed port expansion, and indeed many parts of Botany Bay, have been greatly altered by human activities. Originally, the northern part of Botany Bay contained large areas of seagrass and very little hard structures. Changes have occurred to water movement affecting larval supply. Coastal processes have also been affected, changing patterns of erosion and accretion at several locations in Botany Bay. Within the study area there are now large amounts of hard surfaces colonised by a variety of algae, invertebrates and fishes. There has been a reduction in the amount of shallow, soft sediments, including those areas that support seagrasses. There has also been creation of deep habitats by dredging and a deep channel between the bay and coastal habitats. It is important in assessing the effects of the proposed port expansion to consider the effects of previous changes in the study area, in addition to the less disturbed (or original) habitats existing there. This will provide an appropriate context for predicting the effects of the proposal and for evaluating the potential for cumulative impacts. These issues are considered in detail in Chapters 4 and 5.

The data available from previous studies, along with the supplementary information obtained allows us to make predictions regarding the effects of the proposed port expansion on the aquatic habitats, flora and fauna of Botany Bay (Chapter 5). It is important to recognise, however, that whilst this information is sufficient for the purposes of an EIS, it is not generally sufficient to serve as a baseline against which the actual effects of the expansion could be measured. This would require additional quantitative surveys of key indicators before, during and possibly after the construction works are completed. This is discussed further in Chapter 6.

3.0 THREATENED SPECIES, POPULATIONS & COMMUNITIES

This chapter addresses threatened species issues at both the Commonwealth and State levels. The assessment of threatened species involves the use of 8 part tests to determine the level of management required for selected species and species groups.

3.1 Introduction

The main purpose of this chapter is to undertake 8-part tests under legislation in NSW applicable to Threatened Species and to recommend if further specific action is required in relation to any of these flora or fauna (e.g. preparation of Species Impact Statements). The specific aims of this chapter are:

1. To identify threatened species, populations, ecological communities or threatening processes that may occur within the study area.
2. To undertake 8-part tests for any threatened species as identified in Aim 1.
3. To recommend whether or not Species Impacts Statements (SISs) are warranted for any of the threatened species identified.

In addition to assessments of species, consideration is given to Threatened Populations or Communities and to Key Threatening Processes.

As requested by NSW Fisheries (correspondence 15/1/02) a draft of this chapter was provided to them to enable early feedback on conclusions regarding the need for preparation of any SISs. The chapter draft was also sent to NSW NPWS and Environment Australia.

NSW Fisheries advised that the 8-part tests were satisfactory, but that any new species listings should be incorporated into the final report (email correspondence, L. Diver, NSW Fisheries, 3/5/02). NPWS also advised that the list of species and structure of analyses was satisfactory, but also advised that the list be upgraded prior to finalisation, if necessary (email correspondence, M. Phillips, NSW NPWS, 24/5/02).

3.2 Species Considered

The identification of and need to protect threatened species, populations, communities and threatening processes has been identified in both Commonwealth and New South Wales legislation. Advice received by SPC from Environment Australia regarding issues under the Commonwealth's *Environment Protection and Biodiversity Conservation* Act (*EPBC*) 1999 indicate that the proposed development is a "Controlled Action" and that the NSW environmental impact assessment process has been accredited by the Commonwealth Environment Minister for the preparation of the EIS. This process includes the use of 8-part tests as an acceptable method of assessing whether the proposal is likely to have a significant effect on threatened species.

3.2.1 Threatened Species Conservation Act 1995

The NSW *Threatened Species Conservation* Act (*TSC*) 1995 applies to terrestrial and aquatic fauna and is administered by NSW National Parks and Wildlife Service. In the aquatic environment, the *TSC* Act includes seabirds, waders, aquatic reptiles, aquatic mammals and some insects (e.g. the giant dragonfly, *Petalura gigantea*). The scope-of-works for The Ecology Lab in this project includes marine mammals, marine reptiles and the threatened population of little penguins at Manly. Terrestrial biota and waders are being considered by other specialists. In addition to species and populations, The *TSC* Act also identifies endangered ecological communities, including "Sydney Freshwater Wetlands in the Sydney Basin Bioregion" which are relevant to The Ecology Lab's work and "The Shorebird Community occurring on the relict tidal delta sands at Taren Point" which may be relevant to other specialists engaged on the project. Finally, the *TSC* Act schedules Key threatening processes, which includes "Predation by mosquito fish *Gambusia holbrooki*". Table 3.1 lists each relevant species and other category under the *TSC* Act and nominates its significance to the proposed port expansion.

3.2.2 Fisheries Management Act 1994

The NSW *Fisheries Management Act* (*FM*) 1994 and 1997 amendments, apply specifically to aquatic flora and fauna, primarily fish, invertebrates and some algae. In addition, the *FM* Act nominates key threatening processes and there are several proposals for listing of species and key threatening processes. Table 3.2 lists each relevant species and categories under the *FM* Act and nominates its relevance to the proposal.

3.2.3 Environment Protection and Biodiversity Conservation Act 1999

The proposed Port Botany Expansion has been declared a "Controlled Action" under the *EPBC* Act by the Commonwealth Environment Minister. Whilst the controlling provisions for the environmental assessment do not include threatened species, listed species have been considered for completeness using 8-part tests.

Threatened Species and Threatened Communities listed under Part 13 Division 1 can have a number of categories, including extinct, extinct in the wild, critically endangered, endangered, vulnerable and conservation dependent. A further category within this group is Key Threatening Processes. Table 3.3 lists the members of Part 13 Division 1 that may be relevant to the proposed development under the *EPBC* Act. This list forms the basis of 8-part tests for Threatened Species under the EPBC Act.

The second group includes Migratory species (Part 13, Division 2), including species listed under JAMBA and CAMBA and hence is being considered by specialists in terrestrial ecology.

The third group includes cetaceans (i.e. whales, porpoises and dolphins) (Part 13 Division 3). This group is separate from threatened species of cetaceans listed in Division 1 of Part 13, hence its members are not subject to the 8-part test, but have nonetheless been considered in this report.

The fourth group includes Listed Marine Species (Part 13 Division 4) covering a range of taxa occurring in the sea. Groups of potential relevance for the present investigation include sea snakes (Hydrophiidae and Laticaudidae), eared and true seals (Otariidae and Phocidae, respectively), dugong (*Dugong* spp.), marine turtles (Cheloniidae), seahorses, pipefish and seadragons (Syngnathidae) and ghost pipefish (Solenostomidae). These species are not listed as threatened, hence they are not subject to the 8-part test. They are, however, considered briefly in Section 3.3.3 of this report and in more detail within the general assessment of impacts for the proposed port expansion.

Table 3.1. List of scheduled species, populations, communities or threatening processes under the *TSC* Act considered for the Port Botany Expansion EIS. Under "Consideration" column in Tables 3.1 -3.3, species are identified as requiring an individual 8 part test (specific), a test as part of a group of species (generic), not subject to the 8 part test but requiring further assessment (Separate or ongoing) or assessed at this stage to not be affected by the current proposal (not relevant) Source: NSW Scientific Committee Web page, last updated 20/12/02 and checked by The Ecology Lab in March, 2003.

Scheduled category or species	Common name	Ecosystem	Consideration
Endangered Species:			
Caretta caretta (Linnaeus 1758)	Loggerhead turtle	Marine & bays	8-part test (generic)
Balaenoptera musculus (Linnaeus 1758)	Blue Whale	Marine	8-part test (generic)
Endangered Population:			
Eudyptula minor (Forster 1781)	Little Penguin	Population in Manly Pt. Area (Pt Jackson)	Separate or ongoing
Endangered Ecological Community:			
Sydney Freshwater Wetlands in Sydney Basin Bioregion	-	Millstream complex	Separate or ongoing
Vulnerable Species:			
Chelonia mydas (Linnaeus 1758)	Green turtle	Marine & bays	8-part test (generic)
Dermochelys coriacea (Vandelli 1761)	Luth, Leathery or Leatherback turtle	Marine & bays	8-part test (generic)
Eubalaena australis (Desmoulins 1822)	Southern right whale	Marine & bays	8-part test (specific)
Megaptera novaeangliae (Borowski 1781)	Humpback whale	Marine & bays	8-part test (specific)
Physeter catadon Linnaeus 1758	Sperm whale	Marine	8-part test (generic)
Key Threatening Process:			
Predation by *Gambusia holbrooki* Girard 1859	Mosquito fish	Mill Stream complex	Separate or ongoing

Table 3.2. List of scheduled species, populations, communities or threatening processes under the *FM* Act considered for the Port Botany Expansion EIS. Source: NSW Fisheries Web page, last updated 21/12/02 and checked by The Ecology Lab in March, 2003.

Scheduled category or species	Common name	Ecosystem	Consideration
Endangered Species:			
Carcharias taurus Rafinesque 1810	Grey nurse shark	Marine & bays	8-part test (specific)
Craterocephalus fluviatalis (McCulloch 1913)	Murray hardyhead	Freshwater	Not relevant
Maccullochella ikei Rowland	Eastern f'water cod	Freshwater	Not relevant
Maccullochella macquariensis (Cuvier)	Trout cod	Freshwater	Not relevant
Nannoperca oxleyana Whitley	Oxleyan pygmy perch	Freshwater	Not relevant
Notopala sublineata (Conrad 1850)	River snail	Freshwater	Not relevant
Pristis zijsron Bleeker 1851	Green sawfish	Marine, bays, estuaries	8-part test (specific)
Endangered Populations:			
Western pop. of *Mogurnda adspersa* (Castlenau 1878)	Purple spotted gudgeon	Freshwater	Not relevant
Western pop. of *Ambassis agassizii* Steindachner 1866	Olive perchlet	Freshwater	Not relevant
Endangered Ecological Communities:			
Aquatic ecology community in natural drainage system of lower Murray R.	-	Freshwater	Not relevant
Vulnerable Species:			
Archaephya adamsi Fraser 1959	Adams emerald dragonfly	Freshwater	Not relevant
Bidyanus bidyanus (Mitchell 1838)	Silver perch	Freshwater	Not relevant
Brachinella buchananensis Geddes 1981	Buchanans fairy shrimp	Freshwater	Not relevant
Vulnerable Species (continued):			
Carcharodon carcharias (Linnaeus 1758)	Great white shark	Marine, bays, estuaries	8-part test (specific)
Epinephelus daemelii (Gunther 1876)	Black cod	Marine, bays, estuaries	8-part test (specific)
Macquaria australisica (Cuvier 1830)	Macquarie perch	Freshwater	Not relevant
Nannoperca australis Gunther 1861	Southern pygmy perch	Freshwater	Not relevant
Key Threatening Processes:			
Introduction of fish to freshwaters in a river catchment outside natural range	-	Freshwater	Separate or ongoing
Removal of large woody debris	-	Freshwater & estuarine	Separate or ongoing
Degradation of native riparian vegetation along NSW water courses	-	Freshwater & estuarine	Separate or ongoing

Marine & Estuarine Protected Species (note: these are not subject to 8-part tests):			
Epinephelus lanceolatus	Giant Queensland grouper	Marine, bays, estuaries	Separate
Epinephelus coioides	Estuary cod	Marine, bays, estuaries	Separate
Anampses elegans	Elegant wrasse	Marine & bays	Separate
Paraplesiops bleekeri	Eastern blue devil	Marine, bays, estuaries	Separate
Chaetodontoplus ballinae	Ballina angelfish	Marine	Not relevant
Odontaspis ferox	Herbst's nurse shark	Marine	Not relevant
Phyllopteryx taeniolatus	Weedy sea dragon	Marine, bays, estuaries	Separate

In summary, for this report, Division 1 members are treated in a similar way to threatened species under the NSW legislation and hence are considered in terms of the 8-part test and the extent to which the preparation of an SIS would be appropriate. Table 3.3 provides an assessment of how each member would be considered in terms of the NSW legislative requirements. Division 2 members are not included within the scope-of-works of The Ecology Lab and are considered by other specialists. Divisions 3 and 4 members are not subject to the 8-part test under the EPBC Act but have been considered as part of the assessment process within this report.

3.3 Results

The taxa, communities or processes listed in Tables 3.1-3.3 are dealt with in one of four ways, based on the current project description for the proposed Port Botany Expansion. Major threatened species that have the potential to be affected by the proposed port expansion are treated individually within 8-Part tests. These tests are intended to indicate if a Species Impact Statement is required for any of the species considered, or if the proposed project should be modified to prevent impacts occurring to a threatened species.

Threatened species with less potential to be affected are considered in terms of 8-part tests within two groups – marine turtles and marine mammals plus whale sharks. For the purposes of this assessment, the ecological requirements of these groups are considered to be similar enough that several species can be evaluated together.

A third group is given separate consideration among species or communities. This includes non-listed cetaceans (under the *EPBC* Act), Listed Marine Species (*EPBC* Act), Sydney freshwater wetlands (*TSC* Act), species under consideration for listing and protected fish species (*FM* Act).

The final group includes key threatening processes (*TSC* and *FM* Acts).

Table 3.3. Listed threatened species and ecological communities or key threatening processes under the *EPBC* Act considered for the Port Botany Expansion EIS. Source: Environment Australia Web page, March, 2003. Note, for brevity, only most relevant species are presented here – see EA Web page for complete list.

Scheduled category or species	Common name	Ecosystem	Consideration
Extinct Fauna:	-	-	Not relevant
Extinct in the Wild:	-	-	Not relevant
Critically Endangered:			
Carcharias taurus – east coast population	Grey nurse shark	Marine & bays	8-part test (specific)
Endangered:			
Caretta caretta	Loggerhead turtle	Marine & bays	8-part test (generic)
Balaenoptera musculus	Blue Whale	Marine	8-part test (generic)
Eubalaena australis	Southern right whale	Marine & bays	8-part test (specific)
Vulnerable:			
Carcharodon carcharias	Great white shark	Marine, bays & estuaries	8-part test (specific)
Rhincodon typus	Whale shark	Marine	8-part test (generic)
Chelonia mydas	Green turtle	Marine & bays	8-part test (generic)
Dermochelys coriacea	Luth, Leathery or Leatherback turtle	Marine & bays	8-part test (generic)
Eretmochelys imbricata	Hawksbill turtle	Marine & bays	8-part test (generic)
Balaenoptera borealis	Sei whale	Marine	8-part test (generic)
Balaenoptera physalus	Fin whale	Marine	8-part test (generic)
Megaptera novaeangliae	Humpback whale	Marine & bays	8-part test (specific)
Key Threatening Processes:	-	-	Not relevant
Fauna under consideration:			
Brachaelurus colcloughi	Colclough's shark	Marine	Separate
Brachionichthys hirsutus	Red handfish	Marine	Separate
Sympterichthys sp.	Zeibell's handfish	Marine & bays	Separate
Centrophorus moluccensis	Endeavour dogfish	Marine	Separate
Centrophorus uyato	Southern dogfish	Marine	Separate
Cheilinus undulatus	Humphead Maori wrasse	Tropical and subtropical reefs	Separate
Raja. sp.	Maugean skate	Marine & bays	Separate
Epinephelus daemelii	Black cod	Marine, bays, estuaries	8-part test (specific)
Pristis zijron	Green sawfish	Marine, bays, estuaries	8-part test (specific)

3.3.1 Specific 8-Part Tests

3.3.1.1 Grey Nurse Shark

a) *In the case of a threatened species, whether the life cycle of the species is likely to be disrupted such that a viable local population of the species is likely to be placed at risk of extinction.*

Grey nurse sharks typically occur on shallow rocky reefs along the NSW coast (Last and Stevens 1994). Typically, they would be most common on rocky headlands at the entrance to Botany Bay and along the coastline to the north and south of the bay, but there have been reports in the past that grey nurses occasionally occur in embayments, including Botany Bay. There is some likelihood that grey nurse sharks migrate along the NSW coast. Young are born live and also occur on shallow rocky reefs, often segregated from the adults. Given that the life cycle of the species is generally confined to the coastline, particularly rocky reefs, it is unlikely that the proposed Port Botany expansion would disrupt the life cycle of the species or a local population.

b) *In the case of an endangered population, whether the life cycle of the species that constitutes the endangered population is likely to be disrupted such that the viability of the population is likely to be significantly compromised.*

Under both the EPBC and FM Acts, the whole NSW population of grey nurse sharks may be considered to be endangered. Notwithstanding this, the location of the proposed expansion is such that it is most unlikely to compromise that population.

c) *In relation to the regional distribution of the habitat of a threatened species, population or ecological community, whether a significant area of known habitat is to be modified or removed.*

The major habitat that would be affected by the proposed expansion of port facilities would be beach and subtidal soft sediments, some of which supports the growth of seagrasses. The major habitat utilised by grey nurse sharks comprises rocky reefs, with small sandy gutters within the reef matrix being often preferred microhabitat. There is some likelihood that the species ranges away from reefs to feed at night, but the extent of this range is unknown. On this basis, the core reef habitat of grey nurse sharks (i.e. reef) would not be affected by the proposal. Moreover, the area that would be affected by the expansion would be unlikely to constitute a significant area of habitat used for feeding or other purposes, given that this type of habitat is common in Botany Bay.

d) *Whether an area of known habitat is likely to become isolated from currently interconnecting or proximate areas of habitat for a threatened species, population or ecological community.*

Since the area of the proposed expansion is not known habitat, nor likely to be significant habitat for grey nurse sharks, it would not become isolated from other habitat used by the species.

e) *Whether a critical habitat will be affected.*

No critical habitat used by grey nurse sharks would be affected by the proposed development.

f) *Whether a threatened species, population or ecological community, or their habitats, are adequately represented in conservation reserves (or other similar protected areas) in the region.*

Grey nurse sharks are protected from all forms of fishing. They occur within the Jervis Bay and Solitary Islands Marine Parks and other areas are being considered for protection (e.g. parts of Seal Rocks). These areas provide a variety of habitats and potential prey species utilised by grey nurse sharks. Given their potential mobility, however, it is unlikely that grey nurse populations are confined to the relatively small spatial scale of these reserves. Notwithstanding this, the species is represented within conservation areas and its protected status provides it with much broader protection within NSW waters.

g) Whether the action proposed is of a class of action that is recognised as a threatening process.

The proposed expansion is not recognised as a threatening process with respect to grey nurse sharks (see also Section 3. 4).

h) Whether any threatened species or ecological community is at the limit of its known distribution.

Grey nurse sharks occur along the NSW coast and extend into southern Queensland and northern Victoria. They also occur in Western Australia and several other parts of the world (e.g. South Africa). The species is therefore not at the limit of its know distribution within the vicinity of Botany Bay.

Conclusion: The proposed expansion of Port Botany is unlikely to have a significant effect on grey nurse sharks, hence no SIS is required for this species, nor should the project be modified to accommodate requirements of grey nurse sharks.

3.3.1.2 Great White Shark

a) In the case of a threatened species, whether the life cycle of the species is likely to be disrupted such that a viable local population of the species is likely to be placed at risk of extinction.

Great white sharks are large, highly predatory animals whose life cycle is poorly understood. They occur from cold temperate to tropical waters worldwide and generally frequent coastal waters, often close to shore. They also swim into bays and estuaries, hence may occur, albeit rarely, in Botany Bay. Great white sharks are live bearers that do not generally appear to be attached to specific habitats. The exception is when they take up residence adjacent to rocky shores, particularly where seals or sea lions are present. Emerging evidence suggests that both juveniles and adults can be wide ranging, with one tagged individual moving from Tasmania along the NSW coast into southern Queensland. There is also anecdotal evidence that the species follows large schools of migrating fish (e.g. sea mullet, Australian salmon) and migrating whales, particularly with calves. Based on our limited knowledge of the life cycle of the species, it is most unlikely that the proposed expansion of Port Botany would affect great white sharks.

b) In the case of an endangered population, whether the life cycle of the species that constitutes the endangered population is likely to be disrupted such that the viability of the population is likely to be significantly compromised.

As in the case of grey nurse sharks, the whole of the NSW (and indeed, Australian) population of great white sharks is likely to be endangered, but given the small scale of the project relative to the range of the species, it is most unlikely that the population would be disrupted by the project.

c) *In relation to the regional distribution of the habitat of a threatened species, population or ecological community, whether a significant area of known habitat is to be modified or removed.*

If great white sharks do prefer a particular habitat, it is likely to be rocky shores with seals or sea lions and this type of habitat would not be affected by the proposed Port Botany expansion. They may also follow schools of fish along the coast, hence it is possible that if the development affected fish behaviour in Botany Bay, it may affect "temporary" habitat of great white sharks. In that case, the area of the proposal would not be considered significant known habitat, as the sharks are likely to simply follow the schools elsewhere.

d) *Whether an area of known habitat is likely to become isolated from currently interconnecting or proximate areas of habitat for a threatened species, population or ecological community.*

Since the area of the proposed expansion is not known habitat, or likely to be significant habitat for great white sharks, it would not become isolated from other habitat used by the species.

e) *Whether a critical habitat will be affected.*

No critical habitat would be affected for great white sharks.

f) *Whether a threatened species, population or ecological community, or their habitats, are adequately represented in conservation reserves (or other similar protected areas) in the region.*

Given the huge range of this species, it is difficult to manage its conservation using conservation reserves. Moreover, as seal colonies are limited to one or two locations in NSW, adequate representation within reserves would probably be best in areas within South Australia and Tasmania. Essentially, this question is not relevant with respect to great white sharks.

g) *Whether the action proposed is of a class of action that is recognised as a threatening process.*

The proposed expansion is not recognised as a threatening process with respect to great white sharks (see also Section 3. 4).

h) *Whether any threatened species or ecological community is at the limit of its known distribution.*

As this species ranges all along the NSW coast and throughout all the oceans of the world, it is clearly not at the limit of its distribution when near the proposed development.

<u>Conclusion</u>: The proposed expansion of Port Botany is most unlikely to affect great white sharks, hence no SIS is required, nor should the project be modified with respect to conservation of this species

3.3.1.3 Green Sawfish

a) *In the case of a threatened species, whether the life cycle of the species is likely to be disrupted such that a viable local population of the species is likely to be placed at risk of extinction.*

Green sawfish occur in shallow, sedimentary habitats as are found in Botany Bay. The species occurs from the northern Indian Ocean and south eastern Africa, through Indonesia and tropical Australia (Last and Stevens 1994). It occurs as far south as Sydney on the East Coast, with one record from South Australia. As far as is known, there is no local population of green sawfish occurring in Botany Bay. If there were such a population, the proposed development may displace individuals, but it is unlikely that it would cause local extinction, as suitable requirements are available in numerous other parts of Botany Bay.

b) *In the case of an endangered population, whether the life cycle of the species that constitutes the endangered population is likely to be disrupted such that the viability of the population is likely to be significantly compromised.*

No endangered population of green sawfish has been identified in Botany Bay and there is unlikely to be such a population; hence, it is most unlikely that an endangered population of this species would be affected by the proposal.

c) *In relation to the regional distribution of the habitat of a threatened species, population or ecological community, whether a significant area of known habitat is to be modified or removed.*

Green sawfish occur over a large geographical range and appear to have relatively broad habitat requirements. Whilst a small amount of habitat that could be utilised by green sawfish would be altered by the proposed port expansion, this is not considered to be significant for green sawfish, as there is extensive alternative habitat available in Botany Bay.

d) *Whether an area of known habitat is likely to become isolated from currently interconnecting or proximate areas of habitat for a threatened species, population or ecological community.*

The subtidal habitat at the proposed development site is bounded to the east and west by massive artificial breakwaters, whilst the depth slopes gradually away into the main section of the bay to the south of Foreshore Beach. Under the proposed development, any "corridor" from the beach area into the bay would be retained, although it would be somewhat reduced. In the event that green sawfish did occur within the study area, there would remain access to other parts of Botany Bay.

e) *Whether a critical habitat will be affected.*

This is considered most unlikely for green sawfish.

f) *Whether a threatened species, population or ecological community, or their habitats, are adequately represented in conservation reserves (or other similar protected areas) in the region.*

Broadly, green sawfish populations would be provided with some protection within parts of the Great Barrier Reef Marine Park and possibly some of the shoreline sections of the Solitary Islands Marine Park. More locally, there is an abundance of shallow, sandy habitat within the Towra Point Aquatic Reserve. Therefore, it is likely that green sawfish have the potential to be well represented in protected areas, although the extent to which they are protected is unknown.

g) *Whether the action proposed is of a class of action that is recognised as a threatening process.*

The proposed expansion is not recognised as a threatening process with respect to green sawfish (see also Section 3. 4).

h) *Whether any threatened species or ecological community is at the limit of its known distribution.*

The core distribution of green sawfish is within tropical and sub-tropical waters, extending into the warm temperate. Any green sawfish occurring in Botany Bay would be at the limit of their distribution, however, for management purposes, northern parts of NSW (e.g. from the Clarence River northward) would be a more practical cut-off point.

<u>Conclusion</u>: The proposed expansion of Port Botany may cause some localised disturbance to green sawfish, but no population of this species is recognised from the area, hence it is highly unlikely that the species would be affected hence no SIS or any special management measures are recommended.

3.3.1.4 Black Cod

a) *In the case of a threatened species, whether the life cycle of the species is likely to be disrupted such that a viable local population of the species is likely to be placed at risk of extinction.*

Black cod, also known as black rockcod and saddled rockcod, occur from southern Queensland to Kangaroo Island (South Australia) and are found at Lord Howe Island, Norfolk Island, Kermadec Islands and the North Island of New Zealand (Heemstra and Randall 1993). They are protogynous hermaphrodites (i.e. change sex from female to male) and occur on relatively shallow coastal and estuarine rocky reefs. Juveniles may recruit to rock pools; adults are highly territorial, usually adopting a cave as a core territory. The life cycle of the species revolves around rocky reefs and possibly rock pools with pelagic dispersal of eggs and larvae.

Within Botany Bay, it is likely that there would be black cod occurring on natural reef (which occurs mostly toward the entrance to the bay) and on artificial breakwaters and rock walls. Rock walls would be created as a result of the proposed port expansion, but there is no intention to remove existing rock walls. Therefore, it is considered most unlikely that the life cycle of the species would be disrupted such that a viable local population would be placed at risk.

b) *In the case of an endangered population, whether the life cycle of the species that constitutes the endangered population is likely to be disrupted such that the viability of the population is likely to be significantly compromised.*

No known endangered population of black cod exists within or near the area proposed for the port expansion. Most environmental disturbance would occur to soft sediments, which are not favoured habitat for black cod. Therefore, it is most unlikely that any endangered population of black cod would be negatively affected in terms of its life cycle or other population parameters by the proposed development.

c) *In relation to the regional distribution of the habitat of a threatened species, population or ecological community, whether a significant area of known habitat is to be modified or removed.*

No extensive areas of natural rocky reef occur within the study area, while artificial rock walls would be added, not removed or otherwise modified in terms of habitat suitability.

d) *Whether an area of known habitat is likely to become isolated from currently interconnecting or proximate areas of habitat for a threatened species, population or ecological community.*

This is most unlikely with respect to black cod.

e) *Whether a critical habitat will be affected.*

No critical habitat for black cod would be affected by the proposed development

f) *Whether a threatened species, population or ecological community, or their habitats, are adequately represented in conservation reserves (or other similar protected areas) in the region.*

Black cod are completely protected from fishing in NSW, which is the main threat to this species. There are numerous protected areas for the species, including aquatic reserves at Bushrangers Bay (Illawarra), Ship Rock (Pt Hacking), Middle Harbour Aquatic Reserve (Sydney), Fly Point and Halifax Park (Pt Stephens), Jervis Bay Marine Park, Solitary Islands Marine Park and Lord Howe Island.

g) Whether the action proposed is of a class of action that is recognised as a threatening process.

The proposed expansion is not recognised as a threatening process with respect to black cod (see also Section 3.3.4).

h) Whether any threatened species or ecological community is at the limit of its known distribution.

Botany Bay is at the geographical mid-point of the distribution of black cod along the NSW coast, and therefore not at the limit of its range.

Conclusion: The proposed expansion of Port Botany does not represent any significant threat to black cod, hence no SIS is recommended, nor any special management required.

3.3.1.5 Southern Right Whale

a) In the case of a threatened species, whether the life cycle of the species is likely to be disrupted such that a viable local population of the species is likely to be placed at risk of extinction.

Southern right whales occur globally in sub-polar and temperate waters, extending as far north as the NSW Central Coast during the winter months (Jefferson *et al*. 1993). They range over a vast area and their population has increased rapidly since they became protected from hunting. They are slow moving and there is some evidence that they are susceptible to vessel strike. Females travel to temperate waters to give birth and mother and calf sightings are becoming more common in the Sydney region as the species' population increases. Recently, one southern right whale spent days in Botany Bay near the northern shore of the bay.

Given that the bulk of the population occurs well to the south of Botany Bay, it is most unlikely that the "local" population of the species (which would extend from Sydney to the Southern Ocean!) would be placed at risk of extinction. Notwithstanding this, management plans should be developed to ensure that no harm is done to southern right whales during the construction of the facility or as a result of increased shipping entering the bay.

b) In the case of an endangered population, whether the life cycle of the species that constitutes the endangered population is likely to be disrupted such that the viability of the population is likely to be significantly compromised.

Under the *TSC* Act, no endangered population of southern right whales has been scheduled (Table 3.1), although under the *EPBC* Act the species is listed as endangered. As in the case of a viable local population, it is most unlikely that an endangered local population would be placed at risk by the proposal, given the scale of the proposal relative to the range of the species.

c) In relation to the regional distribution of the habitat of a threatened species, population or ecological community, whether a significant area of known habitat is to be modified of removed.

The major habitats of southern right whales are the feeding areas of the Southern Ocean, the mating and birthing areas of southern Australia (e.g. Great Australian Bight) and some birthing areas along the east and west coasts, principally adjacent to coastal sandy beaches.

Whilst southern right whales may, from time to time occur in Botany Bay, this area is most unlikely to provide a significant area of habitat.

d) Whether an area of known habitat is likely to become isolated from currently interconnecting or proximate areas of habitat for a threatened species, population or ecological community.

Southern right whales migrate along the NSW coast and may move into embayments. The area proposed for the port expansion does not constitute a habitat for southern right whales that would become isolated from any other currently interconnecting or proximate areas of habitat.

e) Whether a critical habitat will be affected.

No habitat critical for southern right whales would be affected as a result of the proposal.

f) Whether a threatened species, population or ecological community, or their habitats, are adequately represented in conservation reserves (or other similar protected areas) in the region.

Due to their vast geographical range, it is difficult to provide conservation areas for many cetaceans, particularly large baleen whales such as the southern right whale. Under the *EPBC* Act, whales are protected within the Australian Whale Sanctuary, which includes all Commonwealth Waters.

g) Whether the action proposed is of a class of action that is recognised as a threatening process.

The proposed expansion is not recognised as a threatening process with respect to southern right whales (see also Section 3. 4).

h) Whether any threatened species or ecological community is at the limit of its known distribution.

Southern right whales reportedly occur as far north as the North West Cape of Western Australia and southern Queensland on the East Coast. In practical terms, however, the species does not venture far beyond the NSW Central Coast or Perth. In the case of this species, this aspect of the 8-part test is somewhat illogical, as there is not an established population at the limit of distribution – rather, some individuals range over the full extent of their distribution.

<u>Conclusion</u>: The proposed expansion of Port Botany is unlikely to have significant effects on southern right whales, hence no SIS is recommended. However, there is a risk of disturbance to some individuals during construction and operation and it is recommended that possible effects of the proposal (e.g. boat strike; noise from construction works) be incorporated into the environmental management plan for the project.

3.3.1.6 Humpback Whale

a) In the case of a threatened species, whether the life cycle of the species is likely to be disrupted such that a viable local population of the species is likely to be placed at risk of extinction.

The life cycle of humpback whales in the Southern Hemisphere involves feeding and advancement to maturity in the Southern Ocean during the summer months, followed by northward migration during winter to mate and give birth in subtropical and tropical waters (Jefferson *et al*. 1993). The East Coast population of humpbacks migrates along the Victorian, NSW and Queensland coasts to the Coral Sea from late autumn to winter and back along the coast in spring and early summer. Often on the return trip, adults are accompanied by new-born calves and pairs may rest in large embayments such as Jervis Bay and Twofold Bay.

During the annual migration, humpbacks swim past Botany Bay and may, at times, enter the bay for short periods. Such occurrences in the bay are rare. Construction and operation works within the bay are most unlikely to disrupt life cycle stages of humpback whales, whilst there is a small risk of boat strike from increased shipping leaving and entering the bay.

b) In the case of an endangered population, whether the life cycle of the species that constitutes the endangered population is likely to be disrupted such that the viability of the population is likely to be significantly compromised.

There are no listed endangered populations of humpback whales in either the *TSC* Act or *EPBC* Act, although both Acts list this species as Vulnerable (Tables 1 and 3). Under these definitions, no endangered population of humpback whales could be disrupted by the proposal.

c) In relation to the regional distribution of the habitat of a threatened species, population or ecological community, whether a significant area of known habitat is to be modified of removed.

Major habitats for humpback whales include the feeding/growth and breeding/mating areas in the south and north of their range, respectively, and the migration corridors which extend at least the width of the continental shelf. In addition, some large embayments such as Jervis Bay and Twofold Bay may be used during migration. Given the location, size and present uses of the proposed development area, it is most unlikely that a significant area of known humpback habitat would be affected by the proposal.

d) Whether an area of known habitat is likely to become isolated from currently interconnecting or proximate areas of habitat for a threatened species, population or ecological community.

The major corridors for migrating humpbacks occur on the continental shelves of east and west Australia. Alterations to the area of Botany Bay where the port expansion would occur would not isolate interconnecting areas of habitat for humpback whales.

e) Whether a critical habitat will be affected.

No habitat critical for humpback whales would be affected as a result of the proposal.

f) Whether a threatened species, population or ecological community, or their habitats, are adequately represented in conservation reserves (or other similar protected areas) in the region.

As for the southern right whale, humpback whales are protected under the *EPBC* Act within the Australian Whale Sanctuary.

g) Whether the action proposed is of a class of action that is recognised as a threatening process.

The proposed expansion is not recognised as a threatening process with respect to humpback whales (see also Section 3. 4).

h) Whether any threatened species or ecological community is at the limit of its known distribution.

The site of the proposed port expansion is well within the limit of distribution of humpback whales, in terms of both individual whales and the population utilising the East Coast of Australia.

Conclusion: The proposed expansion of Port Botany is unlikely to have significant effects on humpback whales, hence no SIS is recommended. However, as with the southern right whale, there is a risk of disturbance to some individuals during construction and operation and it is recommended that any possible effects of the proposal on humpbacks (e.g. boat strike; noise from construction works) be incorporated into the environmental management plan for the project.

3.3.2 Generic 8-Part Tests

3.3.2.1 Listed Marine Turtles

There are four listed marine turtles in the *TSC* and/or *EPBC* Acts and they are grouped here because they have similar distribution and many similar ecological requirements (e.g. come ashore to lay eggs). These include the loggerhead, green, hawksbill and leatherback turtles. In addition to these species, marine turtles are listed generally under Part 13, Division 4 of the *EPBC* Act. For the purposes of this assessment, these additional turtles are included in the 8-part test, presented as follows.

a) In the case of a threatened species, whether the life cycle of the species is likely to be disrupted such that a viable local population of the species is likely to be placed at risk of extinction.

Most of the listed marine turtles tend to prefer warmer waters, ranging from tropical to warm temperate seas (Marquez 1990). The hawksbill turtle tends to stay in tropical waters while the leatherback and loggerheads have a wider distribution and may be observed all around Australia. For a large part of their life cycle, marine turtles are pelagic, particularly leatherbacks and loggerheads, while hawksbill and green turtles tend to stay in coastal waters and may even take up residence in some areas.

All the marine turtles listed under the legislation are vulnerable to hunting through much of their range, particularly in developing countries. The species are probably most vulnerable when they come ashore to nest – at this time adults, eggs and hatchlings are subject to direct harvesting, predation by natural fauna, feral animals and pets and various forms of human disturbance.

Botany Bay is outside the range of nesting of most of the above species and existing disturbances to Foreshore Beach (e.g. humans, pets, and feral animals) would make it almost impossible to use as a nesting area. Moreover, although marine turtles are not uncommon in Sydney's coastal waters during summer, it is unlikely that there is a viable local population within or near to Botany Bay. On this basis, it is unlikely that a viable local population of any marine turtles would be placed at risk of extinction by the proposed port expansion.

b) In the case of an endangered population, whether the life cycle of the species that constitutes the endangered population is likely to be disrupted such that the viability of the population is likely to be significantly compromised.

No endangered populations of marine turtles are identified in the legislation, although loggerhead turtles are listed as endangered species in the *TSC* and *EPBC* Acts (Tables 1 and

3). For the reasons described above, it is unlikely that loggerheads would be at risk of extinction because of the proposal.

c) In relation to the regional distribution of the habitat of a threatened species, population or ecological community, whether a significant area of known habitat is to be modified of removed.

In theory, Foreshore Beach could potentially provide habitat for marine turtles and seagrasses adjacent to the beach could be used by green turtles. Given the high level of human usage of the area (particularly the beach) it is unlikely that study area would constitute a significant area of known habitat.

d) Whether an area of known habitat is likely to become isolated from currently interconnecting or proximate areas of habitat for a threatened species, population or ecological community.

This is most unlikely to occur for marine turtles in the context of the present proposal.

e) Whether a critical habitat will be affected.

This would not occur for marine turtles in relation to the present proposal.

f) Whether a threatened species, population or ecological community, or their habitats, are adequately represented in conservation reserves (or other similar protected areas) in the region.

Marine turtles occur in numerous reserves in Australia and internationally. They would also be afforded some protection within marine reserves/parks at Towra Point, Jervis Bay and the Solitary Islands.

g) Whether the action proposed is of a class of action that is recognised as a threatening process.

The proposed expansion is not recognised as a threatening process with respect to marine turtles (see also Section 3. 4).

h) Whether any threatened species or ecological community is at the limit of its known distribution.

As noted above, marine turtles tend to prefer warmer waters, but most, with the exception of hawksbill turtles, may occur all around Australia. Hawksbills would tend occur in Botany Bay only as stragglers and so for practical purposes the bay would be considered outside the normal range of this species

<u>Conclusion</u>: The proposed expansion of Port Botany is unlikely to have any effect on marine turtles, hence no SIS is recommended, and no special management measures are required.

3.3.2.2 Additional Listed Marine Mammals and Whale Sharks

There are four additional listed marine mammals in the *TSC* and/or *EPBC* Acts and they are grouped together here because they tend to occur in coastal or oceanic waters and rarely enter bays and estuaries. They include the sperm, blue, sei and fin whales. Whale sharks also occur in oceanic environments (although typically at lower latitudes) and are also included here. Recent changes to the *TSC* listing have seen the removal of the sei and fin whales and the Indo-Pacific humpbacked and long-snouted spinner dolphins, while the blue whale has been added (Table 3.1).

a) In the case of a threatened species, whether the life cycle of the species is likely to be disrupted such that a viable local population of the species is likely to be placed at risk of extinction.

Because of their more oceanic distribution and wide-ranging behaviour, viable local populations do not occur in and around Botany Bay and so are unlikely to be placed at risk by the proposed port expansion.

b) *In the case of an endangered population, whether the life cycle of the species that constitutes the endangered population is likely to be disrupted such that the viability of the population is likely to be significantly compromised.*

The blue whale is listed as an endangered species in the EPBC Act and all other species considered here are listed as vulnerable (Table 3.1 and 3.3). As discussed above, blue whales occur over a vast range, generally confined to ocean or coastal waters and rarely enter embayments (they are known, however, to occur at the entrance to Twofold Bay – Cat Balou Cruises, Eden, pers. comm.)

c) *In relation to the regional distribution of the habitat of a threatened species, population or ecological community, whether a significant area of known habitat is to be modified of removed.*

None of these species has significant habitat requirements within Botany Bay.

d) *Whether an area of known habitat is likely to become isolated from currently interconnecting or proximate areas of habitat for a threatened species, population or ecological community.*

No areas of known habitat occupied by these species would become isolated as a result of the proposed port expansion.

e) *Whether a critical habitat will be affected.*

No habitat critical to these species would be affected by the proposed development.

f) *Whether a threatened species, population or ecological community, or their habitats, are adequately represented in conservation reserves (or other similar protected areas) in the region.*

It would be highly problematic to define conservation reserves for these species, given their range and behaviour. Moreover, this item is essentially irrelevant for these species in the context of the proposed port expansion, given its scale relative to the movement of the species and lack of habitat that would be utilised by them.

g) *Whether the action proposed is of a class of action that is recognised as a threatening process.*

The proposed expansion is not recognised as a threatening process with respect to the additional marine mammals considered here (see also Section 3.4).

h) *Whether any threatened species or ecological community is at the limit of its known distribution.*

All the species considered here are distributed much further than the location of the proposed port expansion.

Conclusion: The proposed expansion of Port Botany is unlikely to have any effect on the marine mammals considered here or on whale sharks, hence no SIS is recommended, and no special management measures are required.

3.3.3 Separate Considerations

In addition to the species considered in the sections above, there are a number of other species and one community listed for consideration in the legislation. Apart from the community, these species are not considered to be at risk because of the proposed expansion of Port Botany. The reasons for this are specified in this section.

3.3.3.1 Endangered Ecological Community

Under the *TSC* Act, Sydney freshwater wetlands in the Sydney Basin Bioregion are scheduled as an endangered ecological community. On this basis, the wetlands associated with the Mill Stream and possibly the Sir Joseph Banks Park need to be considered. The Mill Stream forms a series of interconnecting ponds extending north east from Sydney Airport to Eastlakes, Pagewood and Daceyville. Sir Joseph Banks Park extends along the northern side of Foreshore Road from Botany to Banksmeadow.

Under the proposed expansion of Port Botany, there would be no direct impact on the wetlands associated with the Mill Stream or Sir Joseph Banks Park.

One potential risk to the wetlands associated with the Mill Stream, Lachlan Swamps or Sir Joseph Banks Park is that the construction of the new facilities may affect groundwater levels, which could then affect water levels within the wetlands. Groundwater issues have been addressed for the proposed port expansion by Merrick and Knight (2003). Modelling shows no change to groundwater within the Mill Stream or Lachlan Swamps. At some of the ponds within Sir Joseph Banks Park there would be a maximum predicted increase in the groundwater level of 0.06 m. This increase is small compared to natural variation in groundwater (at least 0.35 m) and hence is unlikely to affect the distribution of aquatic habitat within, or aquatic flora and fauna of these ponds.

3.3.3.2 Endangered Population of Little Penguins

Under the TSC Act, there is an endangered population of little penguins at Manly Point, in Sydney Harbour. Adults from this population could be expected to range 10 to 30 km from Manly while hunting prey (NSW NPWS 2002). Thus, it is possible that they would travel as far as Botany Bay. Populations of little penguins from the Hawkesbury area (i.e. Lion Island) and the Wollongong area (i.e. Five Islands Nature Reserve) – which are not listed as endangered – would be unlikely to range as far as Botany Bay.

It is unlikely that the habitat within the area proposed for the expansion would be particularly significant for the Manly population of little penguins. Moreover, the types of impacts associated with the project (e.g. shipping, dredging, etc) would be similar to disturbances that have occurred or are currently occurring in Sydney Harbour, where the endangered population exists. On this basis, it is considered that the Manly population of little penguins does not require special consideration in relation to the proposed port expansion.

3.3.3.3 Listed Marine Species (*EPBC* Act)

As noted in Section 2.0, Listed Marine Species constitute a diverse group of marine animals. Many of them occur rarely in and around Botany Bay – examples being sea snakes and dugong. Whilst they are reported in the bay from time to time their rarity in the study area suggests that effects of the proposed port expansion would be intermittent and difficult to pinpoint. Moreover, any disturbance would be highly unlikely to affect populations of these species.

Fur seals and, to a lesser extent, leopard seals, are regular visitors to the NSW coastline and several of our coastal islands (e.g. Montague Island, Five Islands and Seal Rocks) have individuals or colonies of non-breeding fur seals. Changes to habitat caused by the proposed port expansion would have little effect on seals and construction and operational activities would be avoidable in most cases, unless an individual was in poor condition and therefore less mobile.

One group that does require some consideration includes the seahorses, pipefish and sea dragons (Syngnathidae) and the ghost pipefish (Solenostomidae). The common or weedy sea dragon (*Phyllopterx taeniolatus*) frequents rocky reefs in central and southern NSW and extending further south (Kuiter 1993). Typically, it occurs around the edges of kelp beds and there are populations at the entrance to Botany Bay, including Henry Head on the north and Inscription Point extending around to Kurnell on the south. Weedy sea dragons may occur around breakwaters within the area proposed for expansion, but would be unlikely to occur in areas proposed for dredging or reclamation.

Ghost pipefish, pipefish and sea horses occur on rocky reefs and seagrass beds (Kuiter 1993). Therefore, they would be affected by the proposal, which would cause disturbances to seagrasses. It is recommended that the assessment and management of the development on pipefishes and seahorses be linked to that for seagrasses and macroalgae, as mapped in Chapter 2 and evaluated in Chapters 5 and 6.

3.3.3.4 Fauna Under Consideration (*EPBC* Act)

Several marine fishes were being considered by the Threatened Species Scientific Committee as at February 2002 (Table 3). Of these, black cod are scheduled under the *FM* Act and were considered above in Section 3.1.4.

All the other species are highly unlikely to occur inside Botany Bay (Edgar *et al*. 1982, Last and Stevens 1994), hence require no further consideration in the context of the proposed port expansion. Examples include Zeibell's handfish and Maugean skate, which occur in Tasmania. Red or spotted handfish occur in deep waters off the NSW coast (Hutchins and Swainston 1986; Kuiter 1993), although Bruce *et al.* (1998) reported them occurring only in Tasmania. Both species of dogfish occur in deep waters of the continental shelf and/or slope, while Colclough's shark occurs in Queensland at locations north of Gladstone (Last and Stevens 1994). Humphead Maori wrasses occur in tropical and subtropical waters (Donaldson and Sadovy 2001) and would occur rarely as stragglers on the NSW mid coast.

3.3.3.5 Protected Species (*FM* Act)

Under the *FM* Act, provision is made for listing of species as protected (Table 2). The protected status reflects more a susceptibility of the species to capture (for food, sport or display in aquariums) rather than known susceptibility to other types of disturbance or known rarity. There is no requirement that 8-part tests are done for these species and it is most unlikely that they would be caught as a result of the proposed development.

3.3.4. Key Threatening Processes

Several key threatening processes are identified under the *TSC* and *FM* Acts (Tables 3.1 and 3.2). In most, if not all cases they are unlikely to be associated with the proposed expansion of the port facilities. Potentially, if groundwater is affected, there may be changes to patterns of surface water that could have some effect on the distribution of mosquito fish (Table 3.1). However, given that groundwater changes that would occur near freshwater habitats would at most be very small compared to natural variability (Merrick and Knight 2003), this key threatening process is not relevant to the assessment process.

Under the FM Act, a key threatening process is the introduction of fish to freshwaters outside their natural range. It is possible that species that can tolerate freshwater may be introduced via ballast water or ships' hulls and this issue needs to be considered during the assessment process in terms of managing exotic species. Two other threatening processes listed under the *FM* Act apply to removal of woody debris and degradation of riparian vegetation. Removal of woody debris is not part of the proposal. If groundwater levels varied because of the proposal, riparian vegetation might be degraded in the catchment of the Millstream. As discussed above, this is not predicted, as the proposed expansion would have minimal effect of groundwater (Merrick and Knight 2003).

3.4. Conclusions

Based on the description of the project proposal and the information presented above, it is concluded that no SISs be prepared for any species, populations or communities considered above. Notwithstanding this, some issues related to the fauna considered should be incorporated into the design of the project or management plans for the construction and/or operational phases of the project, subject to its approval. These include the following:

- The proposal should, as a precautionary measure, be designed to avoid any changes to groundwater that are beyond the levels of natural variability.
- A management plan should be developed for marine mammals, particularly southern right whales and humpback whales, which might move into the vicinity of the port expansion occasionally.
- The assessment and management of impacts to ghost pipefishes, pipefishes and seahorses should be linked to the assessment and management of seagrasses in the vicinity of the proposed port expansion.

4.0 HUMAN ACTIVITIES AND THEIR EFFECTS ON BOTANY BAY

This section discusses existing and historical human activities in the study area and other parts of Botany Bay and their effects on aquatic flora and fauna. Part of this chapter evaluates the effects of existing port operations and describes a small field experiment examining wild populations of Sydney rock oysters as an indicator of the present impact of antifouling paints.

4.1 Introduction

Botany Bay has been subject to many changes, within the bay, around its shoreline and within its catchment over the past two centuries. An understanding of the major changes is important for two reasons: it provides a framework for assessing the significance of impacts likely to occur as a result of the proposed port expansion and it assists in identifying where cumulative effects may occur. Chapter 2 provided a description of existing aquatic habitats, flora and fauna, much of which occurs within or as a result of new habitat created from the anthropogenic changes. This chapter provides an overview of previous changes in the bay, with emphasis on the study area. The chapter concludes by describing current operations at the Port of Botany, including issues such as response to accidents, management of the potential for introduced species and effects of antifouling paints.

4.2 Creation and Removal of Habitats

Prior to European arrival, Botany Bay was generally very shallow and its shoreline, particularly on the northern and western sides, was dominated by sandy beaches and dunes. Major physical changes have included realignment of streams entering the bay, deepening of subtidal areas as a result of dredging for navigation and to obtain fill and large scale reclamations which have introduced hard surfaces to many intertidal and subtidal areas of the bay. These physical changes have created and removed aquatic habitat and hence changed the occurrence, diversity and abundance of many assemblages.

There have been several major dredging and reclamation programs undertaken within Botany Bay (SPCC 1981, Jones 1981, Jones and Candy 1981, Kinhill 1990, 1991, AMBS 1993, 1998, MPR 1998, Lawson and Treloar 2003). Major programs include the following:

- Creation of a borrow area near the entrance to Cooks River for fill for the original North-South airport runway, and construction of training walls at the mouth of Cooks River
- Works associated with construction of the original Port Botany, including
    - creation of the Revetment Wall (Molineux Point)
    - reclamation along the northern shore of Botany Bay to create Foreshore Road, which also created Foreshore Beach
    - Creation of Brotherson Dock and Penrhyn Estuary
    - dredging of the channel at the entrance to Botany Bay to enhance navigation and direct wave energy away from the northern side of the bay

- Construction of the Parallel Runway, which entailed:
  - Addition of the runway extending out into Botany Bay, with associated loss of sandy or muddy vegetated and unvegetated habitat
  - Redirection of the Mill Steam and channelisation with vertical seawalls
  - Creation of borrow areas to obtain fill for the reclamation
- Construction of groyne fields at Silver Beach and Lady Robinsons Beach in order to arrest beach erosion. It is understood that there are also currently plans for measures to address problems of erosion at Towra Beach, although these have not yet been submitted for approval.

The net effect of these works has been to cause a loss of shallow, sandy intertidal and subtidal habitat and to create two types of habitat.: 1) deep areas that contain much finer sediments and 2) rock or concrete intertidal and shallow subtidal areas that function as artificial reefs.

The invertebrate fauna of deep holes was studied by Jones and Candy (1981), Kinhill (1991) and AMBS (1998). The study by Jones and Candy (1981) concluded that dredging did not affect the diversity of species compared to adjacent, undredged areas, but the assemblage was different. AMBS (1998) studied benthic ecology in dredged holes for two years following dredging for fill for the Parallel Runway. They concluded that recolonisation of dredged holes was relatively rapid, in the order of months. However, compared to other deep holes in the Sydney region, "recovery" (i.e. assemblages in the dredged holes tracking those in undredged reference holes) did not occur after two years. They also observed that deep holes isolated by a sill tended to acquire finer surface sediments and were relatively more depauperate. NSW Fisheries found that fish and mobile invertebrates (e.g. prawns and crabs) tended to differ in deep holes compared to shallow areas (SPCC 1981a, b).

Creation of seawalls, revetments, etc have removed large amounts of existing habitat and created a new, very large habitat in its place. The existing reclamation for the Port Botany was about 205 ha (URS 2003). As discussed in Chapter 2, these new habitats support relatively distinctive assemblages of flora and fauna that may be quite different to the original habitats. Even though these habitats may be structurally very homogeneous, they can show variability in terms of the plants and animals that utilise them. For example, MPR (1998) observed that there were differences in assemblages along the eastern side of the Parallel Runway and attributed these to differences in wave exposure. Lawson and Treloar (2003) have identified a gradient in wave energy along the Parallel Runway. They predict there will be a reduction in both the gradient and in peak wave heights of up to 20% as a result of the proposed expansion. As discussed in Chapter 5, this could also change the aquatic assemblages occurring on and around the runway.

4.3 Water Quality and Sediment Contamination

4.3.1 Catchment Processes

Lawson and Treloar (2003, Volume 2) have considered in detail existing and new information on water quality within the catchments of Springvale and Floodvale Drains, the Mill Stream and stormwater drains discharging along Foreshore Beach. Their findings indicate that whilst the waters of Botany Bay generally have a good standard of water quality, input of some water quality indicators from the catchments are problematic. In particular, there are likely to be inputs of poorly oxygenated water and water with high levels of nutrients and some heavy metals.

URS (2003) have identified contamination in surface waters, but more particularly ground waters, associated with Floodvale and Springvale Drains. These contaminants include volatile halogenated compounds (VHCs) originating from the former ICI (now ORICA) industrial site at Banksmeadow. Of primary concern is the finding that VHCs are migrating towards Botany Bay in the groundwater, with discharge potentially occurring into Penrhyn Estuary and the south eastern end of Foreshore Beach over many years. According to URS (2003), VHCs are relatively volatile and evaporate soon after contact with the atmosphere. They also have a very limited tendency to bioaccumulate; hence aquatic organisms are unlikely to "transfer" the contamination to other areas. They can, however, be quite toxic and may be expected to affect benthic invertebrates as they move through beach sediments and on into Botany Bay.

Merrick and Knight (2003) have identified three major plumes of contaminated water within the groundwater:

- The Southern Plume, consisting mostly of 1, 2-dichloroethane (EDC) and trichloroethane (TCE) and which has reached Penrhyn Estuary in a zone between Floodvale and Springvale Drains at the eastern end of the estuary. Contaminant concentrations in groundwater at this location are expected to become reduced over time due to cessation of chemical production, removal of previous manufacturing locations, remediation strategies and natural attenuation (Merrick and Knight 2003).
- The Northern Plume, consisting primarily of EDC and extending to the south west of the Orica site. It is predicted to arrive at Botany Bay by 2006 and would enter the bay along Foreshore Beach adjacent to the proposed access channel into Penrhyn Estuary (Figure 19 in Merrick and Knight 2003).
- The Central Plume, which is predicted to enter Penrhyn Estuary to the south west of Floodvale Drain over a period of about three years, from 2007 to 2010.

It is important to recognise that, although there are issues of contamination within the catchment, the issue of concern for the proposed port expansion is whether the development would exacerbate the problem. If the development has a positive or no effect on contamination, then it could not be considered unsustainable due to an already existing problem. The extent to which the proposed expansion interacts with these pre-existing issues is considered in Chapter 5.

4.3.2 Dredging and Reclamation

During the construction of the Parallel Runway, there was extensive monitoring of the effects of dredging on water quality and bioavailability of contaminants within Botany Bay (Dames and Moore 1995, 1998, White *et al.* 1994, MPR 1994, 1998). These studies concluded that generally there was little transfer of contaminants into Bay waters or biota as a result of the dredging operation (see also Lawson & Treloar 2003).

4.4 Introduced Species

Alien species introduced into Australian habitats can have a highly detrimental effect on local biota, habitats and economic interests. They can be introduced via numerous vectors, including commercial shipping (Section 4.5.3). There have been at least 3 surveys of introduced species into Botany Bay (The Ecology Lab 1993, Pollard and Pethebridge 2000 and Pollard in press).

Currently, there is concern in Botany Bay and several other estuaries in NSW about the spread of the green algae, *Caulerpa taxifolia*. This species appears to have been introduced by discarding water from aquaria and not via ballast water or commercial shipping. It spreads vegetatively, reproductively, via fragmentation and often on anchors or nets transferred from one estuary to another. In Botany Bay, there is a large outbreak at Towra Point and, during the investigations for the proposed port expansion, The Ecology Lab observed small patches at Foreshore Beach.

It is unlikely that the existing port operations at Port Botany would have contributed to the introduction or spread of *C. taxifolia* in Botany Bay. An issue for consideration, however, is that works associated with construction, particularly any dredging, movement or anchoring of vessels in shallow water, etc, does not lead to unconfined detachment of this species, which could allow it to spread further. This issue is considered further in Chapters 5 and 6.

4.5 Fishing Activities

Fishing is a very important activity in and around Botany Bay. This activity has undoubtedly had some effect on the flora and fauna of the bay and would be affected by aspects of the proposed port expansion.

4.5.1 Commercial Fishing

Botany Bay has been traditionally an important local fishing area supplying the local Sydney markets (SPCC 1979, Steffe and Murphy 1992). Several types of commercial fishing have occurred in Botany Bay, including prawn trawling, beach hauling (also called seining), mesh netting, and trap and line fishing. At the entrance to the bay commercial activities include lobster trapping on coastal reefs, trawling for fish and prawns, collection of abalone and sea urchins and trap and line fishing. A significant proportion of the prawns trawled adjacent to Botany Bay (particularly school prawns) are likely to have migrated out of the bay.

Commercial fishing can affect the flora and fauna of Botany Bay by removing target species and by-product or trash fish. It can also lead to alteration of habitats. In particular, prawn trawling and beach hauling are believed to affect the seabed. Studies done on such impacts have yielded complex results. Traditional grounds for commercial fishing within the study area included Foreshore Beach for hauling and, further offshore, for prawn trawling; and areas around the artificial seawalls, where some fish and lobster trapping was done.

With the declaration of the Towra Point Aquatic Reserve in 1987, commercial fishing was closed in many of the southern parts of the bay. In 2002, the NSW Government closed Botany Bay to all forms of commercial fishing. Areas outside the bay are still open, and it may be expected that commercial fishers will be able to capture fish and invertebrates that leave Botany Bay.

Given the closure of Botany Bay to commercial fishing, there are only two issues that need to be considered in relation to the effects of the proposed port expansion:

- Whether the proposed expansion might interfere with any studies initiated to measure the recovery of habitats and fish stocks following the closure.
- Whether the proposed expansion is likely to affect fishing activities outside the bay (e.g. by affecting stocks that migrate from the bay and hence become available to fishers).

These issues are discussed in Chapter 5 of this report.

4.5.2 Aquaculture

There have been three forms of aquaculture within Botany Bay, all restricted to the southern parts of the bay. The most significant of these was oyster farming and there are extensive oyster leases in Quibray Bay and Woolooware Bay, as well as further upstream in Georges River. In recent years oyster farming in the bay has declined to the point where now it has virtually ceased (NSW Fisheries, pers. comm.) due to a combination of factors, particularly disease and loss of market due to fears of pollution.

Apart from oyster farming, there have been two experimental aquaculture ventures in the bay: a small "mussel raft" was deployed in Quibray Bay by the University of NSW as a substratum for black mussels; and a fish farm initiated by NSW Fisheries for grow-out of snapper and mulloway and located at Silver Beach, to the west of the Caltex Oil Refinery terminal wharf. The mussel raft is no longer present in Quibray Bay and the fish farm has been commercialised.

The construction of many oyster leases within Botany Bay has, over the years, introduced artificial habitat with some issues of potential pollution (e.g. use of tar on sticks). As many of the leases have now become derelict, a problem has arisen regarding disposal of the lease materials, land-based infrastructure, etc. Given that the leases and other aquaculture ventures are confined to the southern sides of the bay, they are likely to have little influence on the aquatic environment surrounding Port Botany. Nevertheless, issues related to water quality and hydrology in relation to the whole of Botany Bay will need to be assessed as part of the environmental assessment for the proposed port expansion (Chapter 5).

4.5.3 Recreational Fishing

Recreational fishing is very popular within Botany Bay, due to the large population centre within its catchment, ready access from shore and boats, relative safety and variety of fish that may be targeted (SPCC 1981c). Most fishing is line fishing done from boats or the shore, including beaches, rocky headlands and artificial breakwaters, groynes, etc.

Large boat ramps are located at Penrhyn Estuary, near the mouth of the Cooks River and at Silver Beach, with several smaller or derelict ramps around the bay. The boat ramp at Penrhyn Estuary was originally located on the eastern side of the inner estuary, but due to accretion of sand at the neck between the inner and outer parts of the estuary, the ramp was relocated in the early 1990s to facilitate navigation.

Further social and economic details of recreational fishing, including usage of boat ramps, is provided in URS (2003).

4.6 Existing Port Operations

4.6.1 Summary of Operations Relevant to Aquatic Ecology

Existing port operations at Port Botany are described in detail in URS (2003). Here issues of relevance to aquatic ecology are summarised, which will assist in identifying how operations would change under the proposed port expansion (discussed in Chapter 5).

The existing operations at Port Botany consist of two container terminals, one on either side of Brotherson Dock and a bulk liquids berth at Molineux Point, on the south eastern side of Brotherson Dock. There is a crude oil berth at Kurnell, but this would not be affected by the present proposal.

Within each terminal at Brotherson Dock, stormwater from the terminal is discharged into Botany Bay. First flush from bunded areas and other specified areas such as maintenance, container wash down and fuel storage areas is treated and discharged to the sewerage system (Arup 2003).

Potential hazards associated with the existing container operations include berthing, loading and unloading of ships carrying dangerous goods and storage and handling of those goods. Impacts to the aquatic environment could include spillages, release of ballast water from ships, introduction of exotic species on ships' hulls and antifouling paints associated with container vessels and tugs that are based at the terminal.

4.6.2 Accidental Spillages

The following information is based on information provided by SPC (correspondence M. Calfas, 6/1/03). Under the Ports Corporatisation and Waterways Management Act, 1995, a key objective of the SPC is to ensure that its port safety functions are carried out properly. The functions include, but are not limited to, dangerous goods handling, emergency response and port communications. The functions are covered by a port safety operating licence (PSOL) granted by the NSW Government.

The emergency response function in the PSOL covers all port related emergencies within Sydney Harbour and Port Botany with particular emphasis on oil spills. SPC must investigate and respond to all reports of oil and chemical spills within its area of operation. Oil spill equipment held by SPC comprises > 10 km of containment booms, skimmers with a recovery capacity of 100 t of oil per hour and fire fighting tugs. In addition, under the National Plan, mutual aid arrangements can provide supplementary equipment from other states, the Australian Navy and industry.

In 2001/02 SPC received and investigated 229 reports of marine pollution, 7 of which (i.e. 3%) were sourced from commercial shipping operations. Trained staff members are present at the commencement of every bulk oil, gas and chemical transfer to ensure that the ship to shore safety checklist is completed and transfer can be done safely. Random audits are also conducted by SPC.

4.6.3 Ballast Water and Hull Fouling

It is recognised that pest species may be introduced into Australia via ballast water (Hewitt and Martin 2001, Barry and Bugg 2002) and hulls (Rainer 1995) on commercial shipping.

The use of antifouling paints inhibits attachment of exotic species to ships' hulls, but some vessels have old, ineffective paint. Organisms can attach to areas not antifouled, or be transported in mud attached to anchor chains, etc. Moreover, antifouling paints are potentially toxic to native organisms occurring within estuaries (see below).

Currently, ships berthing at Brotherson Dock are held at the berth by cables and do not need to use their own anchors. They are also typically in port for 36 hours or less. Moreover, they are not allowed to clean hulls (e.g. by divers) whilst in port. Hence, there is a limited chance fouling organisms to be transferred to Botany Bay whilst in port.

With respect to the discharge of ballast water, container ships have more import containers than export containers at Port Botany, hence there is more of a need to take on ballast water and rarely a requirement to discharge it. Therefore, Port Botany is not subject to frequent large discharges of ballast water (URS 2003). Within Botany Bay, ballasting may be required at the Bulk Liquids Berth and the crude oil berth at Kurnell, but operations for neither of these facilities would change under the proposed port expansion.

Prior to discharge of ballast water, all international ships must obtain approval from the Australian Quarantine Inspection Service (AQIS), who use a computer modelling programme to assess whether the vessel can discharge in port, or must treat its ballast water (i.e. by exchanging ballast with offshore waters). The programme essentially determines the risk of introducing one or more of 12 designated pests (nominated by the then Australian Ballast Water Management Advisory Committee, ABWMAC). The pests include several species of toxic dinoflagellates and a range of invertebrates, including polychaete worms, crustaceans, molluscs and sea stars. The programme, known as the "Ballast Water Decision Support System" (BWDSS) is highly precautionary in favour of the environment, with some 90% of requests for discharge by international shipping being required to exchange ballast water offshore (Barry and Bugg 2002).

Currently, there is no equivalent procedure in place for domestic shipping, despite the fact that numerous pest species have already been introduced into other Australian ports. Since 1991 there has been a trial in Western Port (Victoria) to develop a nationally based scheme that will, hopefully, be extended to all Australian ports by the time the new terminal would be operational (Meyrick, in preparation).

4.6.4 Antifouling

As part of the scoping for the proposed port expansion, the issue was raised that an increase in shipping to Port Botany would lead potentially to an increase in the amount of antifouling paints, particularly the use of tin-based compounds. Therefore, it was resolved to seek advice on current practices of the use of antifouling paints on commercial shipping and to conduct a brief survey of the condition of oysters growing around Brotherson Dock and other parts of Botany Bay. Oysters show physical evidence of the effects of tin-based antifouling paints (Scammel 1990, Batley *et al.* 1992) and would provide a simple way of assessing the potential environmental effect of one aspect of the current port operation.

4.6.4.1 Use of Antifouling Paints on Commercial Shipping

Antifouling is required to ensure the efficiency of vessels, by maintaining low water resistance and to reduce the risk of transferring biota from one port to another. This section is based on advice obtained from Dr Marcus Scammel commissioned by The Ecology Lab on behalf of the SPC.

Approximately 70% of the world fleet is currently protected with modern tributyltin (TBT) based self-polishing copolymer paint systems. Therefore, most of the ships visiting Port Botany, as well as the tugs employed there use TBT antifouling paints. While the biologically active ingredient is chemically fixed to the polymer chain, a controlled and slow hydrolysis at the active zone of the paint guarantees a constant, but very low, TBT release from ship hulls.

The Marine Environmental Protection Committee of the International Maritime Organization (IMO) intends to ban, in the long term, all antifouling systems that exhibit harmful effects, including TBT based systems (IMO/MEPC 40 1997). This requires development of antifouling systems with acceptable performance standards and the fewest possible adverse effects for the marine environment. In November 1999, the IMO agreed that a treaty be developed by the MEPC (Maritime Environmental Protection Committee) to ensure a ban on the application of TBT based antifouling paints by January 1, 2003, and a ban on the use of TBT by January 1, 2008 (see also AMSA 2002).

There are essentially two types of TBT based paints:

- Free Association TBT based Paints. Within free association paints the biocide is dispersed through a resinous matrix. The release rate for the biocide is uncontrolled and tends to be rapid initially, with the effect wearing off in 18 to 24 months as the biocide leaches out of the paint.
- TBT Self Polishing Copolymer Paints. The Self Polishing Copolymer systems are self-smoothing or self levelling. In this type of coating the biocide (TBT) is attached to the plastic molecule making up the backbone of the paint. This plastic hydrolyses when in contact with seawater, releasing both TBT and the plastic molecules. The leach rate is dependent on hydrolysis of the surface layer and in this way a controlled and uniform leach rate is obtained. As seawater moves past the hull, those areas with greater turbulence breakdown more quickly enhancing fuel efficiency via creating increasingly smooth surfaces.

The two different systems reflected the needs of boating and were thus highly successful. A boat on a mooring, such as a recreational vessel, needs a paint that leaches while the boat is stationary. A boat that is constantly moving requires a paint that is effective when the boat is underway, but does not require protection while stationary. As a consequence of this different paint type usage, moored recreational vessels were associated with dramatically larger environmental impacts than commercial vessels.

This is part of the reason why the vast majority of action against TBT has been focused on moored recreational vessels. The second environmental reason was that large vessels needed effective antifouling paint to reduce the transport of exotic organisms.

In many countries the use of TBT has now been restricted on vessels less than 25 m in length and in NSW a ban on the use of TBT on recreational vessels has been in place since 1987. The move to ban the chemical globally has been progressively brought forward by the IMO as viable alternatives have become available. It is noteworthy, however, that the scientific community has not sought a call for global control at large. The view to ban TBT seems to be associated with the precautionary principle rather than with a measured concern. The scientific community has expressed concern with respect to the spread of exotic species and it is for this reason that "wait for an alternative approach" has been supported. It would appear, however, that the IMO is satisfied that adequate technology now exists to replace the Self Polishing Copolymer varieties of TBT.

It is reasonable to expect that existing impacts of TBT will dissipate as the global ban is implemented and alternatives become more widely used. It is also reasonable to believe that booster biocides will follow the trend towards chemicals that have poor environmental persistence. Regulatory avenues now exist for the protection of the marine environment that did not exist when TBT was commercially introduced. The probability of a TBT like impact occurring again is considered small given the regulatory process that exists because of it.

The impacts associated with commercial vessels is generally not of major concern locally because they are not often in locations that threaten sensitive areas and their antifouling agents are generally ineffective while stationary.

4.6.4.2 Supplementary Survey of Oysters in relation to TBT

4.6.4.2.1 Aim

The aim of this supplementary survey was to determine if the proportion of wild oysters showing deformities consistent with TBT toxicity is greater at sites close to the existing Port of Botany compared to the proportion of oysters sampled in other parts of Botany Bay.

4.6.4.2.2 Methods

Four sites were visited by boat at low tide on 18/7/02, two around Port Botany and two reference sites. Positions were recorded using a hand held GPS, with chart datum WGS 84 and format in eastings and northings (Zone: 56H). The four sites were:

- The seawall at the front of the Patrick Terminal, on the north western side of Brotherson Dock (Easting: 0334351; Northing: 6239870).
- The seawall at the south western end of Molineux Point, i.e. the opposite end to the bulk liquids berth (Easting: 0334631; Northing: 6238357). This site had a large amount of flotsam and jetsam in the upper intertidal, indicating that currents may move surface waters, including contaminants, into this area.
- The end of the third groyne from the western end of Silver Beach, which lies immediately to the east of the boat ramp (Easting: 0333058; Northing: 6235660).
- The southern breakwater at the entrance to Cooks River, approximately 75 to 100 m west of the mouth of the river (Easting: 0330755; Northing: 6241903).

At each site, an observer and scribe were put ashore. The observer counted all live oysters and the number of oysters showing deformities (i.e. shell curling) within 7, 50 x 50 cm quadrats thrown haphazardly within the mid-tide level. Data were recorded on waterproof paper by the scribe. Data were analysed using a 1-way Analysis of Variance (ANOVA) comparing sites (n = 7). Prior to analysis, homogeneity of variances was tested using Cochran's C Test and data transformed where necessary. Where ANOVA indicated significant effects, individual means were examined using Student Newman Keuls (SNK) Tests. Details of these procedures are available in Winer *et al.* 1991 and Underwood 1997.

4.6.4.2.3 Results and Conclusions

Live oysters were common at all sites. There were significant differences in the number of live oysters per quadrat among sites (F = 6.69, P = 0.002, 3, 24 df) but the SNK test did not clearly differentiate sites. Graphical inspection indicates a trend to larger numbers of oysters at Molineux Point and Silver Beach (Figure 4.1a). There were also significant differences in the proportion of oysters with shell deformities (F = 4.58, P = 0.011, 3, 24 df) but again the SNK Test could not differentiate means. The trend here is for higher proportions of deformities at Molineux Point, followed by Brotherson Dock, with very small incidences of deformities at the reference locations (Figure 4.1b).

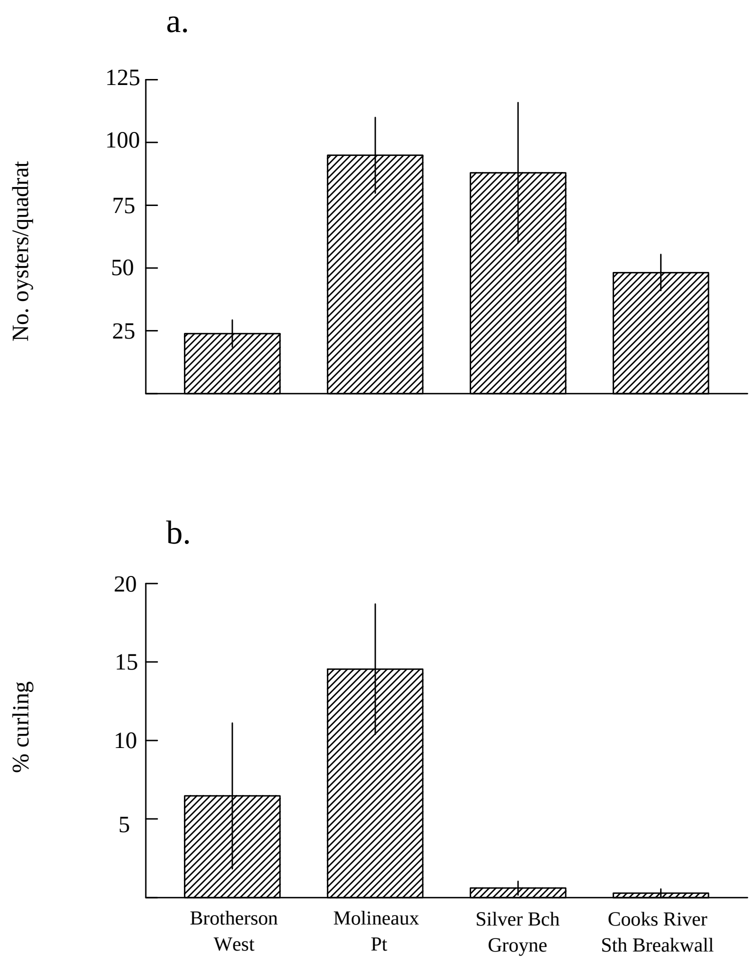


Figure 4.1. Survey of oysters at sites around the current Port of Botany (Brotherson Dock and Molineux Point) and at control locations elsewhere in Botany Bay (Groyne at Silver Beach and Cooks River Breakwall). a) mean (+ SE) number of oysters per quadrat; b = mean percentage of oysters per quadrat (+ SE) with shell curling. n = 7 quadrats for both figures.

The results of this survey indicate that live oysters are relatively common around the existing port, but that between 5 to 15% of oysters show some physical evidence of effects due to TBT. They also showed relatively large variability among replicates at Brotherson Dock and Molineux Point as shown by the large standard errors in Figure 4.1. This suggests that any future studies that may be required should collect more replicates. The trend to slightly higher percentages at Molineux Point may reflect either that ships are moving more rapidly past this point, and hence are leaching TBT in close proximity to the point, or that TBT, which tends to accumulate at the water surface, may be carried in currents to this area.

According to Scammel (pers. comm.) the percentages of deformities recorded are relatively small compared to areas that are heavily affected by TBT. Nevertheless, it would appear that commercial vessels and/or the tugs based in Port Botany are leaching TBT, which is affecting oysters and possibly other components of the aquatic environment. The extent to which this trend may be affected by the proposed port expansion (and also the proposed ban on TBT from 2003) is assessed in Chapter 5.

5.0 ASSESSMENT OF IMPACTS FOR PROPOSED PORT EXPANSION

This chapter presents a description of the proposed development as described in the EIS, with emphasis on those features most relevant to the aquatic environment. It then discusses physical, chemical and biological stressors and their predicted effects on the aquatic environment, both within the study area and in other parts of Botany Bay.

5.1 Description of the Proposed Port Expansion

5.1.1 Port Footprint, Layout and Staging

A detailed description of the proposal is presented in URS (2003). This section summarises those aspects of the proposal most relevant to aquatic ecology, conservation and fisheries and assists in identifying those issues that need to be assessed in detail.

The proposed port expansion would be developed in two phases (URS 2003):

- Phase 1, which would involve the reclamation and associated construction work to prepare additional terminal land of about 60 ha.
- Phase 2, which would involve the incremental completion of up to five container berths, services, etc. It is important to note that the assessment for this proposal includes consideration of the Phase 2 components.

The layout of the port facility, including the proposed expansion, is shown in Figure 5.1. The expansion would create an additional 1850 m of wharf face – 550 m extending east-west from the existing northern wharf face (i.e. Patrick's Terminal) at Brotherson Dock and 1300 m extending north-south, parallel with the Third Runway. The expansion would create enough space for an additional 5 container berths at Port Botany. The container berths would each comprise 600 tubular steel piles, coated with heavy duty epoxy paint. There would also be space allocated at the north-western end of the terminal for 6 tug berths.

Under the proposal, Penrhyn Estuary would be retained, but it would become semi-enclosed, with a tidal connection to Botany Bay along a channel 130 m wide running parallel to Foreshore Road. Tidal flushing would be maintained to the estuary throughout the reclamation phase and the area of the access channel would not be filled at any time (URS 2003). The total area of the estuary would be about 27 ha and it would be enhanced to provide habitat for bird waders and seagrasses (Section 5.1.5).

The construction schedule for key elements of Phase 1 of the proposed port expansion is as follows:

- Dredging & reclamation: 15 months duration.
- Public recreation areas: intermittently over 9 months duration.
- Consolidation: 18 months duration.
- Road and rail infrastructure: 33 months duration.
- Deck construction: 21 months duration.

Figure 5.1. Layout of proposed port expansion. Source: Sydney Ports Corporation, 14/5/2003.

Note that some of the activities would be likely to occur simultaneously.

5.1.2 Dredging and Reclamation

The reclamation would require 7.5 million m^3 of sand and 175,000 m^3 of rock. The sand would be sourced mostly from the bed of Botany Bay, including:

- The bay floor on the western edge of the new terminal (i.e. between the new terminal and the Parallel Runway). The deep area created by dredging would become part of the navigational channel and berthing area for container vessels.
- Several areas ("high spots") within the current shipping channel which are shallower than the main channel and are problematic for manoeuvring vessels. These areas would yield about 220,000 m^3 fill.

A cutter suction (hydraulic) dredge would be used to obtain fill for the reclamation. The fill, comprising mostly fine to medium grained sands, would be transferred to the reclamation site in a slurry, via a floating pipeline. This methodology is effective for pumping material up to 2 km from the point of dredging.

Due to the heavy structures and high pavement loads of the new terminal, structurally better sandy material would be used. A small proportion of dredged material would be fine marine silt and mud unsuitable for the terminal reclamation; the actual amount of this cannot be estimated until detailed boreholes are drilled during the detailed design (URS 2003). It is understood that any fines would be used in the estuary.

Silt curtains would be used to contain any turbid plumes created during dredging and reclamation. The positioning of the curtains is shown in Figure 8.4 of URS (2003).

The dredging program would run 24 hours per day, 7 days per week and the weekly transfer of fill would be 175,000 $m^3 wk^{-1}$, with a campaign spanning 12 to 15 months. The time estimated to dredge the navigation "hot spots" would be 4 weeks.

At the completion of dredging, the dredged area adjacent to the new terminal would form an extension of the existing navigation channel. It would be from -16 m to -20 m deep (LAT). The batters of the slope would be: 1:2.5. A small amount of dredging would be required to create the navigational channel for the new boat ramp. This would be far shallower than the main dredging works. The amount of material to be dredged for the access to the boat ramp would be determined during the detailed design phase, but it would be confined to the channel area as shown in Figure 8.3 of URS (2003).

Rock delivery would be to the area adjacent to Foreshore Road near the car park for the proposed new boat ramp. From this point barges would be used to place the rock to form a multi-terraced embankment for the reclamation (URS 2003). This would be created by barging rock to the marine working face, where it would be delivered to the construction site using a telescopic chute.

In addition to the reclamation for the proposed terminal, some of the dredged material would be used to enhance the beach and provide a public recreation area. Sandy material dredged from the channel would be allowed to dry and then used as a surface layer for construction of the new beach (URS 2003).

5.1.3 Construction

Upon completion of the reclamation, the wharf face would have a rock margin. Four possible embankment designs are described within the EIS (see Figure 6.2 in URS 2003). The preferred alternative wharf structure is a steel-piled, concreted deck wharf above a revetted slope (URS 2003). The berth structure and container crane rails would comprise:

- 3,300 tubular steel piles (750 mm diameter and of variable length, depending on subsurface conditions);
- 200,000 m^3 rock armouring berm consisting of blocks of igneous rock up to 750 kg in weight; and
- 70,000 m^3 reinforced or pre-stressed concrete.

The basic wharf work would involve continual use of large mobile cranes, a pile driving hammer and earthmoving plant for the infilling and ground compaction operations. Construction of the first berth would take approximately 2 years, each subsequent berth would take about 21 months to build. It is expected that the new terminal would be fully operational by 2025, with the first berth being operational by 2010.

The tug berths would be a composed of a piled jetty. The tidal channel into Penrhyn Estuary would involve excavation of the channel to -1.5 m LAT. The channel would have a sandy beach on its northern side and a sloping rubble rock wall on its southern side. This type of seawall is different to the vertical, relatively smooth concrete wall around the perimeter of the Parallel Runway.

Rail access to Port Botany would be upgraded under the proposed expansion. The rail line would involve the following.

- a rail bridge crossing over the proposed channel adjacent to Foreshore Road to connect to the new terminal;
- a rail bridge or culvert crossing over Springvale and Floodvale Drains;
- signalling, signage and lighting; and
- landscaping, including footpaths and cycleway.

As noted above, the public recreation area would cover about 11 ha and would extend from the mouth of the channel to Penrhyn Estuary northwest to the mouth of the Mill Stream. At each end of the area there would be a breakwater – one each at the entrances to Penrhyn Estuary and the Mill Stream. The recreation area would consist of a boat ramp, access road and car park, a sandy beach, landscaping, fencing, water reticulation, lighting, etc. This would also include enclosed fish cleaning facilities and appropriate bins for fish refuse in accordance with minimising the attraction of birds to the area, hence the risk of bird strike on aircraft (URS 2003).

According to URS (2003), the existing boat ramp in Penrhyn Estuary would be phased out by the completion of the construction of road and rail access. The new boat ramp would be completed to a stage where it could be used immediately following the last of the rock emplacement during dredging and reclamation works, to ensure that access to a usable boat ramp is maintained throughout project construction.

5.1.4 Operation

Operational aspects of the proposed port expansion are generally considered as part of Phase 2 of the expansion and include physical movement of traffic and cargo and design and implementation of management systems. Key aspects of Phase 2 for aquatic ecology include:

- Stormwater management and drainage, including containment of "first flush" runoff from storms and discharge into Botany Bay of water to an appropriate standard by capturing and treating, if necessary, the first 10 mm of any rainfall event. The discharge would occur at two points – one at the access channel to Penrhyn Estuary and the other toward the northern end of the western face of the terminal (Arup 2003).
- Sewerage and trade waste disposal.
- Lighting and noise, including noise barriers that would also restrict light. It is understood that there would be no requirements for blasting as part of the proposed port expansion.
- Use of a permanent surface boom to be placed in the tidal channel into Penrhyn Estuary. This would provide a barrier into Penrhyn Estuary against oil spills and would also prevent boat access. A means of opening the boom (either totally or in part) would facilitate access for research, maintenance, etc.
- Emergency systems, including emergency and incident planning and response, particularly in relation to spillages that could enter Botany Bay.

5.1.5 Enhancement and Restoration of Aquatic Habitat

5.1.5.1 Penrhyn Estuary

Extensive restoration works are proposed for Penrhyn Estuary as part of the port expansion, (Figure 5.2). These include the following:

- Creation of habitat for wader birds by limiting access for humans, dogs, etc and enhancing or creating:
  - Up to 6 ha saltmarsh habitat (by levelling existing fore dune) and removing mangroves;
  - 12.5 ha intertidal sand and mud flats with a substratum suitable for prey species, created by filling deeper areas of the estuary; and
  - up to 8 ha of seagrass habitat, distributed along the main tidal channel to the estuary and in the entrance area to the estuary (see below).
- Suitable tidal flushing and provision for water dispersal during wet weather events.
- Potential for installation of traps at the mouth of Springvale and Floodvale Drains to capture sediment and gross pollutants (e.g. litter). This would be subject to detailed design.

Larger mangroves with extensive root systems would be cut down in a way that would minimise disturbance of sediment. Smaller mangroves (e.g. seedlings and saplings) would

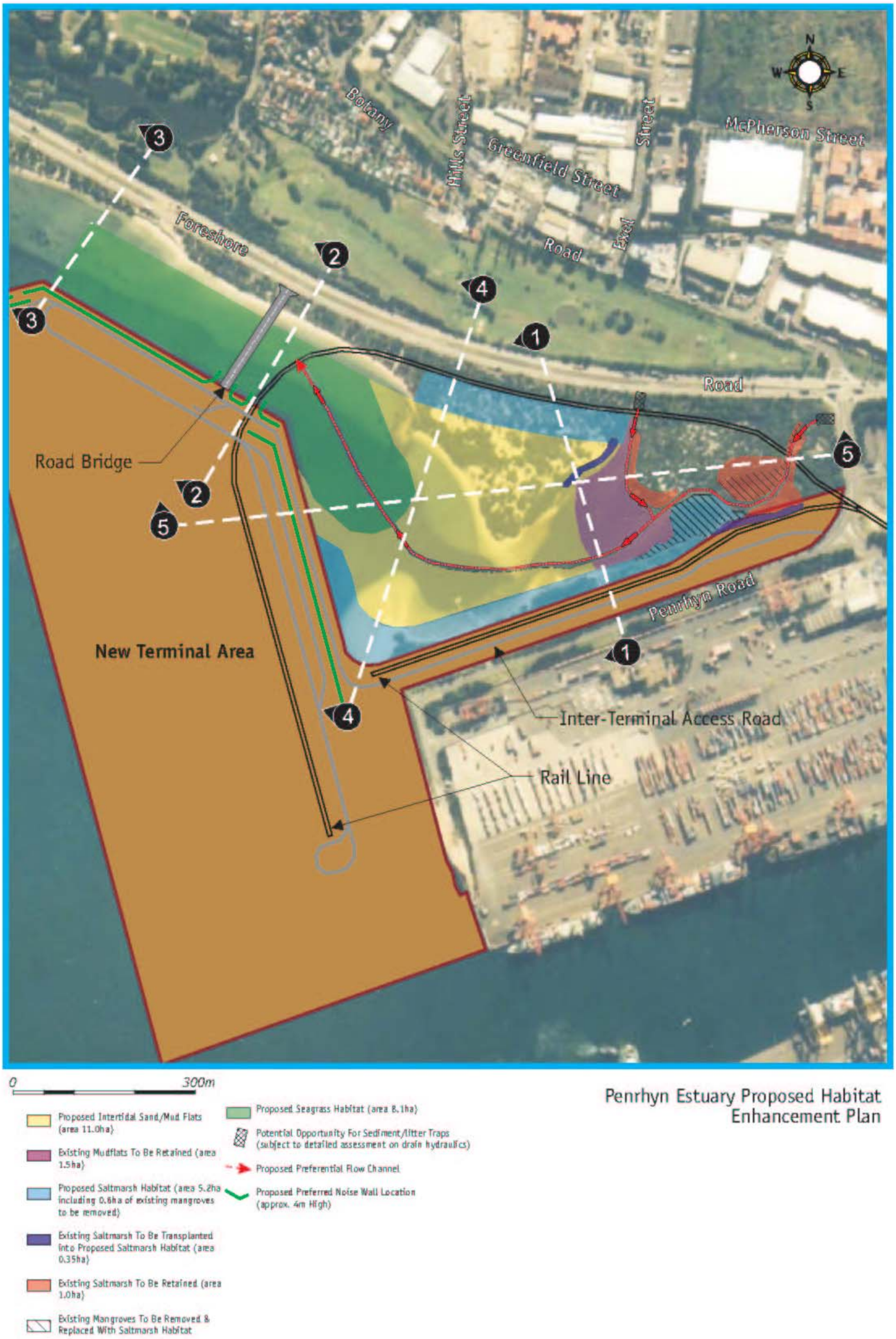


Figure 5.2a. Proposed habitat enhancement for Penrhyn Estuary. Source: Sydney Ports Corporation, 14/5/2003.

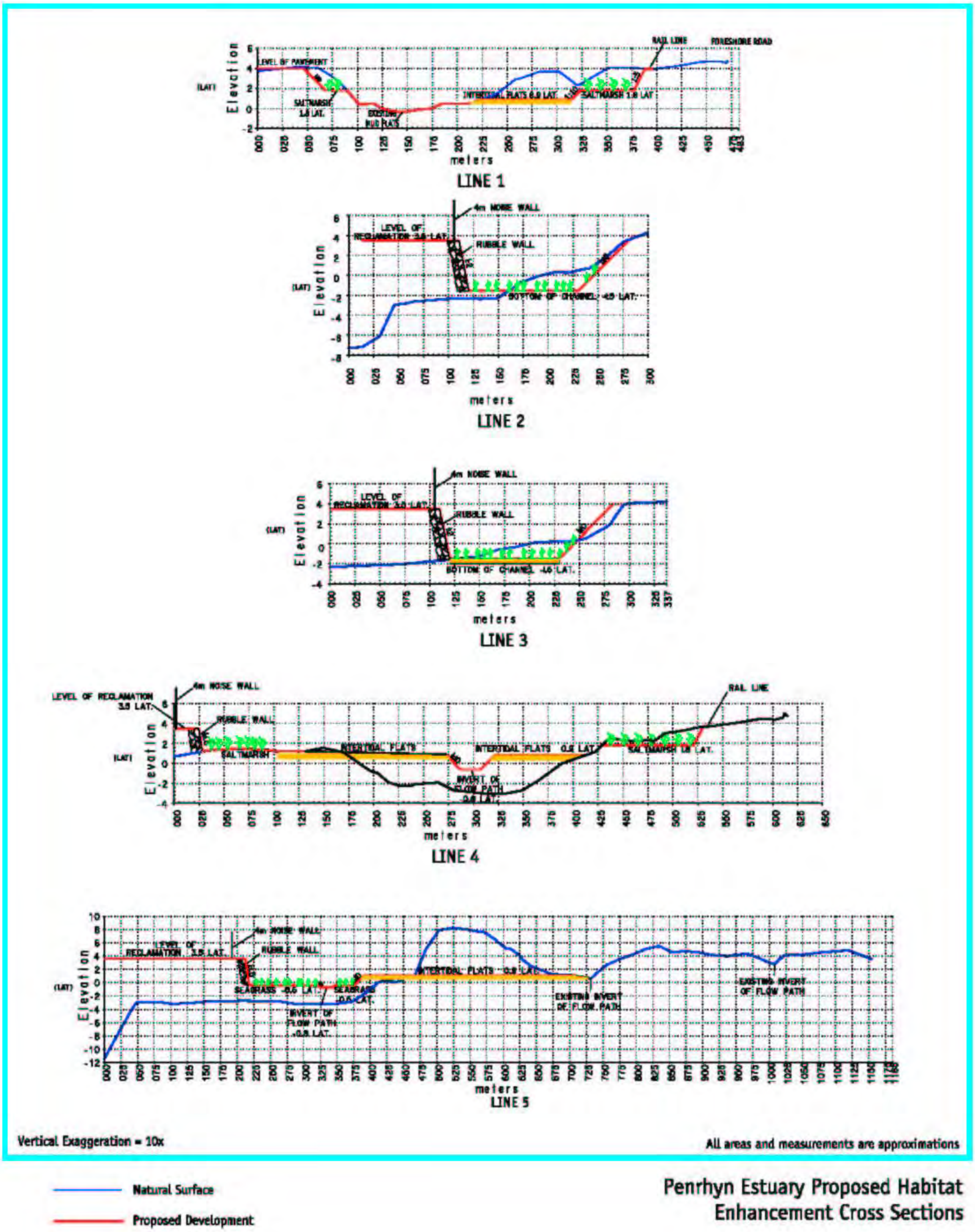


Figure 5.2b. Proposed habitat enhancement for Penrhyn Estuary. Preliminary Cross Section. Source: Sydney Ports Corporation, 14/5/ 2003.

be available to be transplanted to other locations by others where mangroves have been lost previously.

5.1.5.2 Compensation for Initial Loss of Seagrass Habitat

Up to 4 ha of the remaining seagrass habitat in the core study area would be lost as a result the proposed port expansion (i.e. reduction in area from 9 to 5 ha). This would be compensated for by the following:

- Relocation of some seagrass to the terrace adjacent to the parallel runway would be required while the habitat for seagrass within the tidal channel and estuary is prepared. This site was used for transplanting seagrasses removed from Lady Robinsons Beach as a result of beach stabilisation works (Gibbs 2001). Relocation of as much seagrass as possible directly into position within the tidal channel and estuary would be done to avoid the need for any double handling.
- Creating 8 ha of seagrass habitat within the access channel and new embayment of Penrhyn Estuary (4 ha of meadows plus a further facilitation of habitat of 4 ha)
- Establishing or facilitating the establishment of seagrasses (primarily *Zostera capricorni*) in these areas by a combination of transplanting and natural colonisation. The transplants would be sourced from those areas to be impacted by the proposed port expansion or from other local projects where approval is given to remove seagrasses. Transplanting could be done in several ways, including removal by large mechanical devices (e.g. Gibbs 2001) or by removing small plugs of seagrass manually by divers and then placing them into position. The methods to be used would be refined during the detailed design phase.

The areas to which seagrass would be transplanted are considered to be suitable for seagrass growth in terms of available light. Gibbs (2001) measured light in and around the study area to determine whether available light might be a factor in the success of seagrass transplanted to the newly created habitat along the eastern side of the third runway from April 1996 to June 2000. Light was measured at 4 sites between the runways, 4 sites east of the Parallel Runway and 2 reference sites, including one off Penrhyn Estuary.

For all sites sampled (except one site between the runways), the maximum depth sampled was always shallower than the compensation depth for the different levels of light. Seagrasses generally had greater than 15% of surface light available for photosyntheses, sometimes reaching above 49%. The control sites sampled included one site near Penrhyn Estuary, which at all sampling times had 20% or more of surface light available at depth for photosynthesis (Gibbs 2001). Even at the maximum depth of just less than 5 m for which light attenuation was recorded, the maximum depths at which 10 and 15% of surface light was available were almost 8 m and 6 m respectively (Gibbs 2001).

These experimental data collected over a moderate time period and in the immediate vicinity of the proposed port expansion suggest that the depths planned for seagrass compensation habitat would have light attenuation characteristics suitable for the growth and reproduction of seagrasses.

In dealing with relatively sensitive habitats such seagrasses, it is recognised that there is a risk that transplanting would not be successful. The relocation of seagrasses from Lady Robinsons Beach yielded mixed success, with the area between the two airport runways being the least suitable area for transplanting. This is probably due to the high degree of wave exposure and turbulence in that area. In the event that transplanting was not successful, NSW Fisheries have directed that a method of secondary compensation be available. This compensation could take several forms and would involve detailed discussions with NSW Fisheries based on the relevant details at the time. One possible example of secondary compensation might include further modifications to the flat within Penrhyn Estuary to make it more suitable for seagrass growth (such modifications could only be determined after monitoring initial success or failure of the transplanting). Another example may involve enhancing a different type of habitat such as the saltmarsh that would be created in Penrhyn Estuary. A third example may be contribution to habitat restoration in another part of Botany Bay. Clearly, until the circumstances and opportunities are known, it will not be possible to provide a detailed proposal for secondary compensation.

Notwithstanding the above considerations, there are good reasons to suggest that transplanting for the present proposal would have a high chance of success and certainly better than the transplanting of seagrasses from Lady Robinsons Beach. First, the terrace on the eastern side of the parallel runway was the main area where previous transplanting was more successful and, as discussed below, the energy regime at this site would become slightly more sheltered as a result of the proposed port expansion. Thus, it should be an appropriate area for further transplanting.

Second, the area prepared in Penrhyn Estuary would be very sheltered and hence not subject to wave action, a major factor attributed to failures in transplanting. There is some risk that a major flood event could cause scouring, but the configuration of the estuary suggests that the intertidal flat would help to dissipate the energy of flood waters. Furthermore, it is unlikely that a temporary reduction in salinity associated with flooding would cause acute stress to *Zostera*, as this can survive in a broad range of salinities (Larkum *et al.* 1989).

Third, the distance required to transport the seagrasses is small, especially in relation to the relocation of seagrass from Lady Robinsons Beach to the area around the Parallel Runway. This reduces the risk of damage during transit and of desiccation. Indeed, it may be possible for the present project to transport the seagrass underwater and this should be investigated as part of the detailed design.

5.1.5.3 Enhancement of Habitats Associated with Hard Surfaces

Recent investigations have shown that enhancement of hard, artificial surfaces can support a variety of intertidal biota, but that such habitat should not be considered as surrogates for natural shores (Chapman and Bulleri 2003). Similarly, subtidal wharf and breakwater structures support a diverse and abundant fish fauna (Burchmore *et al.* 1985, Lincoln Smith *et al.* 1993), but these often show substantial differences compared to natural rocky reefs. There is also potential for enhancement of artificial structure to optimise diversity and abundance of biota. As part of the proposed port expansion, the habitats associated with wharf structures would be enhanced in the following areas:

- Penrhyn Estuary – that part of the perimeter comprising hard surfaces.
- Foreshore Road Channel
- Container Berths

Details of the nature of enhancement should be developed as part of the detailed terminal design and incorporated into the construction program.

5.2 Potential Physical, Chemical and Biological Stressors

There are a number of potential stressors associated with the proposed port expansion that my affect the aquatic habitats, flora and fauna within the study area or even throughout Botany Bay. Many of these have been identified by other specialists, particularly in terms of water quality, hydrological processes and geomorphology (Lawson and Treloar 2003a, b, c) and groundwater (Merrick and Knight 2003).

5.2.1 Wave Energy and Water Circulation

5.2.1.1 Predicted Changes to Wave Energy and Direction

Lawson and Treloar (Volume 3 in 2003) presented the findings of wave climate studies in relation to the proposed port expansion. These studies are based on the proposed configuration of the reclamation and dredging, including removal of some of the high spots in the navigation channel. They noted that the wave climate of Botany Bay has already been changed significantly by human intervention since European settlement.

In regard to the proposed expansion, further changes in swell waves (i.e. originating outside Botany Bay) would be confined to the area of the bay between the Parallel Runway and Molineux Point (i.e. the core study area). Any changes at potentially sensitive areas, such as Silver Beach, Towra Point and Lady Robinsons Beach would be very small in relation to the existing conditions and hence are not of concern in relation to aquatic ecology.

Within the core study area, numerical modelling predicts that there would be no change or a very small decrease in wave height at the southern tip of the Parallel Runway using the rock wall configuration proposed favoured for the port expansion (Lawson and Treloar 2003, Volume 3). Further to the northwest, the wave height would also decrease. This is an important prediction, because it indicates that there would be a decrease in wave energy in the area of the terrace, which was used previously for seagrass transplanting from Lady Robinsons Beach and is proposed to be use for some transplanting under the current proposal. This decrease in wave energy is likely to favour the growth of seagrasses there.

On the eastern side of the study area, Brotherson Dock would experience little or no change in wave height. Finally, within Penrhyn Estuary any effect due to swell waves would be negligible due to the land creation around most of its perimeter.

Apart from swell waves, local sea conditions can develop within Botany Bay due to the wind and tide. In particular, construction of the port facilities would reduce the fetches for waves propagating to the southern shoreline (Lawson and Treloar 2003). At Silver Beach, modelling showed no change in wave height, whilst the direction of waves shifted about 1° to the west; this was considered to be a very small change with no negative impact on the shoreline (Lawson and Treloar 2003). At Towra Beach, modelling predicted no change in wave height and directional changes of < 1°.

Within the core study area, modelling predicted that the shorter fetch created by the port expansion would reduce wave heights for local seas impinging on the eastern face of the Parallel Runway. There would be some changes in wave direction but this would not affect longshore transport along the runway wall (Lawson and Treloar 2003). At Brotherson Dock there would be either a very small reduction or no change in wave height, whilst changes in wave direction vary from 0 to 6.8°.

Predicted changes in wave direction along Brotherson Dock are not of significance, particularly given the wave heights. Some minor shoreline sand drift in Penrhyn Estuary could occur due to wind waves, but this would not be consistent or significant given the short fetches (Lawson and Treloar 2003).

5.2.1.2 Water Currents and Tides

Water currents were modelled by Lawson and Treloar for both the existing and proposed shoreline configuration (Volume 3 in Lawson and Treloar 2003). The modelling shows little change to currents on a bay wide basis. It was also concluded that there would be very little change in the tidal prism of the bay.

Tide heights in Penrhyn Estuary are and would be the same as in the rest of Botany Bay. Since these heights are unchanged, the tidal penetrations in the two drains would also remain the same. Current velocities in the access channel would be relatively small, reaching 0.15 ms^{-1} during a 1 in 1 year event and 0.3 ms^{-1} during a 1 in 5 year event.

5.2.1.3 Sedimentary Processes

The beach occurring between the proposed new boat ramp and the Mill Stream is currently subject to sand erosion from the eastern end towards the west and has formed a substantial bar at the mouth of the Mill Stream channel. This has probably caused erosion of seagrasses along Foreshore Beach (The Ecology Lab 2001). According to Lawson and Treloar (2003, Volume 3) this sand transport would be likely to continue, with erosion of sand from the new eastern section (i.e. near the proposed boat ramp) and accretion at the Mill Stream (i.e. near the proposed breakwater).

Lawson and Treloar (2003) have predicted that there would be a need to for long term beach maintenance by removing sand as it is transported to the Mill Stream end of the beach and replacing it near the proposed boat ramp. This task would be necessary to keep the entrance to the Mill Stream clear and to ensure the integrity of the boat ramp foundations.

5.2.2 Water and Sediment Quality

Water and sediment quality issues were addressed by Lawson and Treloar (Volume 2 in 2003) and URS (2003). This study by Lawson and Treloar (2003) is based on the use of existing data with limited dry-weather sampling. Staff from URS Australia have been involved previously with extensive studies on contamination associated with Penrhyn Estuary and its catchment, which forms the basis of information provided in URS (2003).

5.2.2.1 Dredging and Reclamation

The physical and chemical characteristics of water and sediments can be affected by dredging and reclamation in several ways, including:

- Decreases in water clarity related to increased concentrations of suspended sediments. This issue is particularly important for the present proposal in order to protect the remaining seagrasses (other than those that would be lost directly) from the potential damage.
- Changes in chemical properties, such as pH and dissolved oxygen.

- Mobilisation of nutrients and toxicants present within disturbed sediments. Potentially, nutrients could trigger algal blooms (either planktonic or benthic) whilst toxicants could:
    - cause direct mortality to aquatic biota,
    - indirect effects by impeding the ability of biota to withstand or avoid other stressors (natural or anthropogenic)
    - bioaccumulate and therefore affect organisms that may consume plants or animals have accumulated those toxicants.

The extent to which these effects will actually occur is hugely dependent on the type of sediment being dredged, the presence of potential contaminants and the method of dredging, including any containment devices used. In addition, there may be similar impacts on water quality in locations where dredge spoil is to be disposed of.

Assessment of the material to be dredged indicates that most of it is sandy with low levels of contamination. Most of the dredging would be done hydraulically, which means that there is limited potential for a plume to develop at the dredge head (most of the slurry is drawn up into pipes and pumped to the reclamation point (URS 2003).

At the terminal site, the dredged material would be deposited just above the seabed. It would not need to pass through most of the water column, which would help to minimise the generation and spread of any turbid spoil plumes (URS 2003). The reclamation would be bounded by a rock perimeter which would essentially form a sill preventing slumping of sand. Using this methodology, it is predicted that any plumes generated by the operation would have low turbidity (Lawson and Treloar 2003, URS 2003). Notwithstanding this, the use of a silt curtain is an accepted precautionary measure providing further control on water quality. The silt curtain would have a pore size in the order of 2 μm, which would result in concentrations of suspended sediment outside the silt curtain not exceeding 50 mg/L. This concentration would reduce to 20 mg/L within 500 m from the curtain (URS 2003).

Geotechnical investigations have concluded that there is some potential for acid-generating soils to be disturbed by the dredging process (Chapter 18 in URS 2003). The investigations concluded that this would not be problematic because most of the material would remain underwater and hence have reduced capacity for oxidation. Moreover, the natural buffering capacity of estuarine water would help to neutralise any acids. For sediments deposited above the water level (i.e. at the top of the reclamation), any acids generated would tend to permeate through the sands below. Moreover, the terminal surface would soon be capped and hence not exposed to the air.

Apart for the sediments that would be dredged and placed within the reclamation, there are two other aspects of the dredging are considered here:

1. A small but at this stage unquantified amount of fine marine silt and mud would be unsuitable for the terminal reclamation for geotechnical reasons. This material has the potential to affect turbidity if not disposed of suitably. At this stage, it is proposed that it would be disposed of in deep water in the berth footprint or used in the estuary enhancement works.
2. Extensive works for habitat improvement are proposed within Penrhyn Estuary. This has the potential to disturb acid sulphate soils and mobilise contaminants. Sediments within the estuary are known to be contaminated with mercury,

chromium and Hexachlorobenzene (HCB). According to URS (2003 – see Chapter 18) this issue is unlikely to be problematic as acid soils and contaminants can be managed effectively during the construction process, for example by capping some of the existing sediments with clean sand.

5.2.2.2 Operational Phase

5.2.2.2.1 Terminal

Operation of the terminal could affect water and sediment quality in three ways:

- Runoff from the terminal surfaces. As described in Section 5.1, stormwater runoff from the terminal would be collected, treated and disposed of into Botany Bay from two locations at the proposed terminal.
- Impacts of antifouling paints. As discussed in Chapter 4, commercial shipping is phasing out the use of organotin antifouling treatment. Consistent with this, tug boats no longer use such treatments.
- Accidental spillages. As discussed in Chapter 4, SPC are required to have established management plans for dealing with spillages in relation to commercial shipping. In addition to this, there would be a boom constructed at the entrance to Penrhyn Estuary in the event of an oil spill that would protect the estuary and access channel.

5.2.2.2.2 Penrhyn Estuary and Mill Stream

Under the proposed port expansion, Penrhyn Estuary and the Mill Stream would continue to discharge water from the surrounding catchments, as at present. Given that there would be no changes to the catchment of the Mill Stream as a result of the proposed expansion and that changes to the entrance of the channel would be relatively small, no changes to water or sediment quality are predicted as a result of the proposal.

Water quality in Penrhyn Estuary is addressed in Volume 2 of Lawson and Treloar (2003). Concentrations were modelled for Total Nitrogen (TN) and Total Phosphorous (TP) in acute and chronic conditions at 7 locations (Figure 7.2 in Volume 2 of Lawson and Treloar 2003). The results are shown graphically here in Figure 5.3.

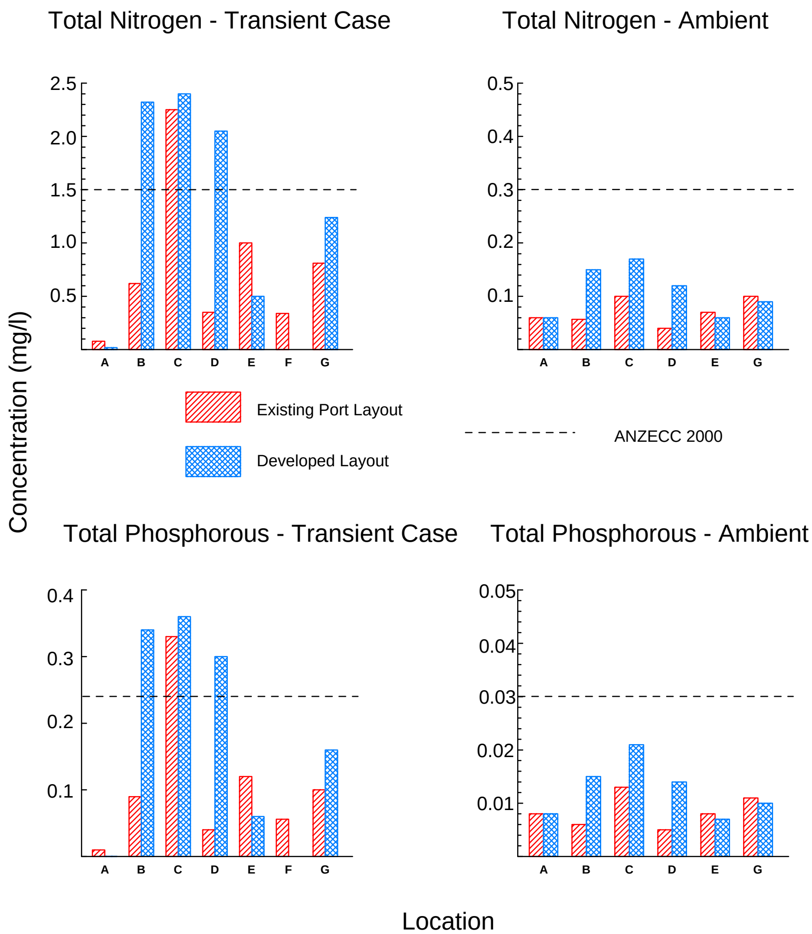


Figure 5.3 Model of Nutrient Concentrations
(Source: Lawson & Treloar, 2003)

The locations modelled by Lawson and Treloar (2003) were:

- A = southern corner of Patrick Terminal, Brotherson Dock.
- B = northern corner of Patrick Terminal, Brotherson Dock – this is the southern entrance to the existing Penrhyn estuary.
- C = gap between the inner and outer parts of Penrhyn Estuary.
- D = Foreshore Beach, near the eastern end of the proposed channel into Penrhyn Estuary.
- E = Foreshore Beach, near the western end of the proposed channel into Penrhyn Estuary.
- F = middle of Patrick Terminal, Brotherson Dock. This location would be reclaimed under the proposed port layout, hence there are no data modelled for the layout condition with a single channel.
- G = Foreshore Beach, western end, near the reclamation for the proposed recreational beach.

For TN and TP, the modelling of transient conditions shows similar trends. At most locations concentrations would exceed ANZECC (2000) guidelines –as they already do – the exception being Location A. A relatively large increase is predicted at Locations B, D and G under the proposed port layout and a small increase at C whilst there is a small decrease at Location E. Under ambient weather conditions, TP and TN are both within the ANZECC (2000) guidelines at all locations. There are, however, relatively large increases in concentrations from the existing to proposed layouts at Locations B, C, and D, which are within or at the entrance to the new estuarine configuration.

It is not possible to predict with precision the effects of these changes on algal blooms, other than to say that the changes are likely to increase the probability of blooms. The likelihood of a bloom occurring at any one time will depend on conditions, including the presence of species capable of rapid response, light intensity, rainfall, temperature, etc. Given the relatively small size and shallowness of the estuary, blooms of phytoplankton are unlikely to be problematic, with the following exception. If toxic algae from ballast water (e.g. species such as *Alexandrium tamarense*, *A. minutum*, or *Gymnodinium catenata*) are transported into the estuary, a bloom may occur and then be transported to other parts of Botany Bay, with possible adverse effects on humans. Such an event is possible but unlikely, given that very little deballasting occurs at the container berths (Chapter 4).

A more plausible effect of increased nutrients would be to increase the amount of macroalgae growing on the floor of Penrhyn Estuary. Such "nuisance" algae could include several groups, including *Ulva*, *Enteromorpha*, *Chaetomorpha*, *Colpomenia* and *Gracilaria*. These cause blooms, particularly during late winter and spring in other estuaries in NSW (e.g. Narrabeen Lagoon, Quibray Bay, Shoalhaven River; The Ecology Lab, pers. obs.). Typical impacts of these algae are to smother seagrasses and, when they rot, to cause offensive odours. This issue would need to be addressed as part of an Environmental Management Plan and is considered further in Chapter 6.

URS (2003) applied the modelling done by Lawson & Treloar to assist with predicting the effects of organic contaminants associated with the ORICA site and that are discharging via the groundwater into and around Penrhyn Estuary (see also Section 4.3.1). A conservative interpretation of these results indicated that, as a result of the proposed expansion, there would be an increase in volatile hydrocarbons (VHC) upstream of the channel between the Inner and Outer parts of the estuary (i.e. Location C) and that the area where VHCs occur at concentrations above laboratory reporting level would increase. It is important to recognise that VHCs behave very differently to nutrients because VHCs:

- occur mainly in groundwater
- are not distributed on a catchment wide basis
- are not likely to accumulate in the catchment during prolonged dry periods
- are quite volatile and may evaporate to the atmosphere
- would tend to be diluted in Penrhyn Estuary by flood events (URS 2003).

5.2.3 Noise, Vibration and Light

Noise barriers and restricted lighting are proposed to be installed to minimise effects of the proposed port expansion on bird waders (URS 2003). It is likely that these devices would also be suitable for minimising effects on fish and invertebrates. Vibration would occur as a result of construction activities (e.g. pile driving) and operation (e.g. shipping movements). Most aquatic animals would tend to habituate to the changes in noise and vibration and impacts could be considered as low to possibly chronic at most.

A possible exception to this could be effects of noise on marine mammals. For example, if southern right whales entered the port during construction their behaviour may be affected by noise associated with dredging and pile driving. At such times the underwater noise associated with pile driving may be acute in relation to southern right whales. However, given the intermittent occurrence of this species in Botany Bay (other than to recognise it is most likely to occur in winter) it is recommended that an environmental management plan be developed to respond to the presence of southern right whales within the bBay (see below).

5.2.4 Introduced Species

The issue of introduced species constitutes a potential biological stressor in relation to the proposed port expansion. It relates to the potential for increasing the risk of introductions into the bay and for creating conditions that may affect the distribution of introduced species that are already within the bay.

Management of ballast water and hull fouling associated with commercial shipping was discussed in Chapter 4. There appear to be no aspects of the proposal likely to enhance the risk of biological introductions, other than an increase in risk associated with greater numbers of vessels using Port Botany.

In terms of introduced species already in Botany Bay, there is some risk of changes in distribution associated with the proposed port expansion for:

- toxic dinoflagellates that present as cysts in sediments that would be dredged and
- *Caulerpa taxifolia* presently occurring along Foreshore Beach.

It is probable that toxic dinoflagellates were introduced originally into Botany Bay via commercial shipping. Dredging has the potential to mobilise cysts currently dormant within the sediments. The likelihood of this occurring is relatively small for two reasons. First, cysts are most likely to settle in deep areas with little water circulation. Most of the dredging will be in shallower water. In fact, the reclamation will cap a deep hole and so may bury cysts occurring within that hole. Second, the sediment would be transported via a pipeline and deposited via a discharge pipe below the water into the reclamation area. Once the dredging penetrates below the recent depositional zone of the sediments (i.e. < 1 m below the sediment surface) it is highly unlikely that there would be any more cysts present.

Caulerpa taxifolia was found along Foreshore Beach during the field studies for the proposed port expansion (Chapter 2). The amount of growth was small, but it is known to be capable of increasing rapidly, with the potential to replace seagrasses and other species of macroalgae. Dredging and reclamation activities could lead to fragmentation of plants which could then be transported to other areas and become established. This issue can be managed by a combination of chemical and mechanical treatment appropriate disposal (see Chapter 6).

5.3 Effects on Aquatic Flora & Fauna

5.3.1 Distribution of Habitats

The proposed port expansion would in some ways continue the major changes to aquatic habitats that have occurred in the northern part of Botany Bay, occurring as a result of previous capital works programs. The changes to habitats would have large effects on the flora and fauna of the area and these effects need to be balanced against the social, economic and ecological benefits of the project and the ability of the project to manage adverse impacts on aquatic habitats, flora and fauna.

5.3.2 The Water Column and Fish Passage

As described in Chapter 2, the water column is important for the transport of food, nutrients and propagules; transmission of light through the water and to the seabed; removal of waste products of aquatic biota and dispersal of contaminants from existing sources.

Following the proposed expansion, all estuarine habitats within the core study area would have access to tidal waters, enabling exchange between these habitats and Botany Bay and the coastal environment. Springvale and Floodvale Drains would flow into Botany Bay via access channels within Penrhyn Estuary and via the main channel into the estuary.

Fish passage is important to enable fish and invertebrates access to spawning sites, nursery habitat, feeding grounds, etc. Some fish species in NSW travel to and from freshwater and barriers can cause local population extinctions. Within the core study area, fish passage would generally not be altered under the proposed port expansion. In Penrhyn Estuary, access needs to be considered in relation to movement between the estuary and Botany Bay; and to movement between Springvale and Floodvale drains and the estuary and into Botany Bay (see also Section 5.3.5).

The freshwater habitats of the drains are limited in size, restricted in diversity (e.g. limited riparian vegetation) and polluted. They are also subject to very rapid flushing due to the highly cleared catchment. Therefore, there would be few fish that access the drains (e.g. some eels, mosquito fish, gudgeons and mullet). Both drains would be crossed by the rail line from the new terminal. Provided that culverts are designed and installed properly (NSW Fisheries 1999) the proposal should have negligible effect on fish passage into and within the drains.

Limited sampling of fish in the existing brackish portion of Penrhyn Estuary indicated usage by a variety of fishes, such as sea mullet, sand mullet, flat-tail mullet, yellowfin bream, tarwhine and silver biddies. These species would use the estuary for a variety of functions, including shelter and feeding. Currently, access to the inner estuary is restricted to a narrow, shallow channel at low tide, but access at high tide is unrestricted.

Under the proposed expansion, the main access to Penrhyn Estuary would be via the Foreshore Road channel, which would be about 1.5 m deep at low tide. Within the estuary, there would be small channel developed for the flow of water from the drains and a deeper lagoonal area to promote the growth of seagrass.

The access channel parallel to Foreshore Road would be sufficiently deep to enable access by fish. It is possible that fish could be affected by any powerful lights shining on the channel at night; hence it would be preferable to have strong lights facing away from the channel.

The drainage channels within the estuary would probably be large enough to permit access by freshwater fish, particularly at high tide. The extent to which fish can use the seagrass lagoons would depend on their depth. Anything more than about 1 m deep would be used by a variety of large and small fish. The design of the seagrass habitat takes this into account as it would be covered during low tide and water would be able to drain into the access channel to prevent stranding of larger fish.

5.3.3 Soft, Unvegetated Sediments

Under existing conditions, Foreshore Beach forms a large, continuous habitat that extends from Penrhyn Estuary to the mouth of the Mill Stream. The beach is currently eroding at the eastern end, with sediment deposited at the western end, causing partial blockage of the Mill Stream entrance (The Ecology Lab 2001, Lawson and Treloar 2003).

Under the proposed port expansion, the beach would be essentially cut in two at the location of the new boat ramp and recreation area. There would be a small loss of sandy intertidal habitat at the ramp, but the amount of similar habitat created in Penrhyn Estuary would be far greater than the small amount lost.

The beach to the east of the boat ramp would be adjacent to the new terminal and would become very sheltered from waves. The beach to the west of the ramp would still be open to the bay, but would be slightly more sheltered than the present situation. Notwithstanding this, it is predicted by Lawson and Treloar (2003, Volume 3) that there would continue to be westward transport of sand from the proposed boat ramp towards the entrance to the Mill Stream. This would require occasional maintenance works to keep the entrance to the Mill Stream clear and preserve the foundations of the proposed boat ramp. The patterns of erosion, accretion and maintenance works could affect beach fauna, bird waders, etc. It is understood that this issue would be addressed during the detailed design phase of the study.

Generally, the flux of groundwater into Botany Bay would not change, however, there may be a reduction in the amount of groundwater entering the bay along the beach, particularly if a drain is built to manage groundwater levels, hence there would be less freshwater entering the bay from the beach. This water would still enter the bay, but more so at either end of the beach compartment.

Given that the western beach would have a similar aspect to the present condition, it is to be expected that similar types of benthic assemblages would be present following construction of the new terminal. Assemblages colonising the beach adjacent to the terminal and in Penrhyn Estuary would be likely to reflect a more sheltered, estuarine habitat. The survey of benthic invertebrates in the intertidal zone (Chapter 2 and Appendix 1) indicated a relatively diverse assemblage of organisms, particularly in sheltered locations around Penrhyn Estuary. A possible reduction in groundwater along Foreshore Beach may have some effect on benthos living within the sediments there, by favouring species with a preference for more saline water.

Subtidally, dredging and reclamation would replace a large area of shallow sandy habitat with deeper soft sediments. The dredging would cause a temporary loss of benthic productivity whilst the reclamation would cause a permanent loss of productivity within the terminal footprint. Importantly, the deeper dredged area would not form an isolated, deep hole, but would be connected to the main navigation channel, hence to the bay and adjacent coastal environment. Thus, there would be good exchange of water and larval invertebrates available for colonisation. Notwithstanding this, it is most likely that the benthic assemblages colonising the dredge hole would be different to those currently existing within the shallower areas (*cf.* AMBS 1993, 1996). Based on the studies done by the Australian Museum, colonisation of the dredge holes would be rapid (i.e. timescale of months), but "recovery" to a condition that could be considered representative of this type of deep habitat could take in excess of two years (AMBS 1996). In addition to benthic invertebrates, it is also likely that fish assemblages in the dredge hole would differ to the shallows (see Chapter 2 and SPCC 1981a, b).

In addition to the deep and shallow unvegetated habitat within the core study area, there would be a third habitat type, formed on the batter or slope of the dredged basin. The batter would have a slope of 1:5 and be designed to prevent slumping; hence the habitat would be relatively stable. Sampling of both fish and benthic invertebrates in similar habitats within Port Hacking indicated that this habitat can be quite productive (Lincoln Smith 1991).

As part of the habitat enhancement works, deeper areas of Penrhyn Estuary, which are only a few metres deep, would be filled to form a broad intertidal flat. A survey of benthic invertebrates of this habitat yielded a diverse and abundant fauna, despite the presence of contaminated sediments (Chapter 2 and Appendix 1). This habitat would be replaced by intertidal flats and a narrow channel with waters from Floodvale and Springvale Drains. Although slightly different sampling methods were used in sampling the intertidal beach and subtidal habitats, results of the benthic surveys (Appendix 1) indicate that there would be a small reduction in biodiversity as a result of the loss of this deeper habitat in Penrhyn Estuary. As this habitat is common in other parts of Botany Bay, the reduction is not considered to be a significant impediment to the proposed port expansion and would be partly offset by gains in wetland habitat, seagrasses, etc.

5.3.4 Hard Substrata

This assessment is based on the first of the alternative embankment designs displayed in Figure 6.2 of URS (2003). If any of the other alternatives is selected during the detailed design phase of the project, a further evaluation of ecological implications would be required. The amount of hard substrata would increase substantially as a result of the proposed port expansion. This includes the following:

- An additional 1850 m of wharf face and some 3,300 tubular steel piles.
- 500 m of seawall adjacent to seagrass habitat within the access channel and Penrhyn Estuary.
- 1000 m of rock wall adjacent to intertidal habitat within Penrhyn Estuary.
- 300 m of seawall used for the tug berths and recreational boat ramp.

Unlike the smooth, vertical walls of the Parallel Runway and the Mill Stream, the rock structures associated with the proposed port expansion would generally be made of rock rubble. This would provide habitat for a variety of invertebrates and animals. There is also opportunity to provide additional structural complexity to enhance the value of this habitat.

As modelled by Lawson and Treloar (2003), there would be no change or a slight decrease in wave height along the Parallel Runway. This has the potential to cause some change in intertidal assemblages as they can be affected by wave energy.

5.3.5 Seagrasses and Associated Assemblages

As discussed in Chapter 2 and in Section 5.1.5.2, up to 4 ha of the existing seagrasses would be removed initially as a consequence of the proposed port expansion. Most of this would consist of *Zostera* of low to moderate density, but with some *Halophila* and mixed beds of these two species. A small patch of several square metres of *Posidonia* would be lost in the middle of Foreshore Beach whilst two other patches of a similar size and occurring nearer the mouth of the Mill Stream channel would be retained (Figure 2.8). The latter two patches would be over 400 m or more from the outer boundary of the proposed port expansion. It is possible that there may other small patches of *Posidonia* in the area and this would need to be confirmed prior to commencement of construction. The loss of seagrasses would be addressed by a combination of seagrass transplanting (including small scale transplanting of *Posidonia*) and creation of compensatory habitat, as discussed in Section 5.1.5.2 and in Chapter 6.

The seagrasses that would not be in the footprint of the proposed development are found mainly just to the east of the Mill Stream channel and on the shallow terrace adjacent to the Parallel Runway. The former comprises the largest single area of seagrass in the core study area and it would need to be protected from any indirect effects of the construction process, such as reduction in water clarity due to sediment plumes or physical damage from construction vessels. These issues would be addressed in an environmental management plan (EMP) developed for the project. The seagrasses on the terrace adjacent to the runway comprise a combination of seagrasses transplanted from Lady Robinsons Beach and naturally colonising species (Gibbs 2001). The presence of the non-transplanted patches indicates that colonisation has occurred in time scales of less than a decade, as the terrace was created as part of the runway construction. Preservation during construction will depend more on water clarity than effects of boat traffic and will also need to be considered in the EMP.

In the longer term, the transport of sand along the remaining beach compartment could affect the large area of seagrasses just offshore from the beach. Additionally, maintenance works to relocate the sand have the potential to affect seagrasses. It is understood that this issue would be addressed during the detailed design phase of the project.

Similarly, the new terminal would cause some changes in wave energy in some parts of the core study area and have no effect in other parts. Importantly, there would be a small decrease in wave height at the sand terrace adjacent to the runway (Lawson and Treloar 2003), which should favour the growth of seagrasses there.

The relocation of the boat ramp could potentially lead to an increase in recreational boat traffic along the beach, which may lead to damage of seagrasses from boat propellers, hulls, wading, etc. This problem has been addressed elsewhere in the Sydney region by the use of signs indicating areas where care is required (Smith *et al.* 1997) and should be considered in the EMP.

It can be predicted with confidence that the compensatory seagrasses would be accessible to and utilised by a wide variety of invertebrates and fish, many of which would be small juveniles of species of economic importance (i.e. caught by recreational fishers inside and outside of Botany Bay, or caught by commercial fishers outside the bay). If appropriately designed, artificially created waterways can support extremely diverse and abundant assemblages of fish and invertebrates (e.g. Lincoln Smith *et al.* 1995). It is known that seagrass beds in different locations can support very different faunal assemblages (e.g. Bell *et al.* 1988, McNeill *et al.* 1992) hence it is not possible to predict with certainty the exact types of assemblage likely to utilise the compensatory seagrasses. The fact that some of these seagrasses would have been transplanted does not mean that they would not be utilised by organisms typical of this habitat: even the use of plastic, artificial seagrasses has been shown to attract and harbour these types of assemblages in Botany Bay (Bell *et al.* 1985).

McNeill *et al.* (1992) found that *Zostera* beds in the former Pilot Station to the north east of the original North South Runway contained extremely large numbers of several species of fish and invertebrates of economic importance compared to beds in Jervis Bay, Port Hacking and elsewhere in Botany Bay. The seagrasses at the Pilot Station were near sandy beaches and a rocky breakwater. This site was also reputed to be in the path of any eddy formed by the North South Runway and which was attributed as concentrating fish larvae, hence providing a powerful delivery mechanism into the seagrass habitat. The construction of the Parallel Runway has lead to the reclamation of the Pilot Station and it appears to have changed hydrological processes so that the eddy no longer forms.

Whilst we cannot predict with certainty the types of assemblage that would occur in the compensatory *Zostera* beds, there are several reasons why we would expect it to support a diverse and abundant fauna:

- The entrance channel would be relatively wide and have good tidal exchange. Therefore, although there may not be an eddy system directing water into the estuary, it could not be considered as a backwater isolated from potential fish and invertebrate recruitment.
- Similarly, the location of the estuary is near the entrance to Botany Bay, hence is close to putative spawning grounds for many of the species of economic importance that use seagrasses as juveniles.
- The design of the compensatory seagrass bed incorporates the potential for there to be three quite distinctive microhabitats within the main seagrass habitat. These microhabitats would be expected to maximise the opportunity for a variety of species with different environmental requirements. The microhabitats include the following:
    - Shallow, very sheltered seagrasses forming as lagoonal microhabitat within the entrance and middle portion of Penrhyn Estuary.
    - Shallow fringing seagrasses adjacent to the sandy beach along the northern side of the access channel.
    - Deeper fringing seagrasses adjacent to the rock rubble seawall along the southern side of the access channel (i.e. the northern side of the proposed terminal).
- Holistically, Penrhyn Estuary provides a diverse range of estuarine habitats in addition to the seagrasses. These include the sandy intertidal and subtidal beach along the northern shore of the access channel, the rubble rock wall around the boundary of the proposed terminal and the estuary, sand flats, mud flats and saltmarshes. As with the seagrass microhabitats, these broader habitats would be expected to provide opportunity for a variety of species to forage and/or shelter within the estuary.

5.3.6 Algae and Associated Assemblages

In addition to seagrasses, there are also extensive areas of benthic algae in the core study areas. These include attached and drifting algae. The attached algae, such as *Ecklonia radiata* and *Sargassum* spp. occurs on some of the seawalls, on rubble near Brotherson Dock and on rubble and derelict pylons at the old coal wharf near Penrhyn Estuary. Whilst the rubble and pylons would be retained for heritage reasons, the water depth would be shallower around these structures and hence macroalgae would be expected to largely disappear. This would be more than compensated for by the creation of new subtidal structures associated with the proposed terminal. There are also some algae that can attach to soft sediments. These include mainly *Caulerpa taxifolia* and *C. filiformis* and *C. scapeliformis*. The former two occur among seagrasses within the core study area, whilst the third species occurs on the southern side of Botany Bay. All three algae are probably introduced species. Management of the possible spread of *C. taxifolia* would form part of the EMP.

Drift algae often occur in response to increased nutrients and can be highly variable in space and time. They are common in shallow sandy habitats in NSW estuaries and embayments. One study found that assemblage associated with a species of *Gracilaria* in Jervis Bay tended to be a subset of adjacent seagrass beds (Langtry and Jacoby 1996). It is expected that drift algae would continue to form beds on the remaining shallow subtidal habitats and possibly the slopes of the dredged basin. They may also occur within Penrhyn Estuary and there is a possibility that an increase in nutrients in Penrhyn Estuary modelled by Lawson and Treloar (2003) could increase the frequency of blooms there (see also Section 5.2.2.2.2).

5.3.7 Saltmarshes and Mangroves

Under the proposed port expansion the small stand of mangroves that has become established in Penrhyn Estuary would be removed to facilitate the growth of saltmarshes and to enhance the value of the area as habitat for bird waders. The mangrove loss would represent about 0.1% of the mangroves of Botany Bay (based on West *et al.* 1985), which are very extensive at Towra Point, whilst large stands also occur in Cooks River and Georges River (Chapter 2). A saltmarsh area of approximately 6 ha would be enhanced and created as part of the habitat enhancement of Penrhyn Estuary, comprising newly planted areas and remnant saltmarsh.

The removal of mangroves would require a permit from NSW Fisheries under the Fisheries Management Act, 1994. Given the small size of the stand relative to other areas in Botany Bay, this loss is considered to be ecologically sustainable. On the other hand, the creation of additional saltmarsh habitat is considered a positive effect as it will represent a substantial increase in the area of this habitat within Botany Bay (i.e. almost 4%, based on West *et al.* 1985). Finally, there is good evidence that mangrove habitat has been replacing saltmarshes within the Sydney region at least over the last 50 years (Saintilan 1997, Williams and Watford 1997, Mitchell and Adam 1989, Saintilan and Hashimoto 1999, Saintilan and Williams 1999, 2000).

This trend appears to be contrary to geological data showing saltmarshes growing in areas occupied previously by mangroves (Saintilan 1997, Saintilan and Hashimoto 1999). A number of factors have been suggested by these authors to account for this, including increased sedimentation and nutrient loads or sea level rise. If sea levels rise as a result of Greenhouse effects, then it might be expected that there would be a further encroachment of mangroves on saltmarshes, with the upward movement of saltmarshes blocked in some areas by terrestrial features (e.g. topography, human structures such as roads, etc).

On balance, whilst the removal of mangroves would represent a relatively small ecological loss, the advantages associated with the opportunity to enhance Penrhyn Estuary with saltmarshes provides a strong justification for that loss.

In the longer term, it is likely that mangroves seedlings would become established within Penrhyn Estuary from time to time. In order to prevent stands from becoming established, a program of regular removal would be necessary. This would be best done when mangroves were very small, to minimise disturbance of sediments and any surrounding saltmarshes (see Chapter 6).

5.3.8 Freshwater Ecosystems

Freshwater habitats associated with the Mill Stream and Sir Joseph Banks Park would not be subject to any change in hydrology or groundwater infiltration as a result of the proposed port expansion (Merrick and Knight 2003), therefore they would not be affected by the proposal. Freshwater sections of Floodvale and Springvale Drains are already highly degraded. Notwithstanding this, proposed changes to Penrhyn Estuary, which include provision of gross pollutant traps and creation of channels for the drains across the intertidal flats would preserve connectivity and hence fish passage. Therefore, the proposal would be unlikely to affect any future rehabilitation of these drains.

5.4 Introduced Species

The issue of introduced species is a management one, as discussed in Section 5.2.4. In summary, two classes of introduced species may be affected by construction activities – cysts of toxic dinoflagellates that could be re-suspended into the water column by dredging and the algae *Caulerpa taxifolia* which could be fragmented and dispersed to other habitats, also by dredging. These possible outcomes are not considered to be problematic as they can be managed as part of the project – see Chapter 6.

5.5 Threatened Species

The issue of threatened species was dealt with in detail in Chapter 3. It was concluded that Species Impact Statements were not required for those species contained within the scope-of-works of the Ecology Lab, but that environmental management could and should accommodate the potential for threatened species to occur within Botany Bay from time to time.

Species likely to be of some concern include southern right whales and humpback whales. Both these species enter Botany Bay from time-to-time and their occurrence is often well-documented, but so far there do not appear to have been any adverse incidents with commercial shipping. As part of an EMP it would be desirable to incorporate a formal strategy for dealing with the presence of whales near to and entering Botany Bay (for example, notification of ships' masters when whales are present). This is discussed further in Chapter 6.

The green sawfish utilises shallow, sandy habitat, but the reduction in this habitat within the core study area is not considered problematic for the species as there is no known population in Botany Bay and, if individuals did occur in the bay, there is extensive habitat present on the southern side of the bay and some of this habitat remaining on the northern side.

The black cod often utilises rocky structures within estuaries. The emplacement of rubble seawalls would therefore represent an increase in suitable habitat that may favour the species.

All the other scheduled threatened species considered are most unlikely to show any effect as a result of the proposed port expansion (Chapter 3). An additional issue identified in Chapter 3 was the likely occurrence of Syngnathidae (pipefishes, sea horses, etc) associated with seagrass and macroalgae. Whilst there may be a short term displacement or loss of individuals, the proposed habitat compensation for seagrasses would also provide compensatory habitat for this group.

5.6 Effects on Fishing and Aquaculture

5.6.1 Commercial Fishing

Commercial fishing is no longer permitted within Botany Bay, hence this activity will not be directly affected by the proposed port expansion. However, there is commercial fishing at the entrance to the bay and within adjacent coastal waters. Based on modelling of hydrology and coastal processes, it is highly unlikely that the proposed port expansion would affect the physical nature of fishing activities outside the bay.

Given that many species of fish and invertebrates utilise the bay waters as juveniles and then migrate into coastal waters, a possible concern is that that there would be some effect on fish stocks as a result of the proposal. Under the proposal there would be an overall increase in the amount of seagrasses present in the core study area, hence it is expected that there would be no net loss, or a small increase, in fisheries productivity that may be related to seagrass beds.

5.6.2 Recreational Fishing

The construction of a new boat ramp to replace the one in Penrhyn Estuary means that anglers would not be disadvantaged in terms of launching facilities. Penrhyn Estuary is currently closed to fishing and would remain so under the terminal expansion. Notwithstanding this, there would be some loss of available area in which to fish, as the reclamation would reduce the total water area of the bay by approximately 62 ha, or 1.5%. (In practice, this percentage loss would be slightly larger as parts of Towra Point Aquatic Reserve are already closed to fishing). There may also be some disruption to angling from increased commercial shipping associated with the port expansion.

Overall, the proposal has sought to accommodate the needs of recreational fishers in Botany Bay. Effects of the expansion would probably represent an inconvenience rather than a major disruption to their recreational amenity.

5.6.3 Aquaculture

Currently aquaculture (including oyster farming) occurs on the southern side of Botany Bay. Studies of coastal processes (Lawson and Treloar 2003) indicate that there would be negligible change to Botany Bay outside the core study area, hence this activity would not be affected by proposed port expansion. As far as is known, there are no plans to introduce aquaculture to parts of the northern section of Botany Bay, particularly the core study area. Moreover, this is unlikely to occur for the foreseeable future due to problems with water quality associated with the Mill Stream and Penrhyn Estuary (Chapter 4 above and Volume 2 of Lawson and Treloar 2003).

5.7 Summary of Environmental Effects and Conclusions

5.7.1 Within the Core Study Area

The proposed Port Botany expansion would cause the following broad scale changes to habitats within the core study area:

- a large increase in the amount of solid artificial structure;
- a large increase in the amount of saltmarsh habitat;
- an initial loss of up to 4 ha of the seagrasses in the core study area, but in the longer term they would be creation of some 50% more seagrass habitat than is currently present;
- a small decrease in intertidal beach habitat but a large increase in sandy intertidal flats at Penrhyn Estuary;
- loss of a small stand of mangroves in Penrhyn Estuary;
- loss of a previously dredged hole and some areas of shallow subtidal sand habitat with the corresponding creation of a deep basin as an extension of the existing navigation channel.

Once operational, there would be some changes in wave height in some parts of the study area, but currents would change little in the longer term. The area of Foreshore Beach forming the northern boundary of the access channel to Penrhyn Estuary would become very sheltered and sand transport due to wave energy would cease. To the west of the boat ramp there would be continued sand transport requiring potentially requiring ongoing maintenance works (Lawson and Treloar 2003).

5.7.2 Within Other Parts of Botany Bay

Apart from levelling some high spots within the existing navigation channel, there would be no physical changes to the bay outside the cores study area. Changes in wave energy and direction are predicted to be small, with negligible effect on sensitive habitats such as Towra Point (Lawson and Treloar 2003).

5.7.3 Greenhouse Issues

Lawson and Treloar (2003, Volume 3) discuss the issue of global warming and changes in mean sea level. Other effects might include increased water temperature and increased frequency of storms and of variability in rainfall. Estimates of mean sea level rise over the next 50 years range from 0.19 m to 0.49 m, with a mean of 0.34 m. The depth distribution of seagrasses in the core study area ranged from 0.72 to -2.65 m LAT, whilst in Penrhyn Estuary they ranged from 0.51 m to -2.26 m LAT, with a mean depth of -0.48 m (Section 2.6.5.3.3). Assuming that depth is a major determinant of distribution, these observations suggest that an increase in depth of 0.34 m due to global warming would probably cause the loss of a relative large (but at this stage unquantified) amount of seagrass in the core study area, with or without the proposed port expansion. This might be partly compensated for naturally by a shoreward expansion of seagrasses as water level rose.

Within the base of the access channel to Penrhyn Estuary water depth could increase to a maximum predicted by global warming of -1.99 m, which is close to the depth limit of seagrasses in the core study area but does not exceed the maximum depth of seagrasses recorded in Penrhyn Estuary. Seagrasses establishing on the shallow flats within the estuary would be well within the depth range and may expand in area towards the head of the estuary as sea level rose.

In addition to soft substrata, organisms growing on hard surfaces such as pilings and rock rocks would also change their distribution in response to increasing sea level. For example, algae growing intertidally and subtidally may advance upwards as sea level rises. Associated fauna, such as barnacles and oysters, would also respond. Enhancement of these habitats should consider these issues during the detailed design of the port.

This discussion suggests that increased water depth due to global warming may, in the next 50 years, marginalise the growth of the seagrasses in the deepest parts of the access channel, although they might be able to expand their distribution shoreward along Foreshore Beach, as this would be retained (but slightly reduced due to the new boat ramp). Under this scenario, seagrasses are not predicted to be lost on the flat within Penrhyn Estuary and may even expand there. Further into the estuary, sea level rise could inundate saltmarshes and some remedial work, such as reforming parts of the tidal flat may be possible to preserve saltmarshes and wader habitat.

If there are increases in water temperature, we would predict that seagrasses, particularly *Zostera* and *Halophila*, could withstand a moderate increase as both species currently occur in tropical waters. There may also be changes in the structure of assemblages of biota, with a larger proportion of subtropical species. Increased flooding could affect the salinity regime and increase the potential for scouring in the estuary and access channel. *Zostera* can withstand a large variation in salinity and should be capable of surviving rapid but not prolonged reductions in salinity associated with flooding. Scouring may become an issue if there are larger storm events, and this may lead to physical stress on seagrasses in the main channel areas (i.e. access channel and channels for Floodvale and Springvale Drains as they flow across the flat).

It must be recognised that these predictions are highly speculative and depend on changes in water level and the rate of change: slower change may allow plants and animals to adapt or redistribute themselves in response. There may also be secondary or indirect effects, such as changes in water clarity or introduction of other biota more suited to new conditions caused by global warming. Such effects may well have a substantial influence on how biota responds. Many of these processes would occur at a scale much larger than the proposed port expansion but, as noted above, there are some specific considerations with respect to the expansion.

5.7.4 Potential for Cumulative Effects

The assessment of cumulative impacts of any human activity can be extremely difficult to predict because effects could be additive or multiplicative. Furthermore, cumulative impacts could trigger ecological thresholds which again are difficult to predict. On the other hand, a reduction in habitat does not necessarily mean a linear decrease in abundance of associated flora and fauna or in biological diversity. Hence, small seagrass beds can be extremely productive on a unit-of-area basis (e.g. McNeill *et al.* 1992). The key to addressing this issue will be implementation of good ecological sampling based on an appropriate experimental design coupled with mechanisms for management response.

There are several key areas that are relevant to cumulative impacts and which should be incorporated into environmental management of the project. These include the following:

1. Continued loss of seagrass for the northern parts of Botany Bay. Existing information indicates that there has been a large loss of seagrass from the core study area and that the decrease is continuing well after completion of the last major capital works, the Parallel Runway. This may be due to erosion occurring along Foreshore Beach or other, unknown factors. The present proposal provides an opportunity to arrest this decline and, hopefully, promote an increase in the seagrasses by providing a stable habitat.
2. Increased amounts of artificial structure in the area. The additional structure provided by the new terminal would continue the increase in this type of habitat and presumably the plants and animals associated with it. These organisms have their own potential benefits, both ecologically (by enhancing biodiversity), socially and economically (as some of these biota are utilised by humans).
3. Continued contamination of Penrhyn Estuary and the effect of habitat enhancement on the ability of the system to discharge, dilute and neutralise the contaminants. URS (2003) have undertaken an ecological risk assessment of the proposed port expansion. It is evident that the expansion would change the hydrodynamic processes within Penrhyn Estuary and that there is likely to be an increase in VHCs due to the migration of groundwater plumes – this latter issue will occur irrespective of the expansion. It was concluded that the expansion would not significantly alter the risks to aquatic organisms as a result of changes to the hydrodynamic regime (URS 2003). Notwithstanding this, there remain concerns that the habitat enhancement proposed for Penrhyn Estuary may place an otherwise thriving assemblage of fish and invertebrates associated with these new habitats at risk due to their relatively close proximity to the point of release of VHCs when they arrive at Botany Bay.

5.7.5 Ecologically Sustainable Development

The concept of ecologically sustainable development (ESD) has been incorporated into environmental planning and legislation in NSW and requires consideration in the context of this proposal. Key components of ESD include:

- Maintenance of biological diversity.
- Use of the Precautionary Principle
- Maintenance of inter- and intra-generational equity.

Whilst the proposed port expansion would affect the aquatic environment of the core study area, it has been designed with the aim of minimising damage to habitats and in several cases, enhancing habitats. Apart from the loss of mangroves, the same habitats would be present in the area following construction, but the relative amounts of these habitats would change. On a broader scale, the loss of mangroves should not be a concern, given the small size of the loss and the aim of enhancing saltmarshes. On balance, it would appear that the proposal would help to maintain biological diversity.

The design of the project also addresses the precautionary principle, by initiating measures to prevent harm to the environment. This is evident in the design of dredging and provision for creation of seagrass and saltmarsh habitats.

Finally, whilst there would be a loss of some aquatic habitat as a result of reclamation works, the proposal seeks to maintain generational equity by works to Foreshore Beach (e.g. construction of a new boat ramp) and provision for enhancing the remaining aquatic habitat as a resource for future use.

6.0 ENVIRONMENTAL MANAGEMENT

Chapter 6 describes mitigative measures and outlines monitoring programs and a range of feedback mechanisms to management, including triggers for response and horizons for monitoring.

6.1 Background

As discussed in detail in Section 5.1 and within the main EIS (URS 2003), where significant impacts have been predicted, many features have already been incorporated into the project proposal to remove or mitigate these predicted effects (e.g. incorporation of compensatory habitat and habitat enhancement in Penrhyn Estuary, use of a silt curtain, installation of a permanent boom across the access channel to Penrhyn Estuary). Moreover, during the detailed design phase of the project prior to construction, there would be further opportunities to anticipate and mitigate any other undesirable effects that may occur. Finally, there are other effects of the proposal that may have a low probability of occurring or the magnitude of which cannot be predicted with certainty. A precautionary approach would, in these cases, dictate that mechanisms are made available for management to respond appropriately in the event that such effects occur. In order to do so, it will be important to implement a monitoring program that is well designed and sensitive enough to detect effects before they can lead to serious environmental, economic and/or social impacts.

This chapter reviews mitigative measures in terms of the construction and operational phases of the proposed expansion, some of which have already be raised in Chapter 5. This chapter also describes a framework for monitoring during these phases. The detailed design and implementation of monitoring, including the need for any pilot investigations, selection of control or reference sites, etc, would be most appropriately incorporated into environmental management plans (EMPs) for construction (CEMP) and operation (OEMP).

6.2 Mitigative Measures

6.2.1 Construction Phase

Mitigative measures should be considered as part of the construction phase of the proposed expansion in terms of:

1. Ensuring that habitats and/or biota not intended to be disturbed are preserved with minimal disturbance.
2. Ensuring successful creation of habitat to compensate for lost habitat or restoration of habitat that may be affected by construction.

6.2.1.1 Minimising Damage to Aquatic Habitat

All areas of habitat that are to be retained as part of the port expansion would need to be clearly delineated as part of all construction plans and, where necessary, by using markers, buoys, etc to ensure that no dredging, reclamation, boat movement or other mechanical damage is done. Moreover, silt containment strategies would need to identify where they should be initiated to have maximum benefit in terms of habitat protection. Specific examples of these include:

- The preservation of large areas of seagrass offshore from Foreshore Beach and to the west of the proposed recreation area.
- Avoiding the potential for disturbance near the terrace adjacent to the Parallel Runway, where seagrasses have been transplanted previously and which could be used for further transplanting as part of this proposal.

A CEMP developed for the project would identify these issues and include appropriate training on the location and significance of seagrasses and consequences of any unapproved damage.

6.2.1.2 Seagrass Transplanting

Prior to commencement of construction, seagrasses within the core study area should be remapped using a new aerial photograph (i.e. taken no more than two months prior to the mapping) with appropriate ground truthing. This is necessary because the seagrass distribution could change in the intervening period between this study and the start of construction; hence the CEMP may require some "fine-tuning".

Zostera seagrass has already been transplanted in Botany Bay with some success (Gibbs 1997, 2001). It appears that the greatest success occurred for seagrasses transplanted to the terrace on the eastern side of the Parallel Runway. This is one location that has been identified as a possible storage location for the proposed port expansion. Notwithstanding this, given the prediction that there would be an increase in wave height in this area (Section 5.3.5) it is recommended that additional storage sites be selected as a possible alternative.

Under the proposed port expansion *Zostera* (with, in some cases, *Halophila*) would need to be removed from an area of up to 4 ha and transplanted into compensatory habitat. Depending on the sequence of construction, some seagrass would need to be transplanted to the terrace adjacent to the eastern side of the Parallel Runway and as much as possible directly to the access channel and tidal flat within Penrhyn Estuary once the compensatory habitat is prepared. It would be desirable, both economically and in terms of limiting stress to the seagrass, to minimise the amount of double handling required, hence the CEMP would seek ways in which compensatory habitat can be prepared prior to removal of seagrass, to avoid andy double handling of seagrass.

At the time of the remapping, a detailed search should be included for any additional areas of *Posidonia* and these should be considered as part of the CEMP. Any areas that are likely to be affected by construction should be transplanted into other parts of the core study area, for example, near those beds found at the western end of Foreshore Beach. Transplanting of *Posidonia* has previously been considered difficult if not impossible but recent work in Port Hacking by Meehan and West (2002) has shown that *Posidonia* can be successfully transplanted. It appears that the greatest success occurs when *Posidonia* is transplanted to gaps in beds of existing *Posidonia*, or to areas where *Posidonia* once existed but where the cause of that loss is no longer present. Note that placement of *Posidonia* at the western end of Foreshore Beach would not require any double handling as it would be moved once, prior to construction.

6.2.1.3 Control of *Caulerpa taxifolia*

As part of the remapping of seagrasses, the occurrence and extent of *Caulerpa taxifolia* should also be established. The CEMP would need to be adapted depending on the extent of any *C. taxifolia* present in areas to be dredged. For example, small areas of this alga can be treated by application of pool salt, which kills it rapidly while leaving seagrasses undamaged. Larger areas may need to be removed mechanically, for example by skim dredging and disposal on land. Alternatively, it may be possible to bury *C. taxifolia* within the reclamation.

6.2.1.4 Marine Mammals

Depending on the time of year, there may be several species of marine mammals present within Botany Bay, the most likely being southern right whales, humpback whales or bottlenose dolphins. Dolphins are swift and hence would avoid most of the vessels associated with construction. They can also utilise numerous parts of Botany Bay. The whales are less mobile and have been observed within the core study area. Of some concern would be the presence of a southern right whale with a calf entering the core study during dredging operations. Under these conditions noise and vessel movements may cause stress or disorientation.

The main period over which southern right whales might be expected to occur in Botany Bay would be mid winter to mid spring. Humpback whales could be present during late autumn and winter (during their northward migration) and mid to late spring (southward migration). At such times, the CEMP would need to have a plan in place to identify the presence of any whales and to respond appropriately, which may mean limiting vessel movements or construction activities.

6.2.2 Operational Phase

During the operational phase, mechanisms described in Chapters 4 and 5 would be established to address issues related to stormwater runoff, emergency procedures (including the use of a permanent boom across the access channel to Penrhyn Estuary). Similarly, management of the risk of introducing pest species via ballast or ship fouling would continue to be addressed at the Commonwealth and perhaps State level, although monitoring programs initiated as part of the management of the proposed port expansion could be used to provide valuable input into the occurrence of pest species (in a similar way to the identification of *Caulerpa taxifolia*, which is not a ballast water species, as part of the EIS process).

Further mitigative measures during the operational phase would be linked to environmental monitoring, such as evaluating the success of compensatory habitat, and this is discussed in the next section.

6.2.2.1 Nuisance Algae

One issue raised in Chapter 5 was the potential for growth of nuisance algae in Penrhyn Estuary, due to runoff from Floodvale and Springvale Drains. One suggested approach to address this issue is considered as a staged process, outlined as follows:

1. Initially monitor to determine if there is a problem with nuisance algae and determine the frequency of occurrence.
2. If growth appears to be problematic on a short term basis, nuisance algae may be addressed by mechanical means, such as skimming algal growth from the mudflats or lagoonal area.
3. If growth of nuisance algae is problematic on a broader scale, SPC may need to consider constructing wetlands at the entrance to Springvale and Floodvale Drains to enhance nutrient stripping.

6.2.2.2 Management of Mangroves

It is likely that mangrove propagules would be transported into Penrhyn Estuary. Therefore, although they may be removed as part of the habitat enhancement for the expansion, they would be likely to recolonise. This issue could be addressed by periodically removing mangrove seedlings before they become established. This could be readily achieved by simply pulling out the mangroves, either by wading or from a boat.

6.2.2.3 Marine Mammals

Under the current configuration of the port terminal it appears that marine mammals are able to co-exist with the port operations. In the longer term, management of the terminal would require appropriate communication between SPC and NSW NPWS to ensure that the occurrence of marine mammals in the vicinity of the port was appropriately managed.

6.2.2.4 Contaminated Ground Water and Surface Water

It is known that contaminated water from the catchment will enter Botany Bay via Penrhyn Estuary and Foreshore Beach adjacent to the proposed access channel, but the ultimate concentrations of VHCs and therefore their toxicity is not clearly understood (URS 2003 and Chapters 4 & 5, above). This process will occur irrespective of the proposed port expansion, although the proposed configuration of Penrhyn Estuary may have some influence on the effects by altering hydrodynamic processes. Of concern is that, by enhancing the habitat in terms of seagrass growth, a larger number of organisms would be exposed to the threat of VHCs than would otherwise occur. Given that VHCs do not persist in the environment for long periods, there may be some mitigative measures that could be considered:

- Delay some of the enhancement works until the northern plume reaches the bay and its effects can be measured. The northern plume is expected to reach the bay by about 2006. The use of benthic organisms living in the sediments of Foreshore Beach would be a good indicator of the toxic effects of the VHCs and could be used to assess impacts. If, following removal, seagrasses are stored temporarily on the terrace adjacent to the Parallel Runway, the effects of the VHCs could be determined before the final transplantation takes place.
- Improve flushing of the middle portion of Penrhyn Estuary (i.e. where the seagrass lagoons are proposed). Under the current design, the seagrass lagoons would form shallow pools at low tide, hence they may tend to retain VHCs prior to volatilisation. Deepening the lagoons may enhance flushing in these lagoons and help to dilute the VHCs.

- Creating a barrier between the beach and the seagrass beds, for example a small bund.

6.3 Monitoring & Feedback to Management

Broadly, monitoring of the effects of the proposed port expansion on aquatic ecology would require investigation during construction and operation, with a suitable amount of time allowed before construction begins to compile appropriate baseline data. It is recommended that between one and two years be allowed for completion of baseline studies. In addition to sampling prior to construction, baseline data would also require, in many cases, that data are compiled from control locations.

It is not within the scope of works for this engagement to provide a detailed description of monitoring, nor would it be appropriate until draft conditions of consent have been developed based on negotiations among stakeholders. The following sections provide a brief overview of the monitoring strategy suggested to measure the effects of the proposed port expansion on key indicators.

6.3.1 The Water Column

During the construction of the new terminal, water quality should be measured in relation to the dredging and reclamation operations. Indicators measured regularly should include turbidity, dissolved oxygen (DO), temperature (T), salinity and pH. Sampling should be done at sites inside and outside the silt curtain, at sites of sensitivity, particularly seagrasses, and at reference locations. In addition to the above indicators, samples of water should be obtained to measure suspended solids, nutrients, heavy metals and organic contaminants. Finally, light (PAR) should be measured at the seabed at several positions where seagrass beds occur.

In the longer term, it is suggested that water quality be measured on a regular basis within Penrhyn Estuary. Indicators should include turbidity, DO, T, salinity and pH, plus nutrients, heavy metals and organic contaminants. In particular, organic contaminants (VHCs) should be measured in relation to studies of groundwater and the movement of organics from the ORICA site (Merrick and Knight 2003).

6.3.2 Unvegetated Soft Sediments

Organisms inhabiting soft sediments could be used to provide to assess the following:

- Recolonisation of the dredged shipping berth and changes (if any) in adjacent shallow habitats.
- Recolonisation and success of habitat enhancement within Penrhyn Estuary.
- Impacts of the arrival of VHCs in groundwater, particularly the Northern Plume

Each of these components would require further baseline data to be collected and the use of control locations. The supplementary survey of benthic organisms done as part of this study (Appendix 1) indicates using the benthos as an environmental indicator would be a suitable monitoring approach. The finding that intertidal assemblages were dominated by a few taxa (Nereidae and Exoedicerotidae) suggests that these may be suitable indicators for future study. This might also lead to efficiencies of sampling if biota samples need not be processed entirely.

6.3.3 Hard Substrata

The proposed port expansion would lead to a large increase in habitat provided by hard substrata within the core study area. Generally, this artificial habitat will have some of the attributes of natural rocky reef, particularly given that rock walls will consist of rubble slope. During the detailed design phase measures should be incorporated to enhance these structures as habitat both as part of the construction process and even when the structures are in place. This would require substantial input from suitably qualified ecologists.

6.3.4 Seagrasses, Algae and Associated Fauna

Subject to its approval, monitoring programs should be designed and implemented for seagrasses during the construction and operational phases of the project. The seagrass indicators that need to be considered include coherence of beds (i.e. patchiness) and morphological characteristics, including shoot density, leaf length and width and extent of epiphytic growth. These indicators would be used to address the following issues:

- Potential changes to seagrasses not within the direct footprint of the proposed expansion occurring as a result of construction activities. This would involve sampling seagrasses adjacent to the expansion and at control locations before, during and perhaps after construction of the terminal and associated works.
- Survival and condition of seagrasses, including *Zostera* and *Posidonia*, following transplanting from the footprint of the proposed expansion. This would involve sampling before removal and following transplanting.
- The condition of the compensatory seagrasses, including those transplanted to the designated areas, as well as any natural colonisation.

As identified in Chapter 5, there is potential for the growth of nuisance algae within Penrhyn Estuary as a result of nutrients from the catchments of Floodvale and Springvale Drains. The occurrence, persistence of any such blooms should monitored to enable an appropriate management feedback response.

Finally, it is recommended that organisms utilising the compensatory seagrass beds be monitored to evaluate diversity and abundance. It is suggested that a good indicator of this would be fish and mobile invertebrates (e.g. prawns) which can be readily collected using standard sampling procedures (e.g. seine nets).

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Report to:

Sydney Ports Corporation

Port Botany Expansion – Aquatic Ecology, Conservation & Fisheries

APPENDIX 1: Supplementary Study on Benthic Communities

FINAL

May 2003

Report prepared by:

The Ecology Lab Pty Ltd

Port Botany Expansion – Aquatic Ecology, Conservation & Fisheries

APPENDIX 1: Supplementary Study on Benthic Communities

May 2003

Report Prepared for:

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SUMMARY

S1. Background & Aims

Sydney Ports Corporation (SPC) proposes to upgrade the port facilities in Botany Bay by expanding the existing container terminal at Port Botany. The expansion will require reclamation of about 60 ha and dredging over about 75 ha between the existing port and airport as well as enhancement of public recreation area and construction of a new boat ramp. The changes proposed would alter the aquatic environment on the northern side of Botany Bay between the Parallel Runway and Molineux Point, which is the area of focus for this technical report.

The Ecology Lab Pty Ltd was engaged by SPC as part of the study team assembled to prepare the EIS and associated specialists' reports upon which the assessment of environmental impacts will be made. In reviewing the existing information on benthic communities that may be affected by the proposal, it was noted that little information existed on the intertidal fauna of Foreshore Beach, or of the subtidal fauna of deeper sediments off Foreshore Beach and in Penrhyn Estuary. Benthic communities consist of a wide range of aquatic invertebrates, often dominated by polychaete worms, crustaceans and molluscs. They provide an important source of food for bird waders, fish and larger invertebrates, are often used as bait by anglers and can be a very useful indicator of environmental stress (both natural and human).

This study on intertidal and subtidal benthic communities was commissioned with the following aims:

- to describe the macroinvertebrate fauna in intertidal and subtidal soft-sediment habitats that may be affected by the proposed expansion of Port Botany,
- to use the obtained information to assist in the EIS process, in terms of predicting and mitigating impacts, and
- to establish locations that may be used as references for potential changes to subtidal benthic communities.

S2. Methods

Intertidal benthic habitats were sampled at five locations from Penrhyn Estuary to the Western end of Foreshore Beach in October 2002 (Figure S1). At each location, three sites approximately 50 m apart were sampled. Six replicate core samples of sandy substrata were taken at each site at the water-sand interface at low tide so that the benthic invertebrate community could be examined. In addition, two replicate core samples were taken at each site for analysing the distribution of particle grain size. In the laboratory, the samples of benthic invertebrates were rinsed through a 1.0 mm mesh size sieve, identified to family level and counted. Subtidal benthic habitats were sampled at six locations, two each at Penrhyn Estuary, Towra Bay and Quibray Bay on 24 and 28 October 2002 (Figure S2). Quibray Bay and Towra Point were selected to provide a spatial comparison for assemblages in Penrhyn Estuary and they may be used as a reference for future monitoring. At each location, three sites were sampled at similar depths. Six samples were collected at each site for examining the benthic invertebrate community and a further two replicates were collected per site for analysis of particle grain size. In the laboratory, the same methods were used as for the intertidal samples of benthic invertebrates and particle grain

sizes. Data were analysed using a variety of statistical procedures, examining variation among assemblages, taxon richness and abundance and abundance of individual taxa.

S3. Findings

The dominant taxa found in the intertidal zone included the polychaete worm *Australonereis* (family Nereididae) and amphipods from the family Exoedicerotidae, both of which are common in estuarine habitats. The intertidal locations, particularly the outer portion of Penrhyn Estuary ("Penrhyn Outer"), differed significantly from each other with respect to their assemblages of benthic invertebrates. Although differences between locations were significant, there was substantial overlap in the structure of the assemblages at each location. Most of the differences amongst the locations were attributed to only a few taxa, particularly nereid worms and exoedicerotid amphipods. Differences among sites within locations were significant and more apparent than differences among locations.

The number of taxa (i.e. taxa richness) per core on average ranged from just over six at the eastern end of Foreshore Beach to about three per core around the outer part of Penrhyn Estuary. Statistically, however, the locations were not clearly different in terms of their taxonomic richness. Statistical analysis of individual taxa showed numerous differences among sites within locations, indicating the importance of small-scale processes. This finding is common in aquatic ecosystems.

The sediments at the intertidal locations were primarily composed of sand, which was mostly fine-to-medium grade (0.15 – 0.3 mm). The percentages of fine-to-medium sand grains were similar among locations. At the scale of sites, however, there were significant differences within all locations except of sites at the Penrhyn Inner location.

The subtidal locations all had relatively distinctive assemblages of benthic invertebrates. However, assemblages from Penrhyn Estuary and Quibray Bay tended to be relatively more similar to all other whilst those from Towra Bay were relatively more dissimilar to the other locations. The dissimilarity of the locations was not strongly attributed to any taxon in particular; rather the contribution of each taxon was moderately even. Differences between sites (i.e. the smaller spatial scale) were significant, but less apparent than differences among locations.

The subtidal locations significantly differed in their numbers of taxa and polychaete taxa, such that Penrhyn Outer contained significantly more than the other locations. The locations differed significantly in their numbers of individuals and polychaete individuals, with Penrhyn Inner containing significantly more than the other locations. These differences in the number of individuals at Penrhyn Inner were mostly due to polychaete worms (Nereididae) and round worms (Nematoda). The locations also differed significantly in their numbers of crustacean taxa and mollusc individuals and taxa. Differences among sites occurred for numerous taxa, but not in any particular pattern, reflecting small scale variability.

The sediments of the subtidal locations were composed primarily of sand, which was mostly very fine-to-medium grade. However, some sites contained substantial amounts of mud. The percentages of fine-to-medium sand grains were similar among locations. With exception of Quibray Outer, all locations showed significant site differences in their percentages of fine-to-medium sand grains.

S4. Conclusions

This study has compiled information of intertidal and subtidal benthos in the study area that will be important for assessing the affects of the proposed port expansion and as part of a baseline for monitoring. Both the intertidal and subtidal data indicated that Penrhyn Estuary had a relatively diverse and abundant invertebrate fauna, despite being subject to contaminants from the catchment. Provided that the proposed works ensure there is appropriate estuarine habitat within Penrhyn Estuary and along Foreshore Beach, it is expected that the area will develop a diverse and abundant invertebrate fauna following completion of construction. These issues are considered further in Volume 1 of this report.

Figure S1: Positions of sampling sites (orange dots) for intertidal benthos along Foreshore Beach and Penrhyn Estuary, Botany Bay sampled 8 October, 2002 by The Ecology Lab Pty Ltd.

Figure S2: Sampling locations for subtidal benthos sampled in Botany Bay on 24 and 28 October, 2002. Each orange dot represents a location: three sites and five replicate grabs were taken at each location.

1.0 INTRODUCTION

1.1 Background and Aims

Sydney Ports Corporation (SPC) proposes to upgrade the port facilities in Botany Bay by expanding the existing container terminal at Port Botany. The expansion will require reclamation and dredging over about 60 ha at the south eastern end of Foreshore Beach and additional public recreation area and construction of a new boat ramp. The changes proposed would alter the aquatic environment on the northern side of Botany Bay between the Parallel Runway and Molineux Point, which is the area of focus for this technical report.

The Ecology Lab Pty Ltd was engaged by SPC as part of the study team assembled to prepare the EIS and associated specialists' reports upon which the assessment of environmental impacts will be made. In reviewing the existing information on benthic communities that may be affected by the proposal, it was noted that little information existed on the intertidal fauna of Foreshore Beach, or of the subtidal fauna of deeper sediments off Foreshore Beach and in Penrhyn Estuary. Although a few studies of the benthos (flora and fauna living on , near or in bottom sediments) of Botany Bay exist, these were either in deeper water habitats (AMBS 1993), were in intertidal habitats at some distance away from beach habitat that may be affected by the proposal (Dexter 1983, 1984, 1985), or were done prior to construction of the Third Runway (all of the above plus Kinhill 1991). Benthic communities consist of a wide range of aquatic invertebrates, often dominated by polychaete worms, crustaceans and molluscs. They provide an important source of food for bird waders, fish and larger invertebrates, are often used as bait by anglers and can be a very useful indicator of environmental stress (both natural and human).

This study on intertidal and subtidal benthic communities was commissioned with the following aims:

- to describe the macroinvertebrate fauna in intertidal and subtidal soft-sediment habitats that may be affected by the proposed expansion of Port Botany,
- to use the information obtained to assist in the EIS process, in terms of predicting and mitigating impacts, and
- to establish locations that may be used as references for potential changes to subtidal benthic communities.

1.2 Existing Information

1.2.1 Intertidal Benthic Studies

There have been relatively few surveys of the sandy intertidal habitats of Botany Bay. Dexter (1983, 1984, 1985) surveyed intertidal invertebrates at Dolls Point and Towra Point with the aim of relating benthic assemblages to different characteristics of beaches, particularly exposure. However, interpretations of results in terms of the proposed port expansion are limited by Dexter's sampling designs and positions of sampling sites, which were remote from Foreshore Beach.

As part of supplementary work for the Parallel Runway, Kinhill (1991) commissioned a survey of beach fauna at Foreshore Beach (denoted as Botany Beach in that study) and at two reference beaches, Towra Point and Runway Beach (on the eastern side of the original north-south runway, but now removed). At each beach three sites were sampled at two heights on the shore, 0.3 to 0.5 m and 0.5 to 0.7 m LAT. Five replicates were taken at each site/height, but these samples were combined to obtain a bulk sample for each of the three sites. Samples were collected by coring and sieved through a 1 mm mesh.

Foreshore Beach was dominated by the nereidid polychaete *Australonereis ehlersi*, which was also abundant at Runway Beach (Kinhill 1991). The fauna was quite distinctive compared to Towra Point, being dominated numerically by the amphipod *Urohaustorius metungi* and the polychaete *Scolopsis simplex*.

Kinhill (1991) surveyed benthos along Foreshore Beach prior to construction of the Third Runway. They concluded that there was a distinctive gradient in abundance of benthos along Foreshore Beach. The northern part was relatively sheltered, with an abundance of benthic invertebrates of 4,835 (± 419 SE) individuals per m^2; the central area supported an average of 1,190 (± 109) individuals per m^2 while the southern, most exposed site sampled had an average abundance of 854 (± 53) individuals per m^2. These differences were attributed mainly to a change in abundance of *A. ehlersi*.

Much of the section of Foreshore Beach surveyed by Kinhill (1991) was lost as a result of the construction of the Parallel Runway. The middle site sampled was close to the present mouth of the Mill Stream, whilst the southern most site was northwest of Penrhyn Estuary. As far as is known, there are no data on the intertidal benthos of the remaining southern portion of Foreshore Beach, or of Penrhyn Estuary. The method of compositing samples used by Kinhill (1991) limits the way in which data can be evaluated.

Given that benthic invertebrates can be a useful indicator of environmental conditions and that intertidal beach and subtidal soft sediments would be affected by the proposed port expansion, it was considered important to collect quantitative information on these animals.

1.2.2 Subtidal Benthic Studies

There has been far more work done on the benthos associated with subtidal than intertidal habitats in Botany Bay. Much of this work has been directed at measuring the effects of dredging on benthos (e.g. Jones and Candy 1981, Kinhill 1991, AMBS 1993, 1998) or fish (SPCC 1981a, b, AMBS 1993). These are discussed in details in Chapter 2 of Volume 1 in this report. Here, studies most relevant to shallow subtidal habitats (i.e. Kinhill, 1991; AMBS 1993) are considered.

Kinhill (1991) sampled six sites in the northern portion of Botany Bay in July 1991, including four sites within the study area for the proposed port expansion (see Chapter 2, Volume 1 of this report). At each site, five replicate samples were collected. The sieved mesh size was not reported. Three of the sites were in areas proposed to be dredged; the other three were not to be dredged. Two sites were at depths < 4 m, two were at a depth of 5 m and two were at depths > 8 m (Kinhill 1991). Sediments were described as sandy mud or muddy sand.

Fifty-six species of invertebrates were collected, including 35, 12 and 9 species of polychaetes, molluscs and crustaceans, respectively (Kinhill 1991). The most abundant organisms found in the samples were deposit feeding polychaetes, including *Chaetozone setosa*, *Notomastus chrysosetus*, *Heteromastus filiformis*, *Mediomastus* sp. and *Augeneria verdis*. A polychaete not recorded previously in Australia, *Notocirrus* sp., was collected at a site to the south of the original North-South Runway. It was suggested that the creation of deep, isolated holes through dredging would be undesirable in areas that would experience high levels of sedimentation possibly due to much more sheltered conditions there (Kinhill 1991).

The Australian Museum sampled benthos and benthic scavengers as part of preliminary sampling for monitoring the recovery of areas to be dredged for obtaining fill for the Parallel Runway (AMBS 1993; see Chapter 2 in Volume 1 of this report). Six sites were sampled in Botany Bay in April and July 1992. Three of the sites were to the east of the original North-South Runway in areas proposed for dredging; the other three were to the west of the runway and were considered as references. Samples were collected using grab samplers.

A total of 303 species were collected comprising 128, 99, 76 and 1 species of polychaetes, crustaceans, molluscs and an echinoderm, respectively (AMBS 1993). In addition, specimens of the phyla or classes Sipuncula, Oligochaeta, Nemertea, Phoronida and Nematoda were collected. The average number of taxa per grab ranged from 22 to 41 in April and from 14 to 48 in July. Sediments were typically sandy (> 80% of each sample, on average), although one of the reference sites had a relatively high percentage of mud.

It was concluded that the benthic fauna consisted of species that also occurred in other shallow, protected embayments of the Sydney region. Spatial patterns tended to be more pronounced than temporal ones, however, there was only a small gap of time between the two surveys. It was also found that the reference sites tended to differ from the intended dredge sites and this was attributed to longitudinal differences (i.e. references were west of the N-S Runway; dredge sites to the east) and to differences in sediment and possibly salinity characteristics (AMBS 1993). It was also suggested that the temporal differences may be linked to recovery of benthic habitats following the end of the trawling season, which occurred at the end of April.

2.0 STUDY METHODS

2.1 Intertidal Habitat

2.1.1 Intertidal Sampling Sites and Field Methods

Sampling was done on 8/10/02 within a two hour window around low tide. The predicted afternoon low tide on 8/10/02 was 0.15 m at 15:35 pm. Five sampling locations were selected along the length of Foreshore Beach and around Penrhyn Estuary (Figure 1). We did not sample within the deltas of Springvale or Floodvale drains because sediments there were visually quite different to the main beach areas (i.e. they were muddier) and because these deltas are subject to freshwater flow (see Chapter 2 in Volume 1), hence would be expected to support very different assemblages to other parts of Foreshore Beach or Penrhyn Estuary. At each location, three sites approximately 50 m apart were sampled. This sampling design allowed us to examine variability at the relatively large scale of locations and at the smaller scale of sites within locations. This type of approach has been found to be very important in understanding patterns of variation in intertidal and subtidal benthic communities (e.g. Morrisey *et al*. 1992).

Before sampling, the location of each site was recorded in WGS 84 datum using a hand-held GPS unit (Appendix 1). Six replicate samples of sediment were collected at each site at the water-sand interface by pushing a 10 cm diameter PVC tube into the sediment to a depth of 20 cm. The sample was placed in a labelled plastic bag and returned to the laboratory for preserving and processing.

In addition to samples collected for analysis of benthic fauna, two replicates samples were taken at each site to be analysed for distribution of particle size. These samples were placed in labelled plastic bags, returned to the laboratory and frozen until dispatch.

2.1.2 Laboratory Methods

Each sample collected for analysis of benthic fauna was preserved using a 5-10% formalin-seawater solution containing dissolved Rose Bengal dye on returning to the laboratory. The dye stains live animals pink, making them easier to find and remove from the sediment. Samples were allowed to fix for a minimum period of three days before processing. They were then decanted of excess formalin and rinsed through a 1.0 mm mesh size sieve. Animals were removed from the samples using a dissecting microscope, sorted, identified to the taxonomic level of family and counted. A few groups which are difficult to identify, such as crab larvae, nemerteans, nematodes, oligochaetes and anemones were identified to higher levels of taxonomic resolution.

Samples collected for analysis of particle grain size were dispatched to Australian Soil Testing Laboratory for analysis. Wet sieving of samples was done and the fraction of the sample retained on each sieve size was recorded.

2.1.3 Statistical Methods

The statistical design used to analyse data on intertidal benthic communities and sediment grains is shown in Figure 2. Locations and sites were compared using multivariate and univariate statistical analyses. Multivariate analyses compared the assemblages of the benthic invertebrates, while univariate analyses compared taxonomic richness, total abundance, abundance of selected taxa and the percentage of sediment grains sized 0.151 - 0.3 mm, from which inspections of the data showed to be the dominant grain size.

2.1.3.1 Multivariate Analyses

Differences in the assemblages of benthic invertebrates among locations and sites were examined using the multivariate procedures in the software of PRIMER 5 (Plymouth Routines In Multivariate Ecological Research). Firstly, data was fourth root transformed (because abundances of certain taxa were well above 100 in some samples). Transformed abundances were then used to calculate Bray-Curtis similarities (Bray and Curtis, 1957). The similarities were then tested for differences among locations and sites using the two-way nested Analysis of Similarities (ANOSIM) randomisation test (Clarke, 1993). For this test the number of replicates was six, which was an insufficient number of replicates for detecting significant differences in pair-wise comparisons of locations. Subsequently, additional one-way ANOSIMs of locations were performed, which yielded eighteen replicates for each location (i.e. three sites x six replicates). This enabled enough statistical power to detect significant differences between pairs of locations. This test was only done if the global test for differences between locations in the two-way ANOSIM was significant. The *a priori* alpha level was 0.05 for all the ANOSIM tests.

The Bray-Curtis similarities were also used to construct a three-dimensional nMDS (nonparametric Multi-Dimensional Scaling) plot of the locations (Clarke and Warwick, 1994). The measure of how well the data have been reduced to three dimensions in the plot is indicated by a stress value (Kruskal and Wish, 1978). Thus, the stress value is only representative of the relationships between samples and is not indicative of the environmental condition.

Similarity Percentages (SIMPER) were calculated from fourth root transformed data to determine the relative contribution of each taxon to the total dissimilarity of the locations (Clarke, 1993).

2.1.3.2 Univariate Analyses

Differences among locations and sites in certain populations of the benthic invertebrates were examined using Analysis of Variance (ANOVA). The variables examined were: the number of taxa and individuals in total, in crustaceans, in molluscs, in echinoderms, in polychaetes, and in other various taxa. The model used was a two-way nested ANOVA comparing locations and sites within locations. Prior to analysis, data were tested for homogeneity of variance by Cochran's C Test and transformed where necessary (Underwood, 1981, 1997). Where ANOVA was significant, Student Newman Keuls (SNK) tests were used to identify which means differed for significant factors (Winer, 1971; Underwood, 1981).

The same univariate procedures as above were followed when testing for differences among sites and locations in the percentage of grains in the size fraction of 0.151 – 0.3 mm .

2.2 Subtidal Habitat

2.2.1 Subtidal Benthos Sampling Sites and Field Methods

Subtidal benthic communities were sampled at three locations on 24 and 28 /10/02: Penrhyn Estuary and two reference locations, Quibray Bay and near Towra Point (Figure 3). At each location two "positions" were selected to represent the range of exposure to wind, waves and currents. The "inner" position at each location was less exposed (located within an embayment) compared to the position "outer", more exposed position. At each position, three sites were selected from which to sample benthic fauna and grain size. Six replicate samples were collected at each site to be analysed for benthic community structure. However, time constraints of sorting the samples meant that only five of the six replicate samples could be processed, hence the sixth replicate sample was archived. In addition to the benthos samples, two replicate samples were collected at each site for the analysis of particle grain size distribution. The sampling design is shown in Figure 4 and, as with the intertidal survey, it enabled a comparison of variability at different spatial scales. Before sampling, the location of each site was recorded in WGS 84 datum using a hand-held GPS unit (Appendix 2). Depth of each sampling site was measured using a hand –held depth gauge, in order to select sites within a similar range of depths. The time of sampling at each site was also recorded, and water depth was later corrected to AHD (m) by subtracting the charted tidal height from the measured water depth.

A van Veen grab was deployed from a small boat to collect all samples. Samples were relatively large and were therefore sieved on the boat through a 1.0 mm mesh sieve. Sediment remaining in the sieve was placed in a labelled plastic bag and preserved using a 5-10% formalin-seawater solution containing dissolved Rose Bengal dye. Samples to be analysed for grain size were placed directly in labelled plastic bags and were not sieved or preserved. It should be noted that the use of divers to collect sediment cores has been common in Botany Bay (e.g. Morrisey *et al.* 1992) and is probably a more rigorous approach than the use of a grab sampler. However, the presence of contaminated sediments in Penrhyn Estuary meant that the use of a grab was safer for field staff as it minimised exposure to the water and sediments. .

2.2.2 Laboratory Methods

Samples were allowed to fix for a minimum period of three days before processing. They were then decanted of excess formalin and rinsed through a 1.0 mm mesh size sieve. Animals were removed from the samples using a dissecting microscope, sorted, identified to the taxonomic level of family and counted. A few groups which are difficult to identify, such as crab larvae, gastropod egg masses, nemerteans, nematodes, oligochaetes, phoronids, hirudinians and anemones were identified to higher levels of taxonomic resolution.

Samples collected for analysis of particle grain size were dispatched to Australian Soil Testing Laboratory for analysis. Wet sieving of samples was done and the fraction of the sample retained on each sieve size was recorded. Data provided by AST were entered into spreadsheet format and data checked by two staff members prior to analysis.

2.2.3 Statistical Methods

The statistical design used to analyse data on subtidal benthic communities and sediment grains is shown in Figure 4. All multivariate and univariate analyses performed on the subtidal benthic community and sediment grains used the same methods as those performed for the intertidal component above.

3.0 RESULTS

3.1 Intertidal Habitat

3.1.1 Description of Habitats

Intertidal sampling sites were sand flats dominated by medium to fine clean sandy sediments. In Penrhyn Estuary sediments appeared muddier than along Foreshore Beach, with the occasional mangrove seedlings emerging from the sediment. Along Foreshore Beach the sandy tubes of *Australonereis ehlersi* could be seen in some places, and on one occasion a worm was observed crawling out of its tube and burrowing into adjacent sediment. Free-living polychaete worms in the family Phyllodocidae were observed in several places crawling in wet ripple depressions in the sand. Their maximum density was estimated to be approximately 30 per 10 m^2.

3.1.2 Sediment Grain Size

All five locations were primarily composed of sand, which was most commonly of a fine-to-medium grade on the Wentworth size class scale (i.e. on average, 50% of the grains were sized between 0.151 – 0.3 mm) (Figure 5; Appendix 3). The five locations shared similar percentages of fine-to-medium sand grains (0.15 – 0.3 mm); however there were significant differences among sites (Table 1). These small scale differences were apparent at all locations except Penrhyn Inner (Figure 6), where grain size was similar among all sites.

3.1.3 Benthos

3.1.3.1 General Findings

The mean number of each taxa collected from each site is shown in Appendix 4. A total of 3,621 individuals, comprising 37 taxa, were collected in the 90 samples processed. The crustaceans were the most abundant group (43% of the 3,621 individuals sampled), followed by the polychaetes (37%), other worm phyla (15%), and molluscs (5%). The greatest number of taxa were found in polychaetes (35% of the 37 taxa sampled), followed by the crustaceans (27%), molluscs (24%), and other worm phyla (8%).

More detailed identification of the dominant fauna indicated that the polychaete worms in the family Nereididae were comprised of *Australonereis ehlersi* and *Ceratonereis* sp. Polychaete worms in the family Spionidae were dominated by an unidentified genus (probably *Spio* or *Microspio*) that may have been found previously in small numbers along Foreshore Beach (Ms Anna Murray, Australian Museum, pers. comm., Kinhill 1991). Other genera in the family Spionidae present included *Scolelepis* sp. The dominant burrowing worm present was *Scoloplos (Leitoscoloplos)* sp., which has been previously recorded from Foreshore Beach (Kinhill 1991). Crustacean amphipods from the family Exoedicerotidae included *Exoediceros fossor* and *Exoediceros maculosus*.

3.1.3.2 Analyses of Assemblages

The locations significantly differed from each other with respect to their assemblages of benthic invertebrates (Table 2). Penrhyn Outer was particularly different to the other locations (as told by the pair-wise R values). Penrhyn Outer was most different to Foreshore East, followed by Foreshore West, Foreshore Middle and then Penrhyn Inner. Although differences between locations are significant, the pair-wise R-values are all below 0.6 which indicates that there was overlap among the assemblages. This point is well illustrated in the nMDS, where samples of each location are obviously grouped together in patterns but are also greatly overlapping (Figure 7). Notably, however, Penrhyn Outer is the most tightly clustered and the least overlapped of all the locations. Up to fifty percent of the dissimilarity of the locations was attributed to only a small handful of taxa, particularly Nereididae and Exoedicerotidae (Table 3). On average, top contributing taxa contributed 14.2% (SE ±1.0%). The greatest contribution of any single taxon to the total dissimilarity of any pair of locations was 22% (Exoedicerotidae in Foreshore West versus Penrhyn Outer).

Differences among sites were significant and more apparent than differences among locations (Table 2).

3.1.3.3 Analyses of Populations

Of 15 variables analysed, all showed significant differences among sites within locations (i.e. small-scale variability) and only one showed significant location differences (Table 4). The locations differed in terms of the number of taxa, which were in greater numbers at Foreshore East, followed by Foreshore Middle, Penrhyn Inner, Foreshore West and Penrhyn Outer (Figure 8). However, SNK tests were unable to determine specifically which locations were different. Likewise, the SNK tests were unable to detect some of the site-scaled differences for some variables. There did not appear to be any conspicuous patterns at the scale of sites for any of the variables (Figure 9).

3.2 Subtidal Habitat

3.2.1 Description of Habitats

Subtidal habitats sampled were in water depths ranging from -0.42 m AHD to 3.34 m AHD. Sampling locations were adjacent to, but not within seagrass (*Zostera capricorni*) habitat. At the Quibray Bay locations, *Posidonia* detritus was observed, but no samples taken were close to *Posidonia* beds. Most grab samples contained seagrass detritus and sediments containing varying amounts sand and mud. Efforts were made to collect samples in areas not affected by strong currents, although water movement due to tidal currents was observed and were particularly strong at the Towra Bay outer sampling sites.

3.2.2 Sediment Grain Size

Most sites were composed of fine-to-medium grade sand on the Wentworth size class scale (i.e. on average, 38% of the grains were sized between 0.151 – 0.3 mm) (Figure 10; Appendix 5). The exceptions to this were Site 1 and Site 2 (Penrhyn Inner), Site 4 (Penrhyn Outer) and Site 14 and Site 15 (Towra Inner), which all contained larger amounts of mud (< 0.76 mm grains). The five locations shared similar percentages of fine-to-medium sand grains (0.15 –

0.3 mm); however there were significant differences among sites (Table 5). These site-scaled differences were apparent at all locations except Quibray Outer (Figure 11).

3.2.3 Benthos

3.2.3.1 General Findings

The mean number of each taxa collected from each site is shown in Appendix 6. A total of 37,110 individuals, comprising 108 taxa, were collected in the 90 samples (i.e. 5 replicates per site) processed. This is more than ten times the abundance and three times the number of taxa recorded within the intertidal habitat for the same number of samples, although the volume collected by the grab (subtidal) was substantially larger that collected using the cores (intertidal). The polychaetes comprised the most abundant group (60% of the 37,110 individuals sampled), followed by the other worm phyla (21%), crustaceans (9%), 'other phyla' (5%), molluscs (5%) and echinoderms (1%). The greatest number of taxa were found in crustaceans (31% of the 108 taxa sampled), followed by the molluscs (28%), polychaetes (27%), and other worm phyla (7%), echinoderms (4%) and 'other phyla' (4%).

3.2.3.2 Analyses of Assemblages

All locations significantly differed from each other with respect to their assemblages of benthic invertebrates (Table 6), with Penrhyn Outer, Penrhyn Inner and Quibray Outer being particularly distinctive (as indicated by the pair-wise R values). Quibray Outer and Quibray Inner showed substantial overlap in their assemblages. Towra Inner, Towra Outer and Quibray Inner also showed considerable overlap in their invertebrate assemblages (with correspondingly small pair-wise R-values). The greatest differences in assemblages were between Penrhyn Inner and Quibray Outer and the smallest differences were between Quibray Inner and Towra Inner. These points are well illustrated in the nMDS, where samples are grouped according to location for Penrhyn Outer, Penrhyn Inner and Quibray Outer but less so for Towra Inner, Towra Outer and Quibray Inner (Figure 12). The greatest contribution of any single taxon to the total dissimilarity of any pair of locations was 11% (Nereididae in Penrhyn Inner versus Quibray Inner). On average, top contributing taxa contributed only 7.6% (SE ±0.5%) (Table 7). Thus, the dissimilarity of the locations was not strongly attributed to any one taxon in particular; rather the contribution of each taxon was moderately even.

Differences between sites within locations were significant, but less apparent than differences at the scale of locations (Table 6).

3.2.3.3 Analyses of Populations

Of 14 variables analysed, 13 showed significant site differences and 10 showed significant differences at the larger scale of locations (Table 8). Penrhyn Outer contained significantly more taxa and polychaete taxa than the other locations (Figure 13). Locations other than Penrhyn Outer did not differ significantly in their numbers of taxa and polychaete taxa. The number of mollusc and crustacean taxa also differed significantly among locations. However, whether Penrhyn Outer differed significantly to the other locations with respect to these variables is unknown because the SNK was unable to determine which locations specifically differed. However, Penrhyn Outer did contain the greatest numbers of mollusc and crustacean taxa. Penrhyn Inner, conversely, contained a significantly greater number of individuals and polychaete individuals than the other locations (Figure 13). Locations other than Penrhyn Inner did not differ significantly in their numbers of taxa and polychaete taxa. The number of mollusc individuals also differed significantly among locations. However, whether Penrhyn Inner differed significantly to the other locations with respect to this variable is unknown because the SNK was unable to identify which locations differed. Penrhyn Inner location contained the greatest number mollusc individuals. Nereididae and Nematoda were mainly responsible for the significant differences in the number of individuals at Penrhyn Inner (Figure 13).

Likewise, the SNK tests were unable to detect some of the site-scaled differences for some variables. There did not appear to be any conspicuous patterns at the scale of sites for any of the variables examined (Figure 14).

4.0 DISCUSSION

4.1 Intertidal Benthic Communities

The fauna collected from the intertidal habitat along Foreshore Beach showed a range of types and numbers of invertebrate animals typical of estuarine habitat. Included in the dominant fauna were burrowing worms (Orbiniidae), shallow burrowing crustacean amphipods (Exodicerotidae), tube-building worms (*Australonereis*) and free crawling worms (*Ceratonereis* and Phyllodocidae). The range and numbers of types present indicate that the current community is diverse and functions as an ecological unit. From the perspective of the current proposal, the habitat supports a diverse community compared to other similar habitats (Dexter 1983, 1984, 1985), and likely provides links to other parts of the ecosystem in Botany Bay by providing food for wading birds and fish. Although the food items of wading birds in this habitat are not known in detail, it is likely that some wading birds feed on at least the larger and more visible components of this fauna, for example the bright orange or green coloured crawling worms of the family Phyllodocidae, which can reach up to 20 cm in length.

Locations along Foreshore Beach differed from one another, with the Penrhyn Outer location notably different from other locations. While the range of animals found at this location was similar to the others, the composition of the assemblage varied. The factors responsible for this differences are not known, but may include subtle differences in the composition of sediment particles, differences in the behaviour of tidal currents at that location or some combination of these and other factors.

The impacts of the proposal on this habitat and the community it supports are discussed more fully in Chapters 5 and 6 of Volume 1 of this report.

4.2 Subtidal Benthic Communities

Larger numbers of animals and a greater diversity of animals were found in subtidal habitats compared to the intertidal habitats, as expected based on evidence from previous studies. Among the many factors that could contribute to this finding was the presence of seagrass detritus in subtidal benthic samples. Among other differences between the two habitats, the presence of this source of food and animals that can exploit it increases the diversity and number of animals compared to the intertidal habitat. The presence of a diversity of feeding types and life styles in the subtidal benthic communities in Penrhyn Estuary indicate a functioning ecological unit, which we would expect would interface with other components of the Botany Bay aquatic ecosystem.

Quibray Bay appears to be a suitable reference for Penrhyn Estuary. Although care was taken to control for factors known to influence benthic communities such as water depth, exposure to currents and tides and composition of sediments, differences were detected between locations. Interestingly, the Penrhyn locations were similar to the outer Quibray Bay location, but the latter also had similarities with the Towra locations. An option may be to place another reference site in Quibray Bay against which changes due to the current proposal can be compared.

The impacts of the proposal on this habitat are discussed more fully in Volume 1 of this report.

4.3 Conclusions

The surveys of intertidal and shallow subtidal benthos within the core study area provide a description of this component of the aquatic environment, which can be used in the EIS process and in designing any future monitoring of this habitat that may be required.

The analysis of sediment grain size suggests that the sediment within each habitat was broadly similar, but that there are some differences, particularly between sites within some locations. These differences do not broadly explain differences in benthos, but further investigation could be done to explore this issue (but is not recommended in this part of this EIS process).

It was found in this study that benthos within Penryhn Estuary, which is known to be contaminated with a variety of chemicals (see Chapter 4 in Volume 1 of this Report), was relatively diverse and abundant. Thus, while we might consider "ecosystem health" to be poor based on contaminant studies, the benthic studies suggest a different condition. Provided that the proposed port expansion maintains a suitable amount of habitat, sufficient water flow and does not exacerbate existing problems with contamination, we would expect Penrhyn Estuary and Foreshore Beach to support a diverse and abundant benthic fauna following the expansion.

A final point to note is that the surveys reported here were done at a single time and therefore represent a "snap shot" picture of the benthos at the sites and locations sampled. Both assemblage structure and population sizes would be expected to vary through time, due to both natural and anthropogenic causes. Notwithstanding this, the use of snap shot surveys within EIS's is a typical approach. This does not infer that additional sampling would not be required following the approval process – before construction begins, then during and after construction. This issue is discussed in more detail in Chapter 6 of Volume 1 of this report.

5.0 ACKNOWLEDGEMENTS

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TABLES

Table 1: ANOVA results comparing percentage of sediment grains sized 0.151 - 0.3 mm among intertidal sites and locations along Foreshore Beach and Penrhyn Estuary, Botany Bay, October 2002. Bold print = term significant. Lo = Location, Si = Site. Alpha (a) = 0.05. Cochran's C value not significant (n = 2).

Source of Variation	df	MS	*F*	p
Lo	4	825.5	2.15	0.149
Si(Lo)	10	384.0	23.22	**0.000**
RES	15	16.53		

Table 2: ANOSIM results comparing assemblages of intertidal benthos between sites and locations along Foreshore Beach and Penrhyn Estuary, Botany Bay, October 2002. Significant terms are in **bold** print. Alpha (a) = 0.05. Pairwise comparisons are not displayed in the two-way nested ANOSIM since there were insufficient permutations to obtain a significant *p*-value. Rather, pairwise comparisons are presented for the one-way ANOSIM.

a) Two-way nested ANOSIM (n = 6)

Source of Variation	Permutations	Global R	Global p
Sites	999	0.658	**0.001**
Locations	999	0.267	**0.015**

b) One-way ANOSIM (n = 18)

Source of Variation	Permutations	Pairwise R	Pairwise p
Foreshore West vs Foreshore Middle	999	0.239	**0.001**
Foreshore West vs Foreshore East	999	0.373	**0.001**
Foreshore West vs Penrhyn Outer	999	0.552	**0.001**
Foreshore West vs Penrhyn Inner	999	0.368	**0.001**
Foreshore Middle vs Foreshore East	999	0.102	**0.026**
Foreshore Middle vs Penrhyn Outer	999	0.48	**0.001**
Foreshore Middle vs Penrhyn Inner	999	0.296	**0.001**
Foreshore East vs Penrhyn Outer	999	0.591	**0.001**
Foreshore East vs Penrhyn Inner	999	0.244	**0.001**
Penrhyn Outer vs Penrhyn Inner	999	0.464	**0.001**

Table 3: SIMPER results comparing the relative contribution of various intertidal benthic taxa to the dissimilarity of the assemblages among location along Foreshore Beach and Penrhyn Estuary, October 2002. Cut-off for low contributions 50.00%.

a) Foreshore West & Foreshore Middle

Taxon	Av. Abundance Foreshore West	Av. Abundance Foreshore Middle	Av. Diss	Diss/SD	Contrib%	Cum%
Exoedicerotidae	1.44	16.56	9.61	1.40	14.30	14.30
Spionidae	2.78	7.33	7.38	1.08	10.98	25.28
Orbiniidae	1.33	3.00	6.83	1.15	10.15	35.43
Capitellidae	0.39	3.67	6.54	1.10	9.72	45.15
Nereididae	1.22	4.33	6.32	1.01	9.39	54.54

Average Dissimilarity = 67.24

b) Foreshore West & Foreshore East

Taxon	Av. Abundance Foreshore West	Av. Abundance Foreshore East	Av. Diss	Diss/SD	Contrib%	Cum%
Exoedicerotidae	1.44	9.94	8.69	1.20	12.03	12.03
Nereididae	1.22	5.28	8.14	1.33	11.28	23.31
Oligochaeta	0.11	22.00	6.75	0.75	9.35	32.66
Orbiniidae	1.33	2.11	6.28	1.29	8.70	41.36
Capitellidae	0.39	3.11	6.14	1.22	8.51	49.87
Nemertea	1.22	0.11	5.98	1.10	8.29	58.15

Average Dissimilarity = 72.19

c) Foreshore Middle & Foreshore East

Taxon	Av. Abundance Foreshore Middle	Av. Abundance Foreshore East	Av. Diss	Diss/SD	Contrib%	Cum%
Nereididae	4.33	5.28	6.12	1.43	11.56	11.56
Oligochaeta	2.50	22.00	5.82	0.83	10.98	22.54
Spionidae	7.33	1.83	5.59	1.12	10.56	33.10
Capitellidae	3.67	3.11	5.03	1.20	9.49	42.59
Leptonidae	3.00	0.78	4.92	1.09	9.28	51.87

Average Dissimilarity = 52.98

d) Foreshore West & Penrhyn Outer

Taxon	Av. Abundance Foreshore West	Av. Abundance Penrhyn Outer	Av. Diss	Diss/SD	Contrib%	Cum%
Exoedicerotidae	1.44	51.11	17.35	1.28	22.05	22.05
Leptonidae	2.06	0.06	9.84	1.25	12.51	34.57
Nemertea	1.22	0.06	8.92	1.09	11.34	45.91
Spionidae	2.78	1.44	8.24	1.15	10.47	56.38

Average Dissimilarity = 78.65

Continued…

Table 3: Continued…

e) Foreshore Middle & Penrhyn Outer

Taxon	Av. Abundance Foreshore Middle	Av. Abundance Penrhyn Outer	Av. Diss	Diss/SD	Contrib%	Cum%
Orbiniidae	3.00	0.11	7.58	1.26	11.93	11.93
Spionidae	7.33	1.44	7.42	1.17	11.68	23.62
Capitellidae	3.67	0.00	7.11	1.11	11.19	34.81
Leptonidae	3.00	0.06	6.96	1.11	10.96	45.77
Nereididae	4.33	0.39	6.49	1.04	10.22	55.99

Average Dissimilarity = 63.49

f) Foreshore East & Penrhyn Outer

Taxon	Av. Abundance Foreshore East	Av. Abundance Penrhyn Outer	Av. Diss	Diss/SD	Contrib%	Cum%
Nereididae	5.28	0.39	8.67	1.54	13.13	13.13
Exoedicerotidae	9.94	51.11	7.39	1.09	11.19	24.32
Oligochaeta	22.00	0.11	7.10	0.76	10.74	35.07
Orbiniidae	2.11	0.11	6.88	1.49	10.42	45.49
Capitellidae	3.11	0.00	6.80	1.31	10.30	55.78

Average Dissimilarity = 66.05

g) Foreshore West & Penrhyn Inner

Taxon	Av. Abundance Foreshore West	Av. Abundance Penrhyn Inner	Av. Diss	Diss/SD	Contrib%	Cum%
Nereididae	1.22	29.22	11.81	1.31	15.03	15.03
Cirolanidae	0.00	1.61	7.30	1.20	9.29	24.32
Leptonidae	2.06	0.22	7.17	1.20	9.13	33.45
Exoedicerotidae	1.44	3.22	6.60	1.16	8.40	41.85
Oligochaeta	0.11	2.33	6.24	0.85	7.95	49.80
Nemertea	1.22	0.33	6.14	1.07	7.81	57.61

Average Dissimilarity = 78.57

h) Foreshore Middle & Penrhyn Inner

Taxon	Av. Abundance Foreshore Middle	Av. Abundance Penrhyn Inner	Av. Diss	Diss/SD	Contrib%	Cum%
Nereididae	4.33	29.22	9.01	1.39	13.44	13.44
Exoedicerotidae	16.56	3.22	6.80	1.20	10.14	23.58
Spionidae	7.33	1.61	6.22	1.04	9.28	32.86
Capitellidae	3.67	2.83	5.79	1.13	8.64	41.50
Orbiniidae	3.00	1.39	5.60	1.12	8.35	49.85
Leptonidae	3.00	0.22	5.55	1.09	8.27	58.11

Average Dissimilarity = 67.06

Continued…

Table 3: Continued…

i) Foreshore East & Penrhyn Inner

Taxon	Av. Abundance Foreshore East	Av. Abundance Penrhyn Inner	Av. Diss	Diss/SD	Contrib%	Cum%
Nereididae	5.28	29.22	7.13	1.30	11.26	11.26
Oligochaeta	22.00	2.33	7.01	1.04	11.07	22.32
Exoedicerotidae	9.94	3.22	6.43	1.18	10.16	32.48
Capitellidae	3.11	2.83	5.50	1.22	8.68	41.17
Cirolanidae	0.11	1.61	5.40	1.18	8.54	49.70
Orbiniidae	2.11	1.39	5.16	1.24	8.15	57.86

Average Dissimilarity = 63.32

j) Penrhyn Outer & Penrhyn Inner

Taxon	Av. Abundance Penrhyn Outer	Av. Abundance Penrhyn Inner	Av. Diss	Diss/SD	Contrib%	Cum%
Nereididae	0.39	29.22	12.50	1.41	17.20	17.20
Exoedicerotidae	51.11	3.22	11.68	1.14	16.08	33.29
Cirolanidae	0.17	1.61	7.15	1.18	9.85	43.14
Oligochaeta	0.11	2.33	6.56	0.87	9.03	52.16

Average Dissimilarity = 72.64

Table 4: ANOVA results comparing intertidal benthic infauna among sites and locations sampled along Foreshore Beach and Penrhyn Estuary, Botany Bay, October 2002. **Bold print** = term significant. Lo = Location, Si = Site. Alpha (a) = 0.05, except if the Cochran's C value is significant and then a = 0.01 (n = 6).

		Number of taxa Ln(X+1); Cochran's N.S.			Number of polychaete taxa Sqrt(X+1); Cochran's N.S.			Number of mollusc taxa Cochran's N.S.			Number of crustacean taxa Cochran's N.S.		
Source of Variation	df	MS	*F*	p	MS	*F*	p	MS	*F*	p	MS	*F*	p
Lo	4	1.009	4.50	**0.025**	1.099	2.36	0.124	4.139	2.93	0.076	3.206	2.05	0.164
Si(Lo)	10	0.224	2.59	**0.009**	0.466	6.00	**0.000**	1.411	2.53	**0.011**	1.567	3.77	**0.000**
RES	75	0.087			0.078			0.558			0.416		

		Number of individuals Cochran's p > 0.01			Number of polychaete individuals Sqrt(X+1); Cochran's N.S.			Number of mollusc individuals Cochran's N.S.			Number of crustacean individuals Ln(X+0.1); Cochran's N.S.		
Source of Variation	df	MS	*F*	p	MS	*F*	p	MS	*F*	p	MS	*F*	p
Lo	4	4963	0.47	0.754	30.66	1.14	0.391	45.57	1.26	0.349	23.94	2.89	0.079
Si(Lo)	10	10473	4.38	**0.000**	26.80	25.70	**0.000**	36.27	9.30	**0.000**	8.283	5.84	**0.000**
RES	75	2392			1.043			3.898			1.418		

		Capitellidae (polychaete) Ln(X+1); Cochran's N.S.			Nereididae (polychaete) Cochran's p > 0.01			Orbiniidae (polychaete) Sqrt(X+1); Cochran's N.S.			Spionidae (polychaete) Ln(X+1); Cochran's N.S.		
Source of Variation	df	MS	*F*	p	MS	*F*	p	MS	*F*	p	MS	*F*	p
Lo	4	3.853	1.21	0.365	2588	1.22	0.361	1.672	0.91	0.496	1.003	0.20	0.931
Si(Lo)	10	3.180	10.72	**0.000**	2118	41.89	**0.000**	1.843	11.97	**0.000**	4.938	12.31	**0.000**
RES	75	0.297			50.56			0.154			0.401		

		Leptonidae (bivalve) Ln(X+0.5); Cochran's N.S.			Exoedicerotidae (crustacean) Ln(X+0.1); Cochran's N.S.			Oligochaeta (annelid) Cochran's p > 0.01		
Source of Variation	df	MS	*F*	p	MS	*F*	p	MS	*F*	p
Lo	4	5.555	2.24	0.137	34.99	2.83	0.083	1572	0.91	0.497
Si(Lo)	10	2.479	5.73	**0.000**	12.34	8.73	**0.000**	1736	2.73	**0.007**
RES	75	0.432			1.414			637.0		

Table 5: ANOVA results comparing percentage of sediment grains sized 0.151 - 0.3 mm among subtidal sites and locations in Botany Bay, October 2002. Bold print = term significant. Lo = Location, Si = Site. Alpha (a) = 0.05. Cochran's C value not significant (n = 2).

Source of Variation	df	MS	*F*	p
Lo	5	622.4	1.02	0.448
Si(Lo)	12	610.4	58.60	**0.000**
RES	18	10.42		

Table 6: ANOSIM results comparing assemblages of subtidal benthos between sites and locations in Botany Bay, October 2002. Significant terms are in **bold** print. Alpha (a) = 0.05. Pairwise comparisons are not displayed in the two-way nested ANOSIM since there were insufficient permutations to obtain a significant *p*-value. Rather, pairwise comparisons are presented for the one-way ANOSIM.

a) Two-way nested ANOSIM (n = 6)

Source of Variation	Permutations	Global R	Global p
Sites	999	0.495	**0.001**
Locations	999	0.55	**0.001**

b) One-way ANOSIM (n = 18)

Source of Variation	Permutations	Pairwise R	Pairwise p
Penrhyn Inner vs Penrhyn Outer	999	0.863	**0.001**
Penrhyn Inner vs Quibray Inner	999	0.559	**0.001**
Penrhyn Inner vs Quibray Outer	999	0.931	**0.001**
Penrhyn Inner vs Towra Inner	999	0.666	**0.001**
Penrhyn Inner vs Towra Outer	999	0.601	**0.001**
Penrhyn Outer vs Quibray Inner	999	0.538	**0.001**
Penrhyn Outer vs Quibray Outer	999	0.812	**0.001**
Penrhyn Outer vs Towra Inner	999	0.695	**0.001**
Penrhyn Outer vs Towra Outer	999	0.528	**0.001**
Quibray Inner vs Quibray Outer	999	0.249	**0.001**
Quibray Inner vs Towra Inner	999	0.155	**0.002**
Quibray Inner vs Towra Outer	999	0.393	**0.001**
Quibray Outer vs Towra Inner	999	0.571	**0.001**
Quibray Outer vs Towra Outer	999	0.609	**0.001**
Towra Inner vs Towra Outer	999	0.308	**0.001**

Table 7: SIMPER results comparing the relative contribution of various subtidal benthic taxa to the dissimilarity of the assemblages among location in Botany Bay, October 2002. Cut-off for low contributions 50.00%.

a) Penrhyn Inner & Penrhyn Outer

Taxon	Av. Abundance Penrhyn Inner	Av. Abundance Penrhyn Outer	Av. Diss	Diss/SD	Contrib%	Cum%
Nematoda	302.40	0.67	3.88	1.23	6.61	6.61
Nassariidae	33.40	0.07	3.08	1.81	5.24	11.86
Capitellidae	576.60	71.40	2.84	1.47	4.84	16.69
Opheliidae	0.53	11.60	2.61	3.52	4.44	21.14
Nemertea	1.67	14.67	2.46	1.97	4.19	25.33
Nereididae	139.20	11.60	2.42	1.78	4.12	29.44
Cirratulidae	0.00	6.87	2.33	2.64	3.96	33.41
Spionidae	200.47	30.40	2.21	1.28	3.77	37.18
Ischyroceridae	4.40	44.00	2.09	1.23	3.56	40.73
Leptochellidae	4.33	19.47	2.03	1.57	3.46	44.19
Sabellidae	40.13	5.27	2.03	1.37	3.45	47.64
Lumbrineridae	1.33	8.47	1.95	1.70	3.32	50.96

Average Dissimilarity = 58.73

b) Penrhyn Inner & Quibray Inner

Taxon	Av. Abundance Penrhyn Inner	Av. Abundance Quibray Inner	Av. Diss	Diss/SD	Contrib%	Cum%
Nereididae	139.20	0.00	7.52	3.22	10.96	10.96
Capitellidae	576.60	37.53	5.19	1.33	7.56	18.52
Nematoda	302.40	5.67	4.97	1.11	7.25	25.77
Sabellidae	40.13	0.87	4.62	1.95	6.74	32.51
Spionidae	200.47	25.47	4.17	1.11	6.08	38.59
Tellinidae	14.20	0.53	3.34	1.47	4.87	43.46
Nassariidae	33.40	5.47	3.28	1.23	4.79	48.25
Oligochaeta	16.00	11.13	2.79	1.07	4.07	52.32

Average Dissimilarity = 68.58

Continued…

Table 7: Continued...

c) Penrhyn Outer & Quibray Inner

Taxon	Av. Abundance Penrhyn Outer	Av. Abundance Quibray Inner	Av. Diss	Diss/SD	Contrib%	Cum%
Ischyroceridae	44.00	4.87	3.47	1.65	5.06	5.06
Nereididae	11.60	0.00	3.44	3.89	5.03	10.09
Opheliidae	11.60	0.73	3.00	2.30	4.38	14.47
Leptochellidae	19.47	2.00	2.88	1.69	4.20	18.66
Hesionidae	6.67	0.27	2.80	1.99	4.09	22.75
Leptonidae	10.73	0.27	2.55	1.31	3.72	26.47
Lumbrineridae	8.47	1.80	2.47	1.52	3.61	30.07
Cirratulidae	6.87	5.40	2.11	1.40	3.07	33.15
Nemertea	14.67	9.13	2.04	1.05	2.98	36.13
Sabellidae	5.27	0.87	2.04	1.37	2.98	39.11
Oligochaeta	0.53	11.13	2.03	1.22	2.96	42.07
Nematoda	0.67	5.67	1.84	1.24	2.69	44.75
Glyceridae	2.60	2.53	1.84	1.45	2.68	47.43
Spionidae	30.40	25.47	1.83	0.96	2.67	50.10

Average Dissimilarity = 68.5

d) Penrhyn Inner & Quibray Outer

Taxon	Av. Abundance Penrhyn Inner	Av. Abundance Quibray Outer	Av. Diss	Diss/SD	Contrib%	Cum%
Nereididae	139.20	0.07	5.63	3.22	8.70	8.70
Sabellidae	40.13	0.53	3.75	2.22	5.80	14.51
Capitellidae	576.60	49.13	3.54	1.38	5.46	19.97
Nematoda	302.40	60.40	3.12	1.43	4.83	24.80
Nemertea	1.67	28.00	3.09	2.05	4.77	29.57
Nassariidae	33.40	1.27	3.08	1.58	4.77	34.34
Oligochaeta	16.00	35.20	2.90	1.60	4.48	38.82
Leptochellidae	4.33	37.87	2.59	1.56	4.00	42.82
Syllidae	0.07	19.00	2.52	1.49	3.90	46.72
Tellinidae	14.20	0.80	2.51	1.42	3.88	50.60

Average Dissimilarity = 64.7

Continued...

Table 7: Continued...

e) Penrhyn Outer & Quibray Outer

Taxon	Av. Abundance Penrhyn Outer	Av. Abundance Quibray Outer	Av. Diss	Diss/SD	Contrib%	Cum%
Nematoda	0.67	60.40	3.38	2.58	5.67	5.67
Oligochaeta	0.53	35.20	3.12	2.67	5.22	10.90
Nereididae	11.60	0.07	2.64	3.40	4.42	15.32
Opheliidae	11.60	0.33	2.43	2.82	4.08	19.39
Ischyroceridae	44.00	27.87	2.11	1.30	3.53	22.92
Hesionidae	6.67	0.80	2.04	1.83	3.43	26.35
Leptonidae	10.73	0.60	1.98	1.37	3.33	29.67
Syllidae	1.00	19.00	1.94	1.45	3.26	32.93
Lumbrineridae	8.47	2.00	1.91	1.72	3.20	36.13
Leptochellidae	19.47	37.87	1.80	1.39	3.01	39.14
Sabellidae	5.27	0.53	1.71	1.45	2.86	42.00
Enteropneusta	0.00	4.60	1.50	1.15	2.51	44.51
Magelonidae	0.00	5.93	1.48	1.18	2.48	47.00
Cirratulidae	6.87	5.47	1.43	1.23	2.40	49.40
Phyllodocidae	1.87	5.00	1.33	1.38	2.22	51.62

Average Dissimilarity = 59.67

f) Quibray Inner & Quibray Outer

Taxon	Av. Abundance Quibray Inner	Av. Abundance Quibray Outer	Av. Diss	Diss/SD	Contrib%	Cum%
Nematoda	5.67	60.40	3.64	1.36	5.92	5.92
Leptochellidae	2.00	37.87	3.49	1.50	5.67	11.60
Oligochaeta	11.13	35.20	3.23	1.10	5.25	16.85
Syllidae	0.80	19.00	3.07	1.33	5.00	21.85
Ischyroceridae	4.87	27.87	2.85	1.25	4.64	26.49
Nemertea	9.13	28.00	2.83	1.14	4.61	31.10
Spionidae	25.47	55.80	2.33	0.88	3.79	34.89
Cirratulidae	5.40	5.47	2.15	1.05	3.49	38.39
Enteropneusta	0.60	4.60	2.10	1.05	3.42	41.80
Magelonidae	0.00	5.93	2.06	1.13	3.34	45.15
Nassariidae	5.47	1.27	1.99	0.97	3.24	48.38
Phyllodocidae	0.93	5.00	1.81	1.03	2.94	51.32

Average Dissimilarity = 61.47

Continued...

Table 7: Continued…

g) Penrhyn Inner & Towra Inner

Taxon	Av. Abundance Penrhyn Inner	Av. Abundance Towra Inner	Av. Diss	Diss/SD	Contrib%	Cum%
Nereididae	139.20	1.40	6.80	2.44	9.99	9.99
Nematoda	302.40	1.60	6.01	1.22	8.83	18.82
Capitellidae	576.60	24.60	5.28	1.50	7.76	26.59
Sabellidae	40.13	0.07	5.08	2.44	7.46	34.05
Spionidae	200.47	45.47	4.26	1.38	6.26	40.31
Tellinidae	14.20	0.00	3.59	1.53	5.27	45.58
Cirratulidae	0.00	14.87	3.37	1.85	4.96	50.54

Average Dissimilarity = 68.03

h) Penrhyn Outer & Towra Inner

Taxon	Av. Abundance Penrhyn Outer	Av. Abundance Towra Inner	Av. Diss	Diss/SD	Contrib%	Cum%
Ischyroceridae	44.00	4.27	3.67	1.80	5.33	5.33
Nemertea	14.67	0.67	3.39	2.31	4.91	10.24
Opheliidae	11.60	0.53	3.27	3.19	4.75	14.99
Leptochellidae	19.47	0.53	3.27	2.22	4.75	19.73
Nereididae	11.60	1.40	2.81	1.89	4.09	23.82
Lumbrineridae	8.47	1.60	2.72	1.81	3.95	27.78
Leptonidae	10.73	0.33	2.50	1.34	3.62	31.40
Spionidae	30.40	45.47	2.35	1.49	3.42	34.82
Sabellidae	5.27	0.07	2.18	1.48	3.17	37.98
Glyceridae	2.60	0.00	2.10	1.78	3.05	41.03
Hesionidae	6.67	2.13	2.08	1.31	3.02	44.05
Oligochaeta	0.53	11.80	1.92	1.04	2.78	46.83
Nassariidae	0.07	5.07	1.83	1.17	2.65	49.48
Syllidae	1.00	4.53	1.68	1.13	2.44	51.92

Average Dissimilarity = 68.89

Continued…

Table 7: Continued…

i) Quibray Inner & Towra Inner

Taxon	Av. Abundance Quibray Inner	Av. Abundance Towra Inner	Av. Diss	Diss/SD	Contrib%	Cum%
Spionidae	25.47	45.47	4.59	1.02	6.92	6.92
Cirratulidae	5.40	14.87	3.85	1.17	5.81	12.74
Oligochaeta	11.13	11.80	3.80	1.02	5.74	18.47
Nemertea	9.13	0.67	3.36	1.14	5.07	23.55
Nematoda	5.67	1.60	3.19	0.99	4.81	28.36
Nassariidae	5.47	5.07	3.18	1.03	4.80	33.16
Syllidae	0.80	4.53	2.89	0.93	4.37	37.53
Hirudinea	0.20	9.80	2.39	0.95	3.61	41.13
Capitellidae	37.53	24.60	2.20	0.82	3.32	44.45
Hesionidae	0.27	2.13	2.04	0.85	3.08	47.53
Lumbrineridae	1.80	1.60	1.83	0.71	2.76	50.29

Average Dissimilarity = 66.23

j) Quibray Outer & Towra Inner

Taxon	Av. Abundance Quibray Outer	Av. Abundance Towra Inner	Av. Diss	Diss/SD	Contrib%	Cum%
Nematoda	60.40	1.60	5.33	2.29	8.00	8.00
Nemertea	28.00	0.67	4.25	2.18	6.38	14.38
Leptochellidae	37.87	0.53	3.81	1.68	5.72	20.10
Oligochaeta	35.20	11.80	3.61	1.44	5.41	25.51
Ischyroceridae	27.87	4.27	2.99	1.23	4.49	30.01
Spionidae	55.80	45.47	2.75	1.37	4.13	34.14
Syllidae	19.00	4.53	2.71	1.30	4.07	38.21
Cirratulidae	5.47	14.87	2.36	1.17	3.55	41.75
Enteropneusta	4.60	0.00	2.19	1.09	3.29	45.04
Magelonidae	5.93	0.00	2.11	1.15	3.16	48.20
Nassariidae	1.27	5.07	2.06	1.13	3.09	51.29

Average Dissimilarity = 66.64

Continued…

Table 7: Continued…

k) Penrhyn Inner & Towra Outer

Taxon	Av. Abundance Penrhyn Inner	Av. Abundance Towra Outer	Av. Diss	Diss/SD	Contrib%	Cum%
Spionidae	200.47	0.33	7.94	2.10	10.15	10.15
Capitellidae	576.60	6.33	7.88	1.65	10.08	20.23
Nereididae	139.20	0.87	7.03	2.53	8.99	29.22
Nematoda	302.40	0.07	6.69	1.25	8.55	37.77
Sabellidae	40.13	0.33	5.12	2.08	6.55	44.32
Nassariidae	33.40	2.40	3.94	1.29	5.04	49.36
Tellinidae	14.20	0.33	3.55	1.38	4.54	53.89

Average Dissimilarity = 78.23

l) Penrhyn Outer & Towra Outer

Taxon	Av. Abundance Penrhyn Outer	Av. Abundance Towra Outer	Av. Diss	Diss/SD	Contrib%	Cum%
Spionidae	30.40	0.33	4.01	2.33	5.36	5.36
Opheliidae	11.60	0.00	3.63	4.35	4.85	10.21
Capitellidae	71.40	6.33	3.42	1.42	4.58	14.79
Ischyroceridae	44.00	1.07	3.38	1.41	4.52	19.31
Lumbrineridae	8.47	0.07	3.21	2.37	4.30	23.62
Hesionidae	6.67	0.13	2.98	2.04	3.99	27.60
Nemertea	14.67	1.33	2.83	1.52	3.79	31.39
Leptochellidae	19.47	3.40	2.82	1.56	3.78	35.17
Nereididae	11.60	0.87	2.77	1.90	3.70	38.87
Leptonidae	10.73	1.73	2.25	1.23	3.01	41.87
Sabellidae	5.27	0.33	2.18	1.38	2.92	44.80
Glyceridae	2.60	0.07	2.13	1.65	2.85	47.64
Cirratulidae	6.87	2.73	2.01	1.24	2.69	50.33

Average Dissimilarity = 74.73

Continued…

Table 7: Continued...

m) Quibray Inner & Towra Outer

Taxon	Av. Abundance Quibray Inner	Av. Abundance Towra Outer	Av. Diss	Diss/SD	Contrib%	Cum%
Spionidae	25.47	0.33	5.90	1.29	7.36	7.36
Capitellidae	37.53	6.33	4.70	0.97	5.87	13.24
Nemertea	9.13	1.33	3.59	1.16	4.48	17.71
Nematoda	5.67	0.07	3.58	0.96	4.47	22.18
Oligochaeta	11.13	0.73	3.54	1.04	4.42	26.60
Cirratulidae	5.40	2.73	3.43	0.87	4.28	30.88
Nassariidae	5.47	2.40	3.37	0.90	4.21	35.09
Leptonidae	0.27	1.73	2.45	0.81	3.06	38.15
Nephtyidae	0.53	3.87	2.42	0.83	3.03	41.18
Orbiniidae	0.07	1.47	2.40	0.87	3.00	44.18
Urohaustoriidae	0.00	3.07	2.38	0.74	2.98	47.16
Leptochellidae	2.00	3.40	2.38	0.88	2.97	50.12

Average Dissimilarity = 80.09

n) Quibray Outer & Towra Outer

Taxon	Av. Abundance Quibray Outer	Av. Abundance Towra Outer	Av. Diss	Diss/SD	Contrib%	Cum%
Nematoda	60.40	0.07	6.21	2.99	7.79	7.79
Spionidae	55.80	0.33	5.73	2.56	7.19	14.98
Oligochaeta	35.20	0.73	5.10	2.07	6.40	21.38
Nemertea	28.00	1.33	3.82	1.63	4.79	26.17
Leptochellidae	37.87	3.40	3.60	1.51	4.52	30.69
Syllidae	19.00	0.33	3.27	1.36	4.10	34.79
Capitellidae	49.13	6.33	3.15	1.22	3.96	38.75
Ischyroceridae	27.87	1.07	2.98	1.30	3.75	42.49
Enteropneusta	4.60	0.00	2.32	1.07	2.91	45.40
Magelonidae	5.93	0.13	2.20	1.13	2.77	48.17
Cirratulidae	5.47	2.73	2.08	1.17	2.61	50.79

Average Dissimilarity = 79.68

Continued...

Table 7: Continued…

o) Towra Inner & Towra Outer

Taxon	Av. Abundance Towra Inner	Av. Abundance Towra Outer	Av. Diss	Diss/SD	Contrib%	Cum%
Spionidae	45.47	0.33	7.17	1.12	9.55	9.55
Cirratulidae	14.87	2.73	4.15	1.15	5.52	15.07
Capitellidae	24.60	6.33	3.96	0.89	5.27	20.34
Oligochaeta	11.80	0.73	3.63	0.85	4.84	25.18
Nassariidae	5.07	2.40	3.31	1.04	4.41	29.59
Syllidae	4.53	0.33	3.24	0.93	4.31	33.90
Nephtyidae	1.60	3.87	2.75	0.88	3.66	37.56
Orbiniidae	1.27	1.47	2.68	0.98	3.57	41.13
Hirudinea	9.80	0.07	2.67	0.95	3.56	44.69
Leptonidae	0.33	1.73	2.54	0.89	3.38	48.07
Urohaustoriidae	0.00	3.07	2.45	0.77	3.26	51.33

Average Dissimilarity = 75.1

Table 8: ANOVA results comparing subtidal benthos among sites and locations sampled in Botany Bay, October 2002. **Bold print** = term significant. Lo = Location, Si = Site. Alpha (a) = 0.05, except if the Cochran's C value is significant and then a = 0.01 (n = 5).

		Number of taxa Cochran's p > 0.01			Number of polychaete taxa Sqrt(X+1); Cochran's N.S.			Number of mollusc taxa Cochran's N.S.			Number of crustacean taxa Ln(x+1); Cochran's N.S.		
Source of Variation	df	MS	*F*	p	MS	*F*	p	MS	*F*	p	MS	*F*	p
Lo	5	432.4	7.18	**0.003**	3.965	8.49	**0.001**	18.16	4.32	**0.018**	3.288	3.21	**0.045**
Si(Lo)	12	60.22	1.78	0.067	0.467	2.31	**0.015**	4.200	2.08	**0.029**	1.024	3.42	**0.001**
RES	72	33.76			0.203			2.017			0.299		

		Number of individuals Sqrt(x+1); Cochran's N.S.			Number of polychaete individuals Cochran's p > 0.01			Number of mollusc individuals Ln(x+1); Cochran's N.S.			Number of crustacean individuals Ln(x+1); Cochran's N.S.		
Source of Variation	df	MS	*F*	p	MS	*F*	p	MS	*F*	p	MS	*F*	p
Lo	5	1531	11.49	**0.000**	1892667	20.33	**0.000**	10.33	6.38	**0.004**	12.82	1.66	0.219
Si(Lo)	12	133.3	5.30	**0.000**	93075	2.39	0.012	1.620	1.24	0.276	7.725	5.36	**0.000**
RES	72	25.15			39011			1.310			1.441		

		Capitellidae (polychaete) Cochran's p > 0.01			Nereididae (polychaete) Ln(x+1); Cochran's N.S.			Spionidae (polychaete) Cochran's (p > 0.01)			Ischyroceridae (amphipod) Ln(x+0.8); Cochran's N.S.		
Source of Variation	df	MS	*F*	p	MS	*F*	p	MS	*F*	p	MS	*F*	p
Lo	5	733029	3.16	0.048	48.54	26.09	**0.000**	76764	1.73	0.202	4586	1.66	0.219
Si(Lo)	12	232250	10.59	**0.000**	1.860	8.64	**0.000**	44293	24.72	**0.000**	2765	1.24	0.274
RES	72	21940			0.215			1792			2230		

		Nematoda Ln(x+1); Cochran's N.S.			Oligochaeta (annelid) Sqrt(x+1); Cochran's N.S.		
Source of Variation	df	MS	*F*	p	MS	*F*	p
Lo	5	39.92	4.79	**0.012**	40.91	3.15	**0.048**
Si(Lo)	12	8.330	13.99	**0.000**	12.98	5.80	**0.000**
RES	72	0.595			2.238		

FIGURES

Figure 1: Positions of sampling sites (orange dots) for intertidal benthos along Foreshore Beach and Penrhyn Estuary, Botany Bay sampled 8 October, 2002 by The Ecology Lab Pty Ltd.

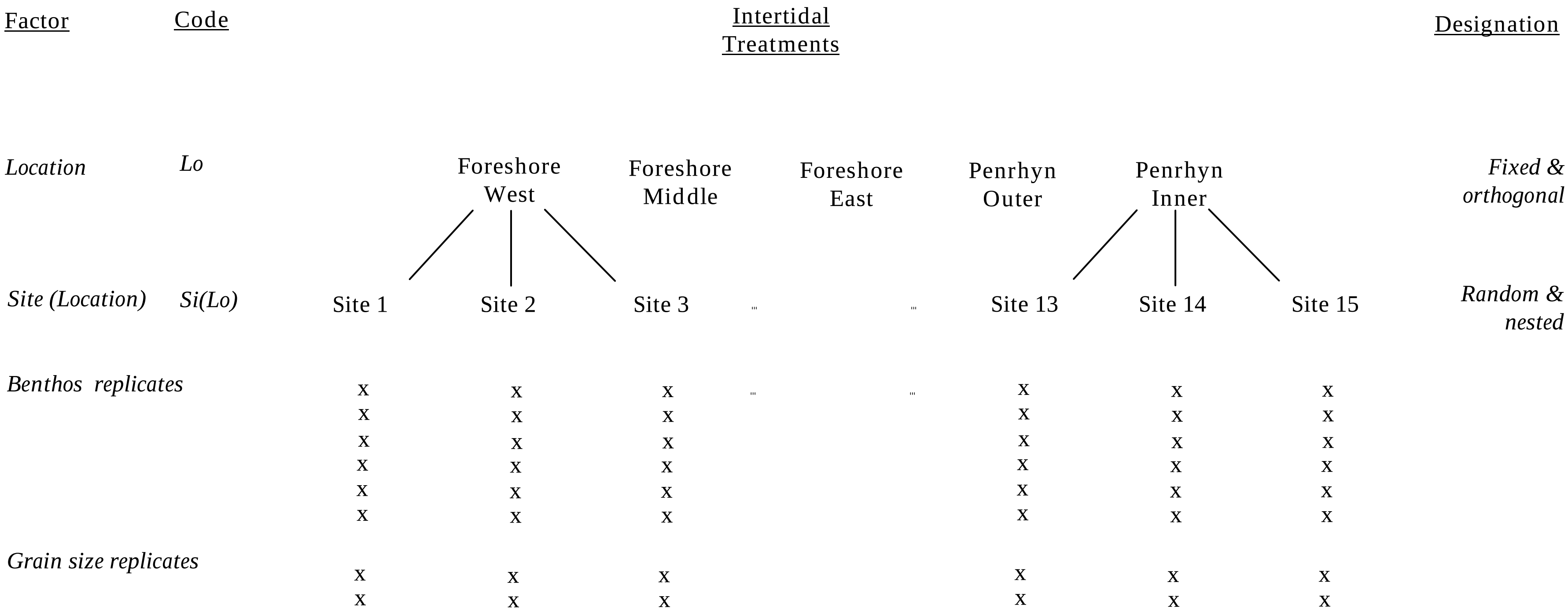

Figure 2: Sampling design for surveys of intertidal benthos and grain size along Foreshore Beach and Penrhyn Estuary in October 2002. (Benthos N = 90; Grain size N = 30).

Figure 3: Sampling locations for subtidal benthos sampled in Botany Bay on 24 and 28 October, 2002. Each orange dot represents a location where three sites were sampled, each with five replicate grabs.

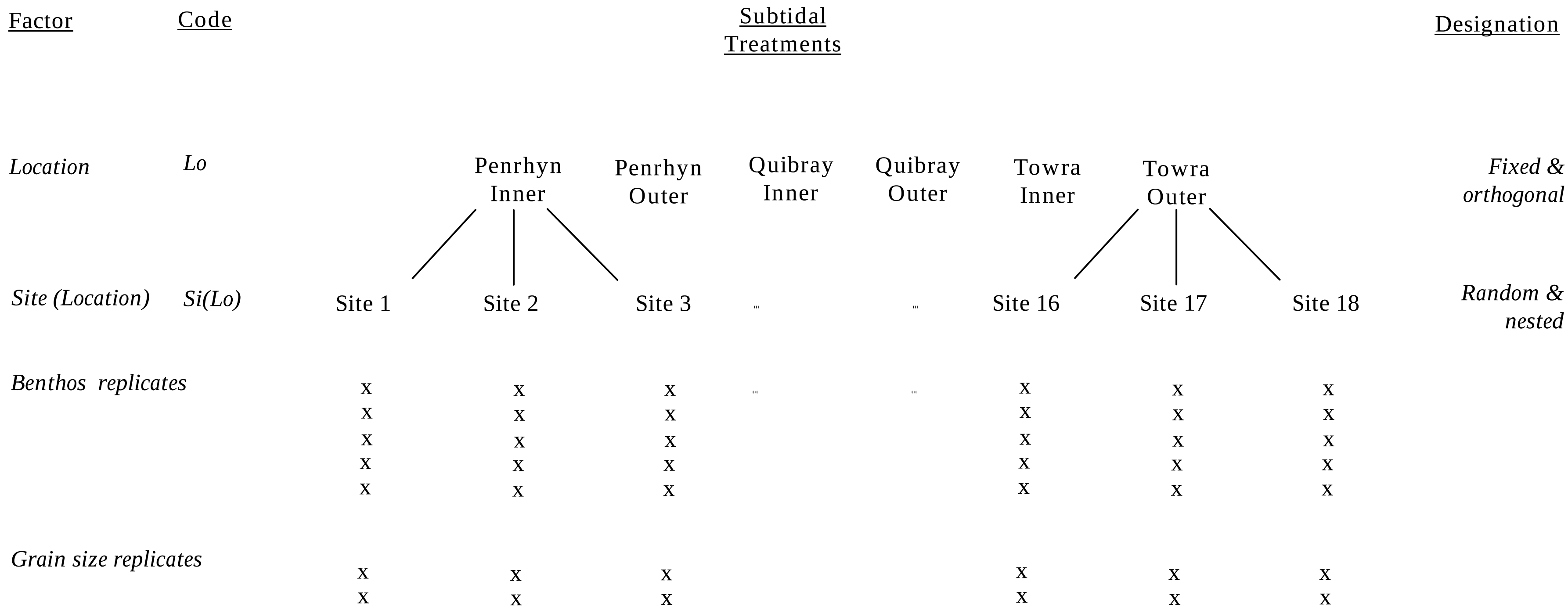

Figure 4: Sampling design for surveys of subtidal benthos and grain size in Botany Bay in October 2002. (Benthos *N* = 90; Grain size *N* = 36).

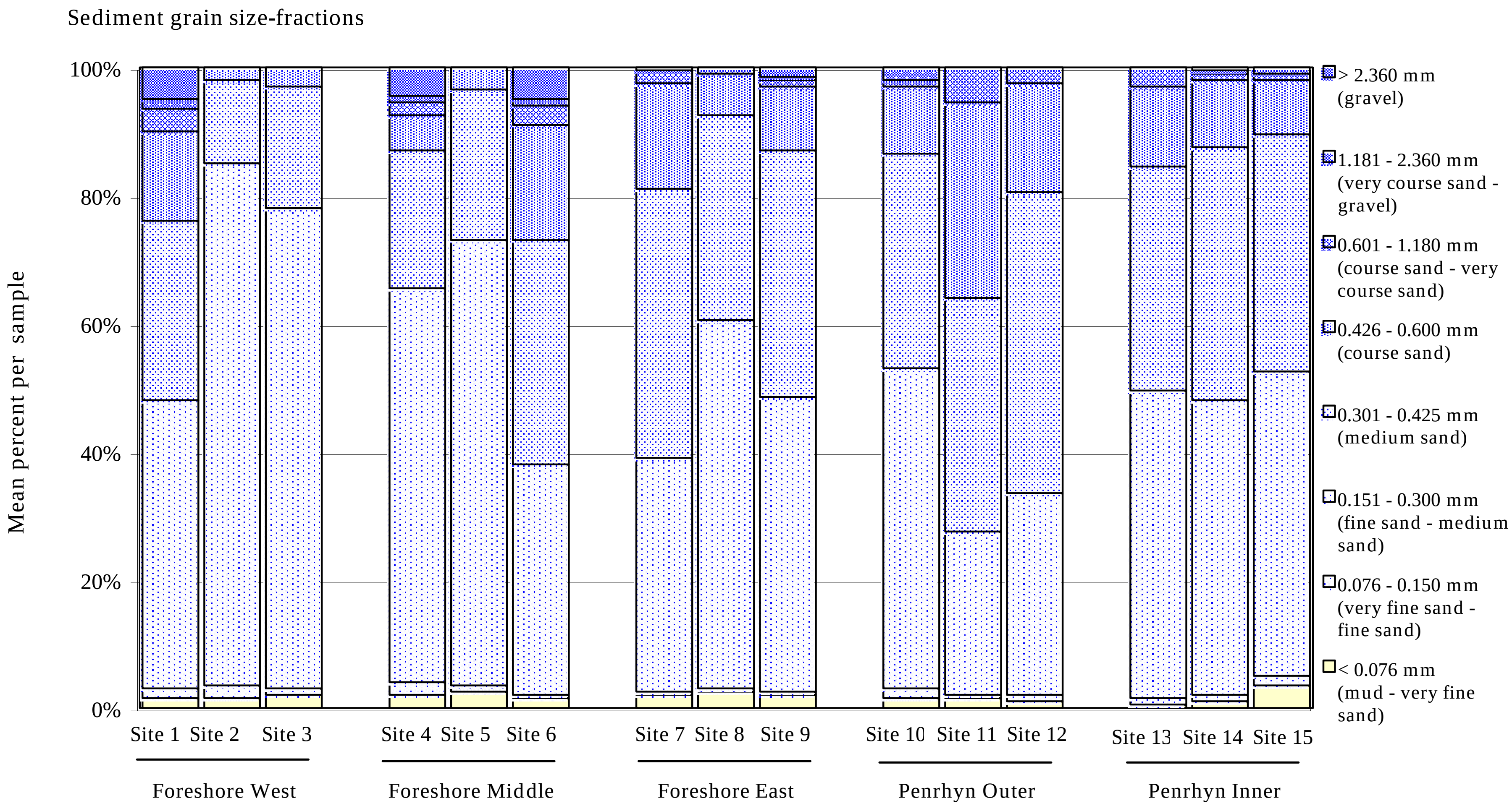

Figure 5: Mean distribution of sediment grains among size classes at each intertidal site along Foreshore Beach and Penrhyn Estuary, October 2002 (n=2).

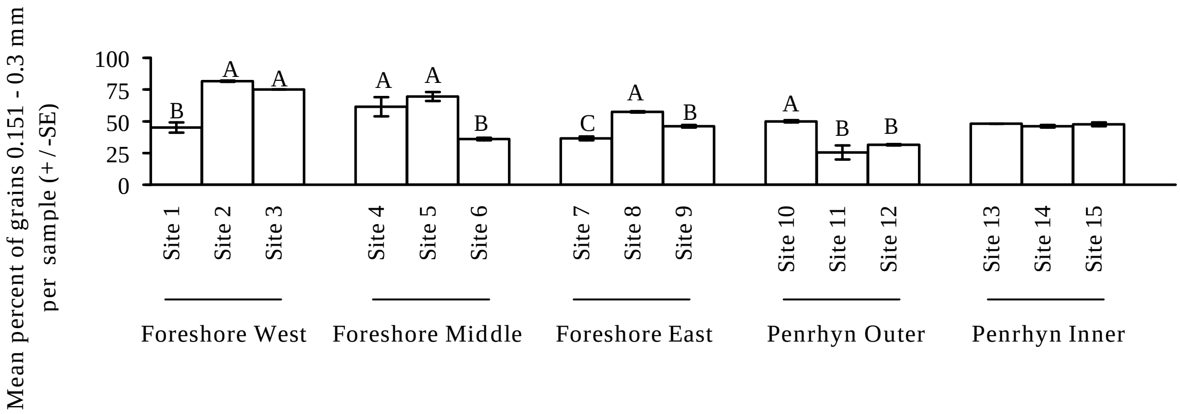

Figure 6: Percentage of 0.151 - 0.3 mm sized sediment grains per sample at each intertidal site along Foreshore and Penrhyn Estuary, October 2002 (n = 6; letters above bars signify significant differences as determined by SNK tests).

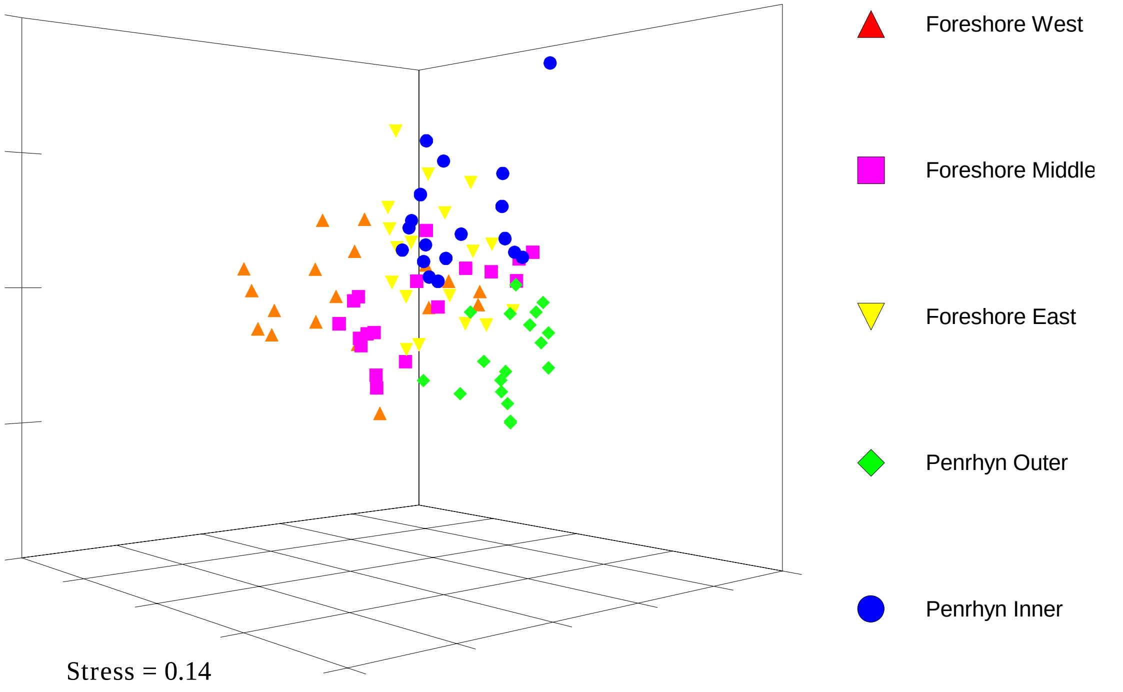

Figure 7: nMDS of intertidal benthic assemblages at the five locations along Foreshore Beach and Penrhyn Estuary in October 2002.

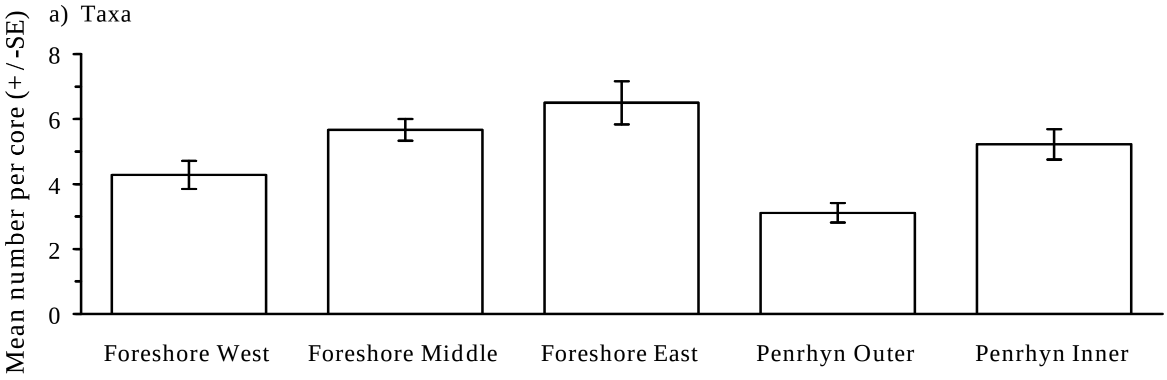

Figure 8: Number of intertidal benthic invertebrate taxa per core sample at each location along Foreshore Beach and Penrhyn Estuary in October 2002 (n = 18; letters above bars signify significant differences as determined by SNK test).

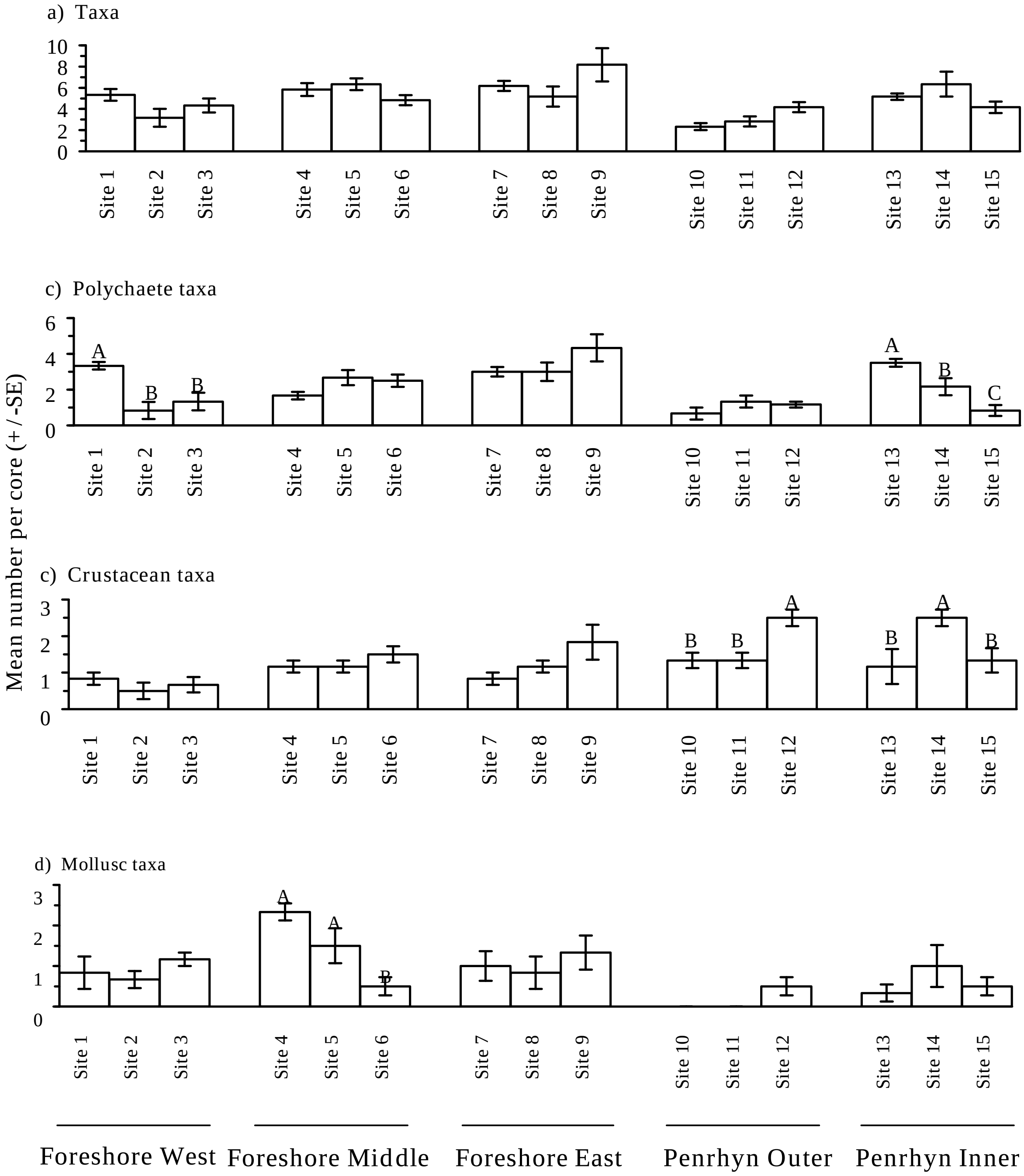

Figure 9: Number of intertidal benthic invertebrates per core at each site along Foreshore Beach and Penrhyn Estuary, October 2002 (n = 6; letters above bars signify significant differences as determined by SNK test).

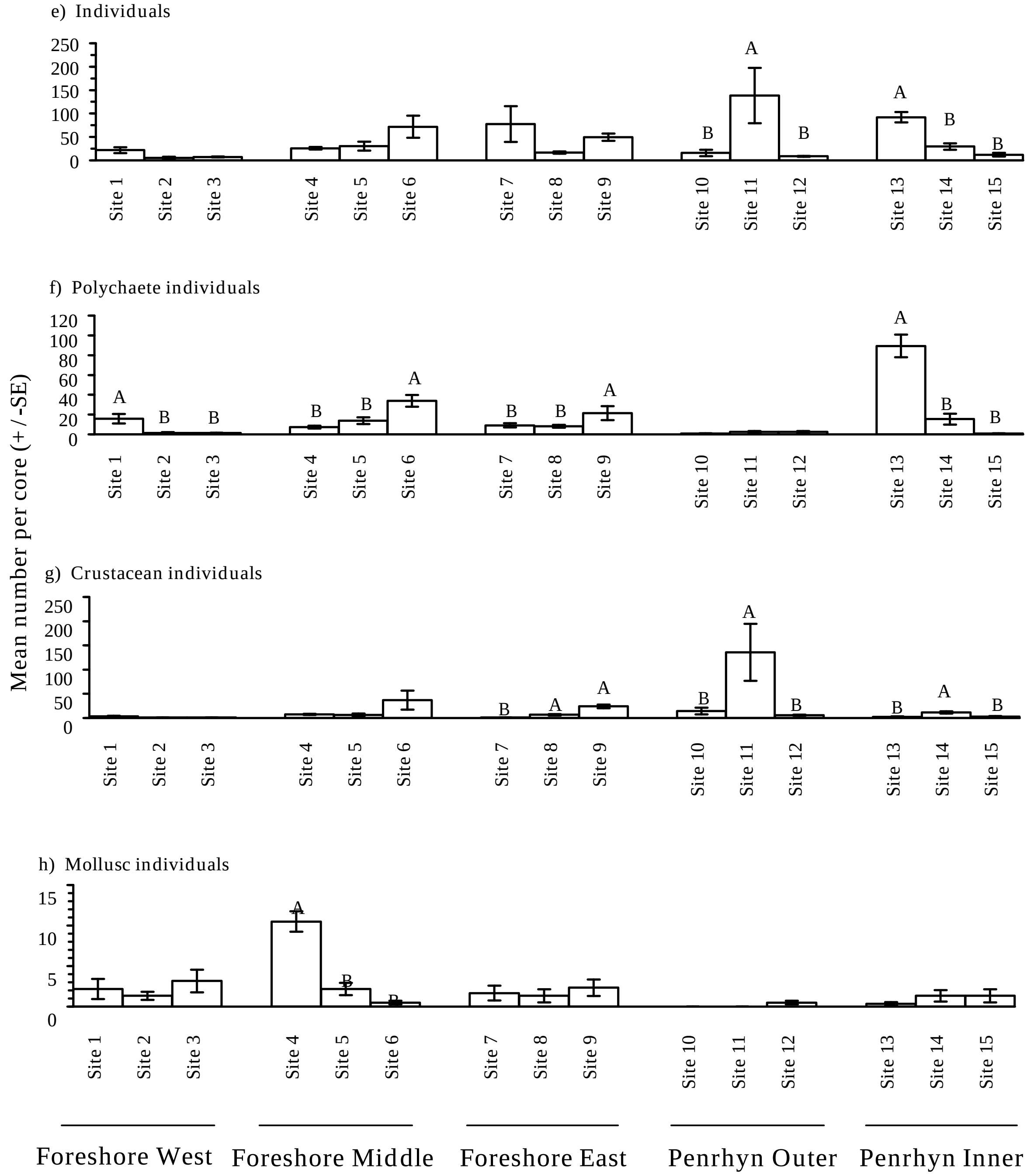

Figure 9: Continued...

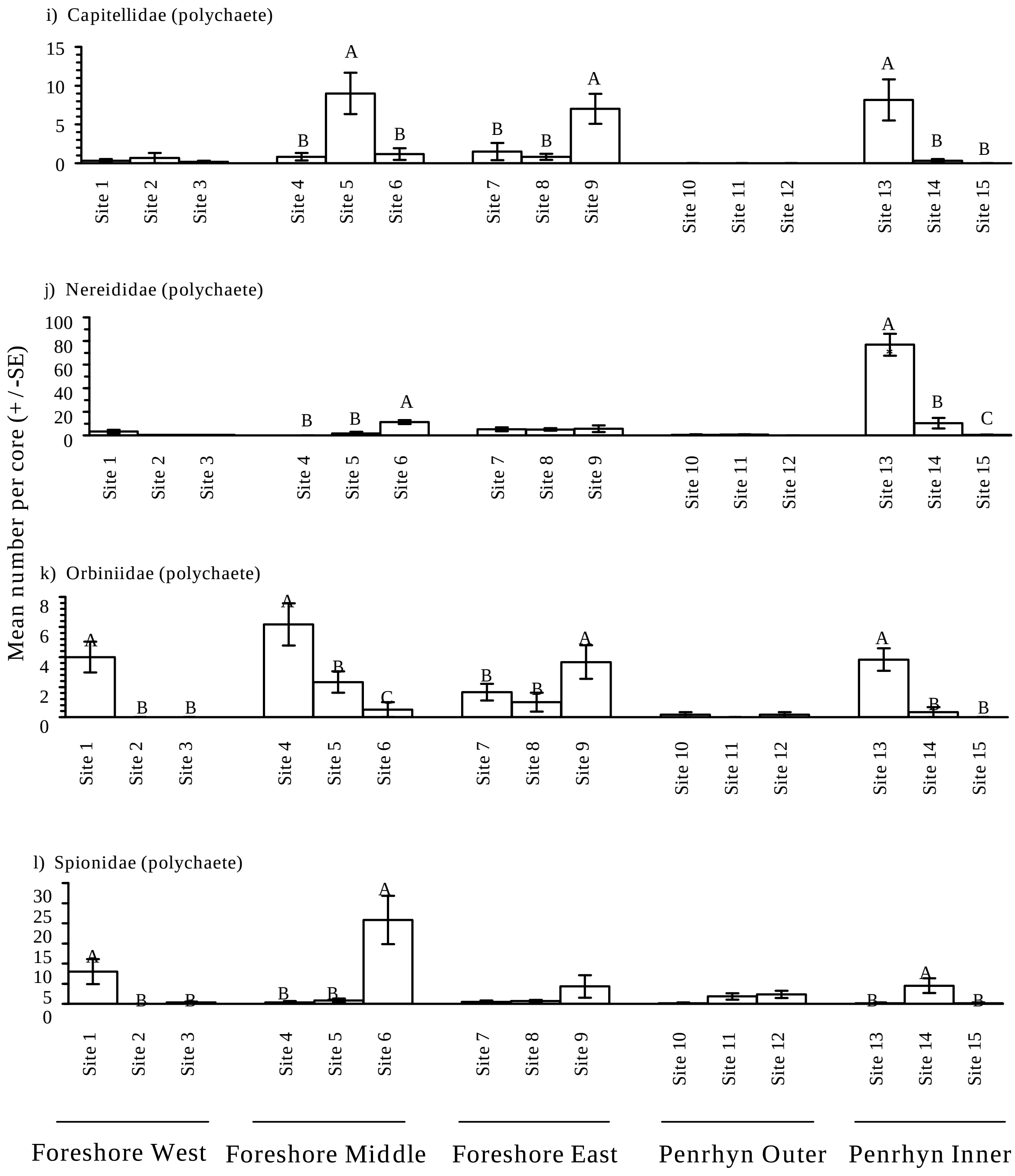

Figure 9: Continued...

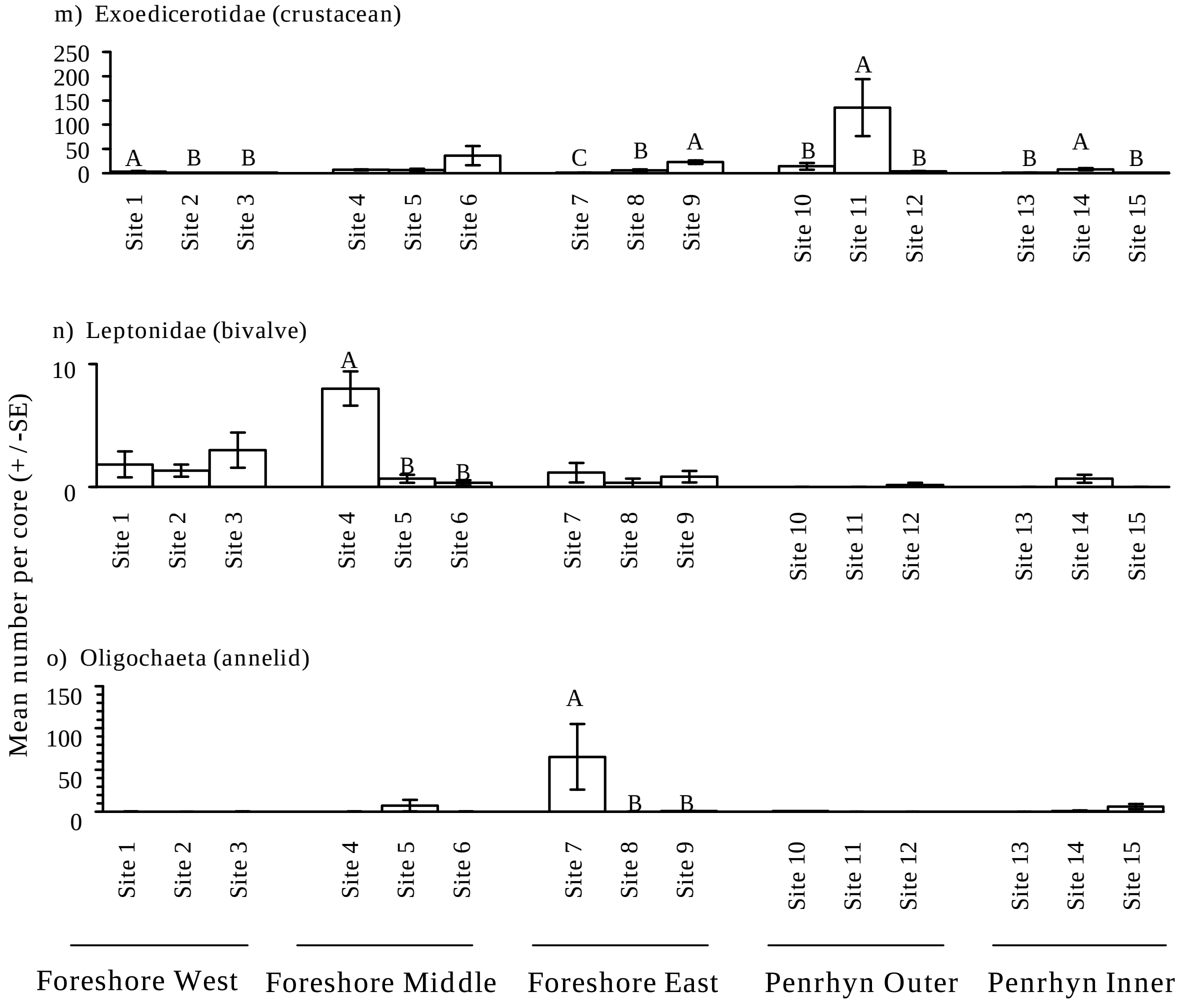

Figure 9: Continued...

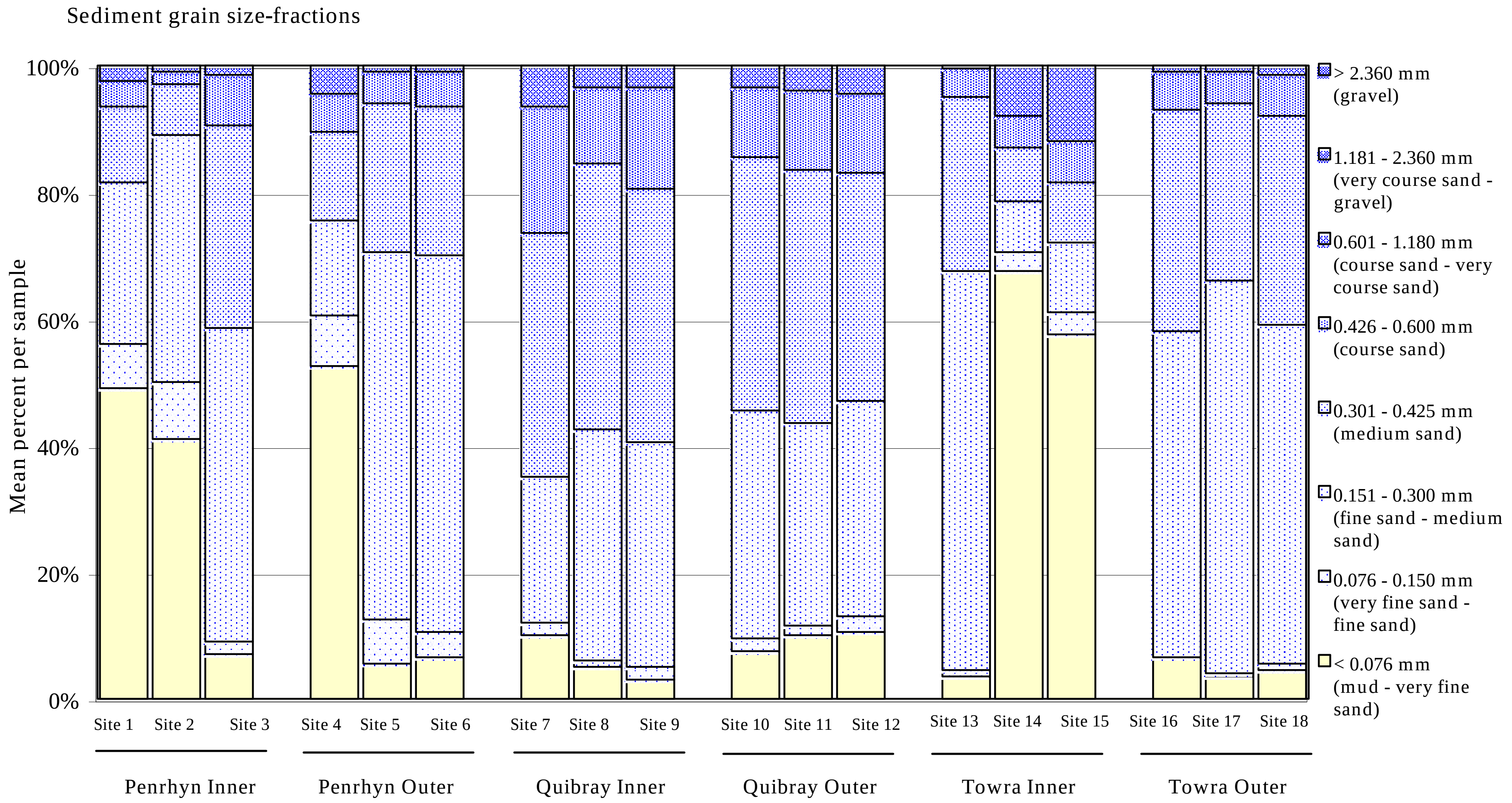

Figure 10: Mean distribution of sediment grains among size classes at each subtidal site in Botany Bay, October 2002 (n=2).

Figure 11: Percentage of 0.151 - 0.3 mm sized sediment grains per sample at each subtidal site in Botany Bay, October 2002 (n = 6; letters above bars signify significant differences as determined by SNK tests).

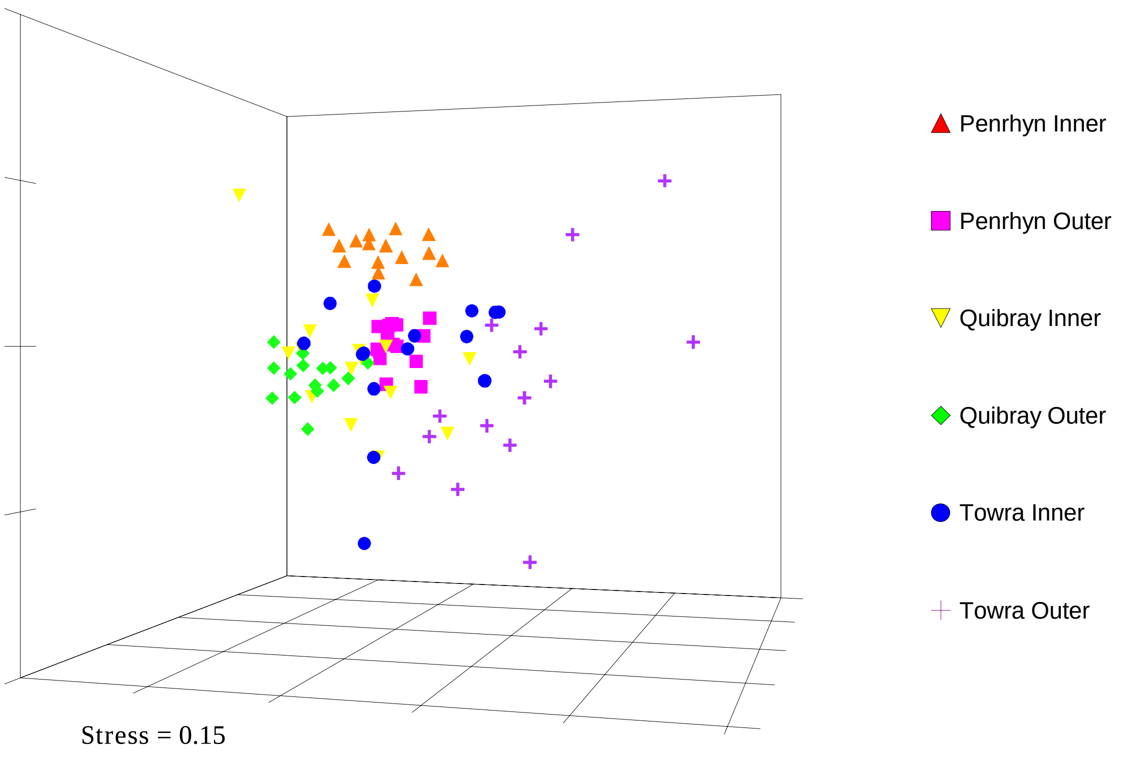

Figure 12: nMDS of subtidal benthic assemblages at the six locations in Botany Bay on October 2002.

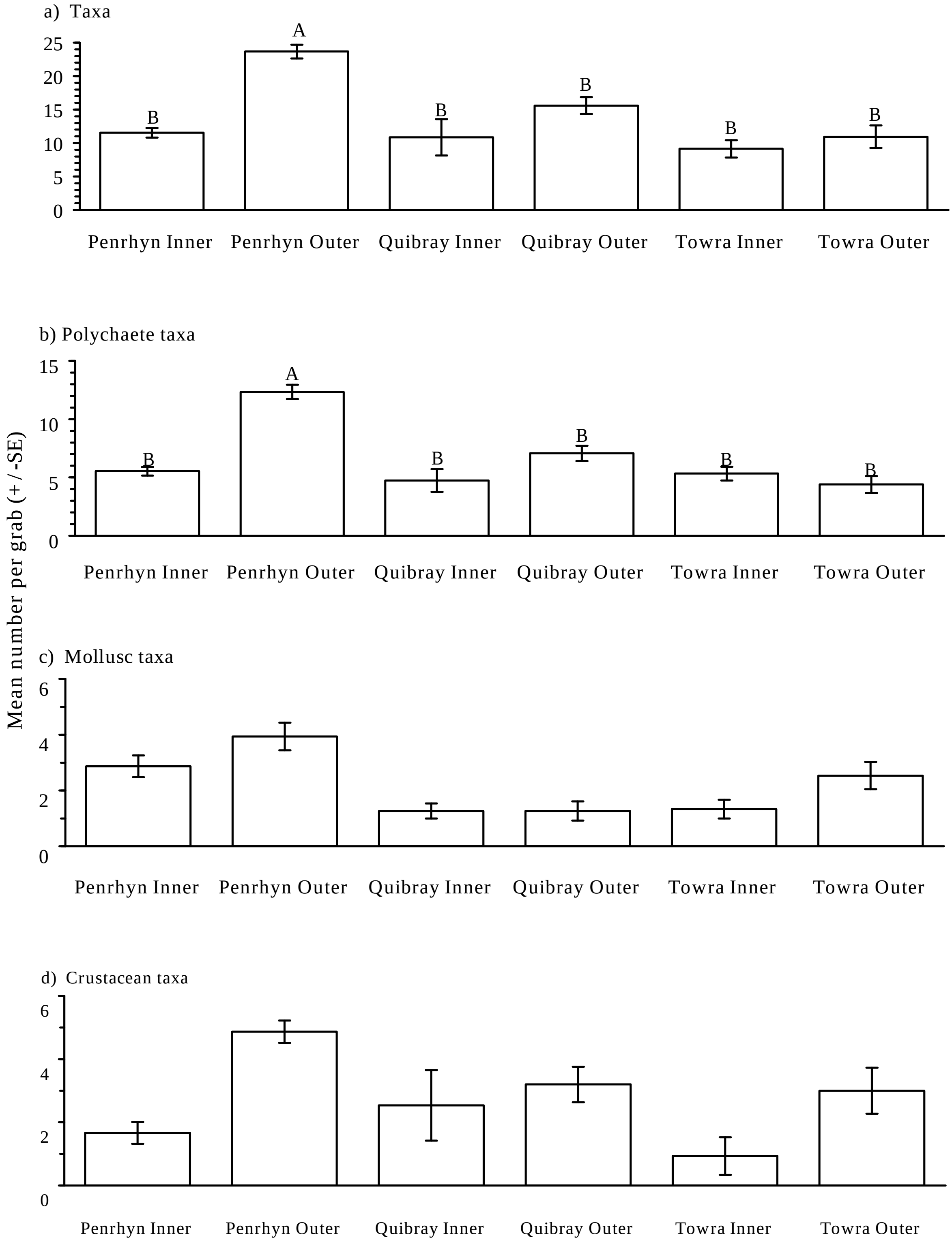

Figure 13: Number of subtidal benthic invertebrates per grab at each location in Botany Bay, October 2002 (n = 18; letters above bars signify significant differences as determined by SNK test).

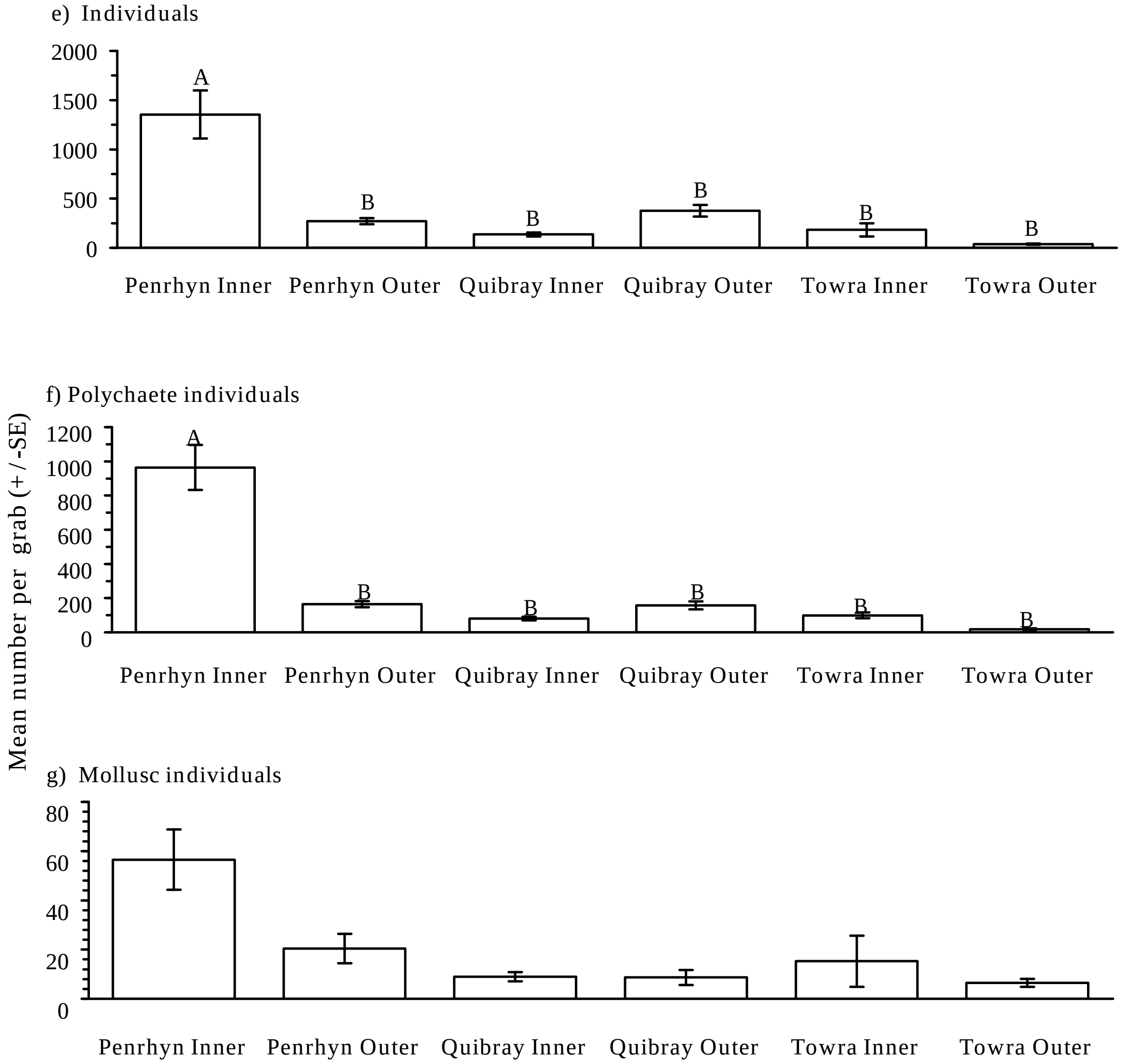

Figure 13: Continued...

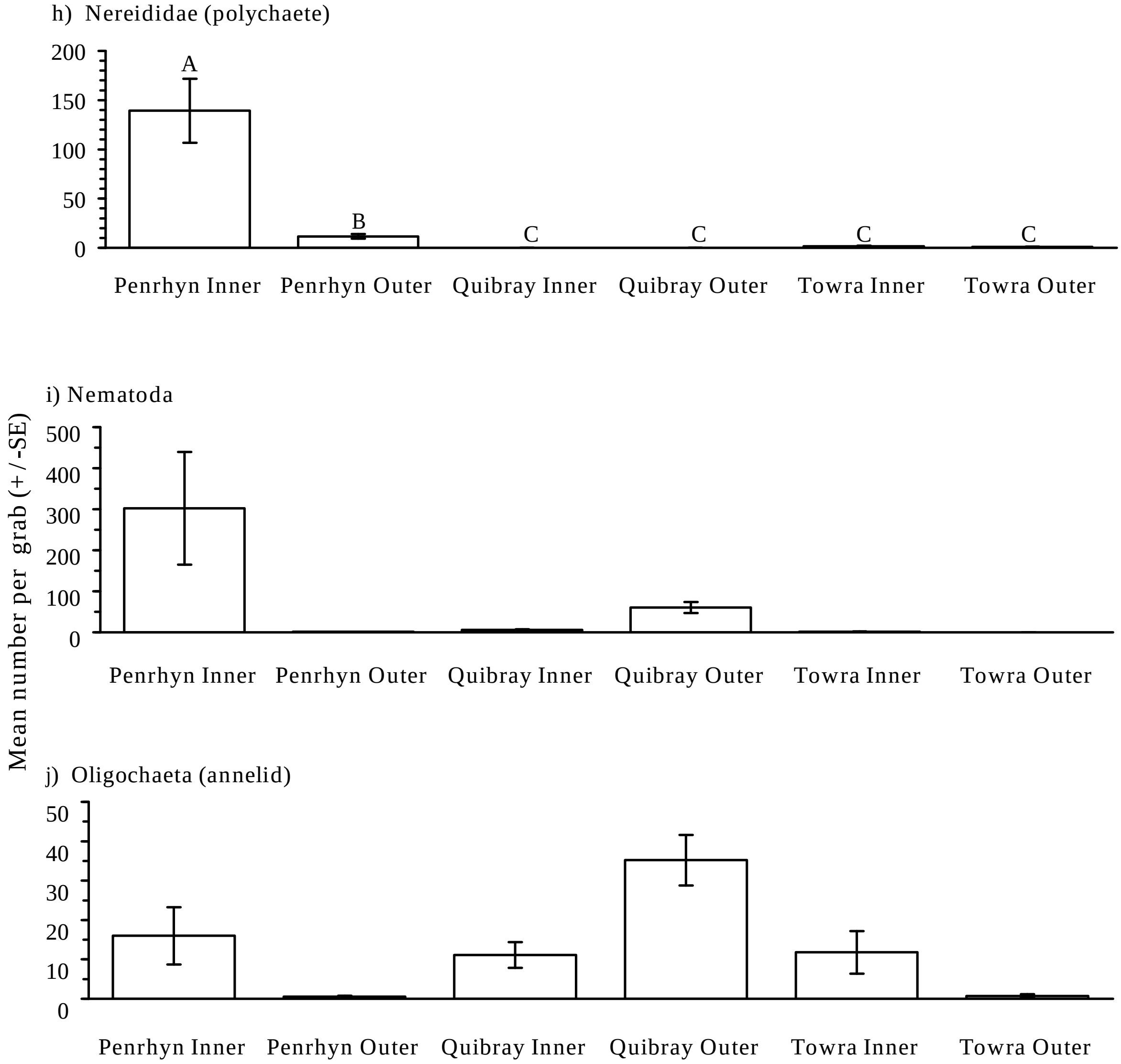

Figure 13: Continued...

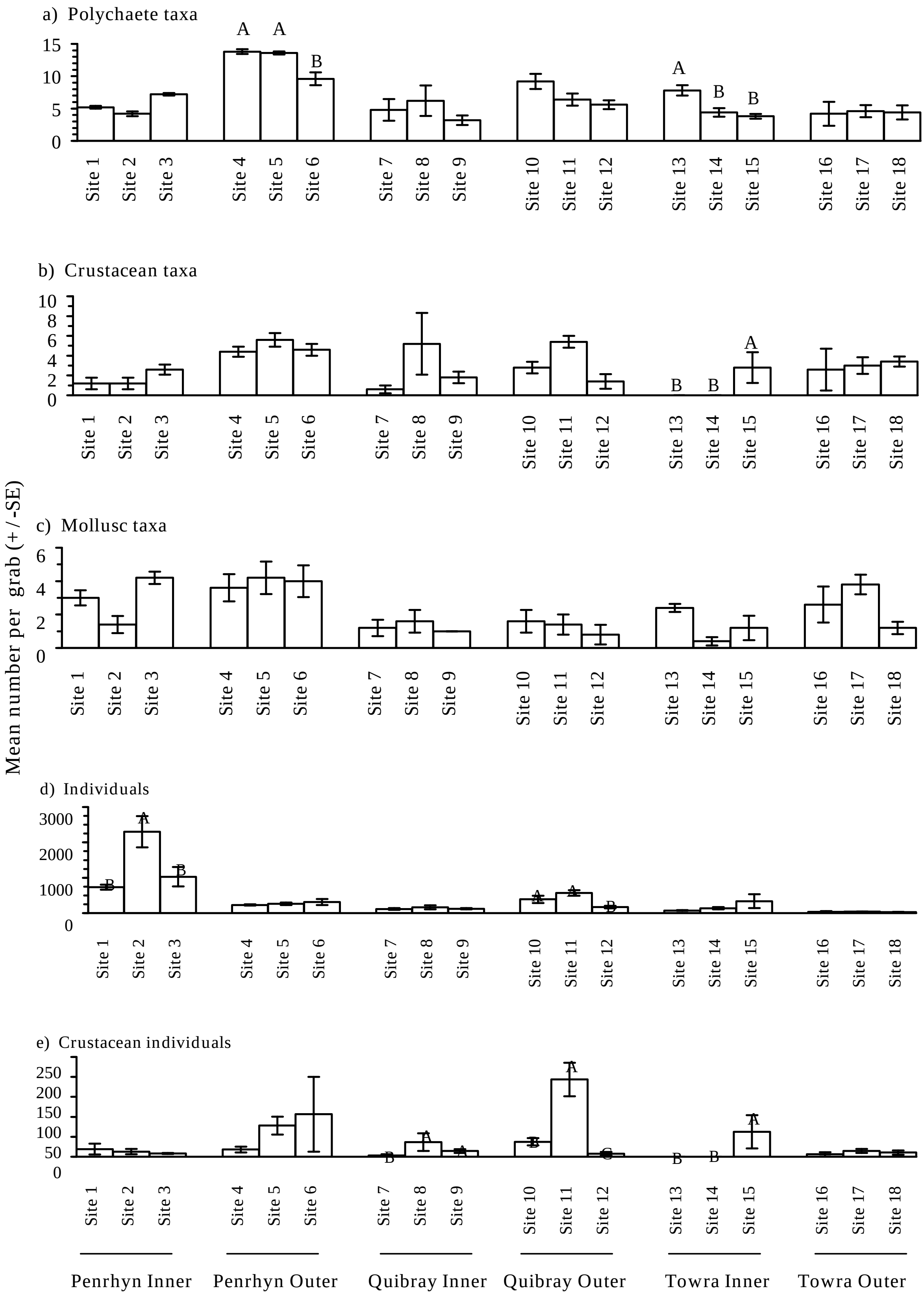

Figure 14: Number of subtidal benthic invertebrates per grab at each site in Botany Bay, October 2002 (n = 6; letters above bars signify significant differences as determined by SNK tests).

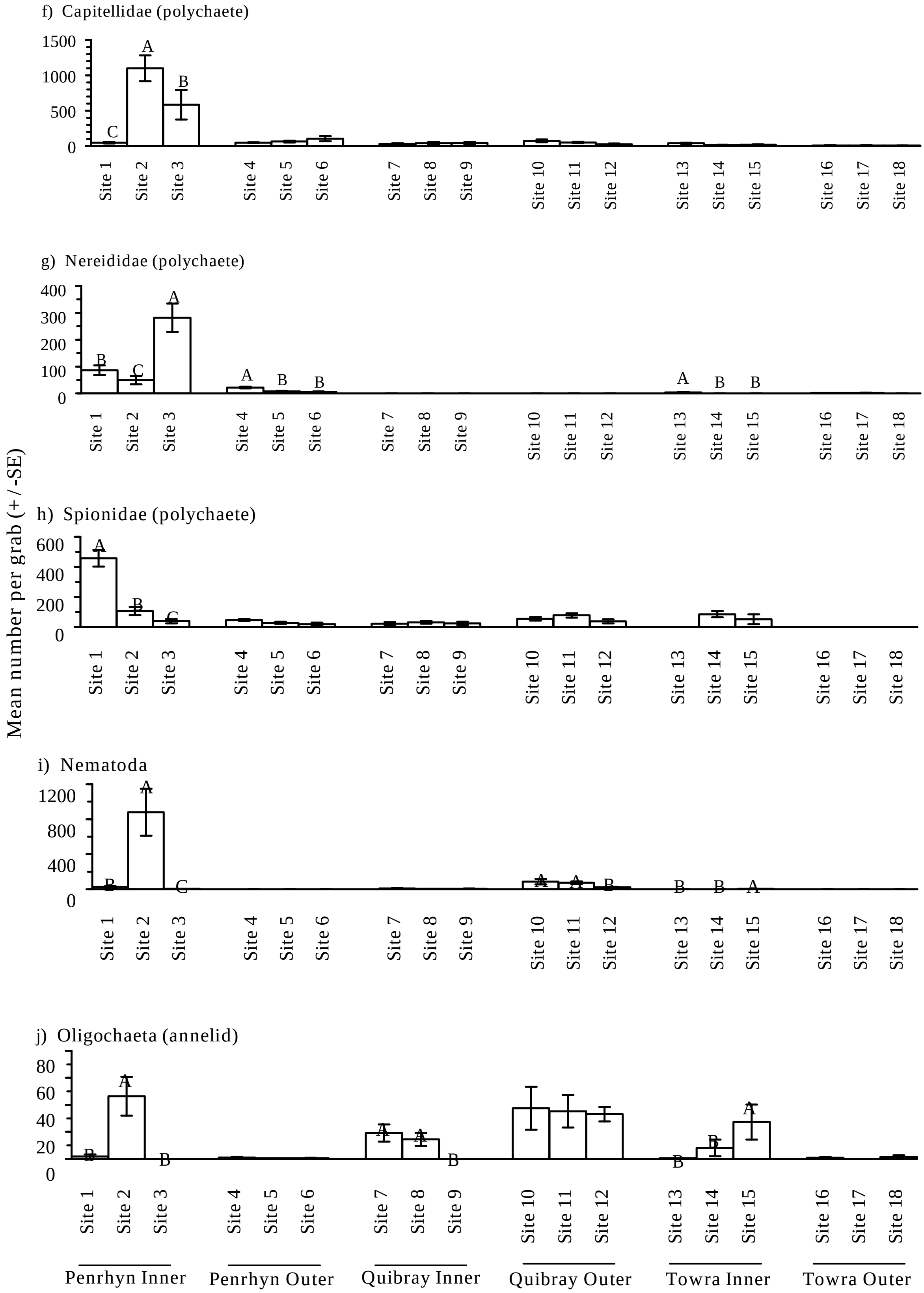

Figure 14: Continued...

APPENDICES

Appendix 1: GPS coordinates for each location sampled for intertidal benthos.

Appendix 2: GPS coordinates for each location sampled for subtidal benthos.

Appendix 3: Mean (and standard error) percentage of intertidal sediment grains in each size class at each of fifteen sites.

Appendix 4: Mean (and standard error) number of each intertidal invertebrate taxa per core at each of the fifteen sites.

Appendix 5: Mean (and standard error) percentage of subtidal sediment grains in each size class at each of eighteen sites.

Appendix 6: Mean (and standard error) number of each subtidal invertebrate taxa per core at each of the eighteen sites.

Appendix 1: GPS coordinates for each location sampled for intertidal benthos on Foreshore Beach and Penrhyn Estuary in Botany Bay on 8 October 2002. Datum: WGS 84.

Location	Site	Easting	Northing
Foreshore West	Site 1	0333220	6241321
	Site 2	0333269	6241277
	Site 3	0333332	6241244
Foreshore Middle	Site 4	0333509	6241127
	Site 5	0333560	6241102
	Site 6	0333610	6241089
Foreshore East	Site 7	0333982	6240870
	Site 8	0333919	6240896
	Site 9	0334026	6240839
Penrhyn Outer	Site 10	0334444	6240446
	Site 11	0334383	6240565
	Site 12	0334422	6240512
Penrhyn Inner	Site 13	0334606	6240499
	Site 14	0334570	6240456
	Site 15	0334561	6240352

Appendix 2: GPS coordinates for each location sampled for subtidal benthos in Penrhyn Estuary, Towra Bay and Quibray Bay in Botany Bay on 24 and 28 October 2002. Datum: WGS 84.

Location	Site	Latitude	Longitude	AHD
Penrhyn Inner	Site 1	33^0 57'.821	151^0 12'.583	1.41
	Site 2	33^0 57'.850	151^0 12'.585	2.18
	Site 3	33^0 57'.827	151^0 12'.605	0.07
Penrhyn Outer	Site 4	33^0 57'.848	151^0 12'.472	3.12
	Site 5	33^0 57'.822	151^0 12'.421	3.34
	Site 6	33^0 57'.867	151^0 12'.428	2.91
Quibray Inner	Site 7	33^0 57'.865	151^0 12'.426	1.15
	Site 8	34^0 01'.016	151^0 11'.021	0.81
	Site 9	34^0 00'.930	151^0 11'.992	1.26
Quibray Outer	Site 10	34^0 00'.930	151^0 11'.021	2.24
	Site 11	34^0 00'.741	151^0 11'.020	3.32
	Site 12	34^0 00'.623	151^0 11'.068	2.8
Towra Inner	Site 13	34^0 00'.378	151^0 09'.472	-0.33
	Site 14	34^0 00'.359	151^0 09'.504	0.13
	Site 15	34^0 00'.361	151^0 09'.505	-0.26
Towra Outer	Site 16	34^0 00'.449	151^0 09'.362	-0.05
	Site 17	34^0 00'.408	151^0 09'.369	0.96
	Site 18	34^0 00'.399	151^0 09'.321	-0.42

Appendix 3: Mean (and standard error) percentage of intertidal sediment grains in each size class at each of fifteen sites along Foreshore Beach and Penrhyn Estuary, Botany Bay, October 2002 (n=2). Laboratory sheets available on request.

	Foreshore West						Foreshore Middle						Foreshore East					
	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6		Site 7		Site 8		Site 9	
Grain size (mm)	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
< 0.076 mm	1.50	0.50	1.50	0.50	2.00	0.00	2.00	0.00	2.50	0.50	1.50	0.50	2.00	1.00	2.50	1.50	2.00	0.00
0.076 - 0.150 mm	1.50	0.50	2.00	0.00	1.00	0.00	2.00	0.00	1.00	0.00	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
0.151 - 0.300 mm	45.00	4.00	81.50	0.50	75.00	0.00	61.50	7.50	69.50	3.50	36.00	1.00	36.50	1.50	57.50	0.50	46.00	1.00
0.301 - 0.425 mm	28.00	1.00	13.00	0.00	19.00	0.00	21.50	1.50	23.50	3.50	35.00	0.00	42.00	1.00	32.00	1.00	38.50	1.50
0.426 - 0.600 mm	14.00	2.00	2.00	0.00	3.00	0.00	5.50	1.50	3.50	0.50	18.00	0.00	16.50	0.50	6.50	0.50	10.00	0.00
0.601 - 1.180 mm	3.50	0.50	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	3.00	0.00	2.00	0.00	1.00	0.00	1.00	0.00
1.181 - 2.360 mm	1.50	0.50	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50
> 2.360 mm	5.00	3.00	0.00	0.00	0.00	0.00	4.50	3.50	0.00	0.00	5.00	1.00	0.50	0.50	0.00	0.00	1.50	0.50
Median	0.32	0.03	0.23	0.00	0.24	0.00	0.26	0.02	0.25	0.01	0.25	0.01	0.34	0.00	0.27	0.00	0.31	0.00

	Penrhyn Outer						Penrhyn Inner						
	Site 10		Site 11		Site 12		Site 13		Site 14		Site 15		
Grain size (mm)	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Average (%)
< 0.076 mm	1.50	0.50	1.50	0.50	1.00	0.00	0.50	0.50	1.00	0.00	3.50	0.50	1.77
0.076 - 0.150 mm	1.50	0.50	0.50	0.50	1.00	0.00	1.00	0.00	1.00	0.00	1.50	0.50	1.07
0.151 - 0.300 mm	50.00	1.00	25.50	5.50	31.50	0.50	48.00	0.00	46.00	1.00	47.50	1.50	50.47
0.301 - 0.425 mm	33.50	1.50	36.50	4.50	47.00	2.00	35.00	0.00	39.50	0.50	37.00	0.00	32.07
0.426 - 0.600 mm	10.50	0.50	30.50	7.50	17.00	1.00	12.50	0.50	10.50	0.50	8.50	0.50	11.23
0.601 - 1.180 mm	1.00	0.00	5.50	2.50	2.50	0.50	3.00	0.00	1.00	0.00	1.00	0.00	1.77
1.181 - 2.360 mm	2.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	1.00	0.00	0.50
> 2.360 mm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.00	0.00	1.13
Median	0.29	0.00	0.39	0.02	0.34	0.00	0.31	0.00	0.32	0.00	0.29	0.00	0.13

Appendix 4: Mean (and standard error) number of each intertidal invertebrate taxa per core at each of the fifteen sites (n = 5).

	Foreshore West					
	Site 1		Site 2		Site 3	
	Mean	SE	Mean	SE	Mean	SE
1. POLYCHAETES Class Polychaeta						
Capitellidae	0.33	0.21	0.67	0.67	0.17	0.17
Cirratulidae	0.00	0.00	0.00	0.00	0.00	0.00
Glyceridae	0.00	0.00	0.17	0.17	0.00	0.00
Hesionidae	0.00	0.00	0.00	0.00	0.00	0.00
Nephtyidae	0.00	0.00	0.00	0.00	0.17	0.17
Nereididae	3.33	1.45	0.17	0.17	0.17	0.17
Orbiniidae	4.00	1.03	0.00	0.00	0.00	0.00
Phyllodocidae	0.17	0.17	0.00	0.00	0.33	0.21
Pilargidae	0.00	0.00	0.00	0.00	0.00	0.00
Sabellidae	0.00	0.00	0.00	0.00	0.00	0.00
Sigalionidae	0.00	0.00	0.17	0.17	0.17	0.17
Spionidae	8.00	3.10	0.00	0.00	0.33	0.21
Syllidae	0.00	0.00	0.17	0.17	0.00	0.00
2. CRUSTACEANS Order: Amphipoda						
Exoedicerotidae	3.50	1.31	0.50	0.34	0.33	0.21
Ischyroceridae	0.00	0.00	0.00	0.00	0.00	0.00
Oedicerotidae	0.00	0.00	0.00	0.00	0.50	0.34
Phoxocephalidae	0.00	0.00	0.17	0.17	0.00	0.00
Platyischnopidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Isopoda						
Cirolanidae	0.00	0.00	0.00	0.00	0.00	0.00
Sphaeromatidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Tanaidacea						
Leptocheliidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Decapooda IOrder Brachyura						
Mictyridae	0.00	0.00	0.00	0.00	0.00	0.00
Crab Larvae (megalopa, zoea)	0.00	0.00	0.00	0.00	0.00	0.00
3. MOLLUSCS Class Gastropoda						
Amphibolidae	0.00	0.00	0.00	0.00	0.00	0.00
Assimineidae	0.00	0.00	0.00	0.00	0.00	0.00
Columbellidae	0.00	0.00	0.00	0.00	0.00	0.00
Hydrobiidae	0.00	0.00	0.00	0.00	0.00	0.00
Nassariidae	0.00	0.00	0.00	0.00	0.00	0.00
Naticidae	0.00	0.00	0.00	0.00	0.17	0.17
Class Bivalva						
Leptonidae	1.83	1.05	1.33	0.49	3.00	1.44
Psammobiidae	0.33	0.21	0.00	0.00	0.00	0.00
Veneridae	0.00	0.00	0.00	0.00	0.00	0.00
4. ECHINODERMS						
Holothuroidea	0.00	0.00	0.00	0.00	0.00	0.00
5. OTHER WORM PHYLA						
Nemertea	0.00	0.00	2.00	0.37	1.67	0.56
Nematoda	0.17	0.17	0.33	0.33	0.17	0.17
Oligochaeta	0.17	0.17	0.00	0.00	0.17	0.17
6. OTHER PHYLA						
Anemone	0.00	0.00	0.00	0.00	0.00	0.00
Summary Statistics						
Number of taxa	5.33	0.56	3.17	0.83	4.33	0.67
Number of polychaete taxa	3.33	0.21	0.83	0.48	1.33	0.49
Number of crustacean taxa	0.83	0.17	0.50	0.22	0.67	0.21
Number of mollusc taxa	0.83	0.40	0.67	0.21	1.17	0.17
Number of individuals	21.83	6.48	5.67	2.14	7.33	0.92
Number of polychaete individuals	15.83	4.70	1.33	0.95	1.33	0.49
Number of crustacean individuals	3.50	1.31	0.67	0.33	0.83	0.31
Number of mollusc individuals	2.17	1.25	1.33	0.49	3.17	1.40

Continued...

Appendix 4: Continued...

	Foreshore Middle					
	Site 4		Site 5		Site 6	
	Mean	SE	Mean	SE	Mean	SE
1. POLYCHAETES Class Polychaeta						
Capitellidae	0.83	0.48	9.00	2.67	1.17	0.75
Cirratulidae	0.00	0.00	0.00	0.00	0.00	0.00
Glyceridae	0.00	0.00	0.00	0.00	0.00	0.00
Hesionidae	0.00	0.00	0.00	0.00	0.00	0.00
Nephtyidae	0.00	0.00	0.00	0.00	0.00	0.00
Nereididae	0.00	0.00	1.67	1.48	11.33	1.69
Orbiniidae	6.17	1.40	2.33	0.71	0.50	0.50
Phyllodocidae	0.00	0.00	0.00	0.00	0.00	0.00
Pilargidae	0.00	0.00	0.00	0.00	0.00	0.00
Sabellidae	0.00	0.00	0.00	0.00	0.00	0.00
Sigalionidae	0.00	0.00	0.00	0.00	0.00	0.00
Spionidae	0.33	0.33	0.83	0.48	20.83	5.99
Syllidae	0.00	0.00	0.00	0.00	0.00	0.00
2. CRUSTACEANS Order: Amphipoda						
Exoedicerotidae	7.17	0.95	6.33	2.65	36.17	19.64
Ischyroceridae	0.00	0.00	0.00	0.00	0.00	0.00
Oedicerotidae	0.00	0.00	0.00	0.00	0.00	0.00
Phoxocephalidae	0.00	0.00	0.00	0.00	0.00	0.00
Platyischnopidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Isopoda						
Cirolanidae	0.00	0.00	0.00	0.00	0.50	0.34
Sphaeromatidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Tanaidacea						
Leptocheliidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Decapooda IOrder Brachyura						
Mictyridae	0.00	0.00	0.00	0.00	0.00	0.00
Crab Larvae (megalopa, zoea)	0.17	0.17	0.17	0.17	0.17	0.17
3. MOLLUSCS Class Gastropoda						
Amphibolidae	0.00	0.00	0.00	0.00	0.00	0.00
Assimineidae	0.00	0.00	0.00	0.00	0.00	0.00
Columbellidae	0.00	0.00	0.00	0.00	0.00	0.00
Hydrobiidae	0.00	0.00	0.00	0.00	0.00	0.00
Nassariidae	0.00	0.00	0.17	0.17	0.00	0.00
Naticidae	0.00	0.00	0.00	0.00	0.00	0.00
Class Bivalva						
Leptonidae	8.00	1.39	0.67	0.33	0.33	0.21
Psammobiidae	2.00	0.45	1.00	0.52	0.17	0.17
Veneridae	0.50	0.34	0.33	0.21	0.00	0.00
4. ECHINODERMS						
Holothuroidea	0.00	0.00	0.00	0.00	0.00	0.00
5. OTHER WORM PHYLA						
Nemertea	0.17	0.17	0.67	0.21	0.00	0.00
Nematoda	0.33	0.21	0.00	0.00	0.00	0.00
Oligochaeta	0.17	0.17	7.17	6.97	0.17	0.17
6. OTHER PHYLA						
Anemone	0.00	0.00	0.00	0.00	0.33	0.33
Summary Statistics						
Number of taxa	5.83	0.60	6.33	0.56	4.83	0.48
Number of polychaete taxa	1.67	0.21	2.67	0.42	2.50	0.34
Number of crustacean taxa	1.17	0.17	1.17	0.17	1.50	0.22
Number of mollusc taxa	2.33	0.21	1.50	0.43	0.50	0.22
Number of individuals	25.83	2.69	30.33	9.68	71.67	23.54
Number of polychaete individuals	7.33	1.31	13.83	3.39	33.83	5.89
Number of crustacean individuals	7.33	1.05	6.50	2.62	36.83	19.66
Number of mollusc individuals	10.50	1.26	2.17	0.75	0.50	0.22

Continued...

Appendix 4: Continued...

	Foreshore East					
	Site 7		Site 8		Site 9	
	Mean	SE	Mean	SE	Mean	SE
1. POLYCHAETES Class Polychaeta						
Capitellidae	1.50	1.12	0.83	0.40	7.00	1.93
Cirratulidae	0.00	0.00	0.00	0.00	0.00	0.00
Glyceridae	0.00	0.00	0.00	0.00	0.00	0.00
Hesionidae	0.00	0.00	0.00	0.00	0.17	0.17
Nephtyidae	0.00	0.00	0.00	0.00	0.00	0.00
Nereididae	5.17	1.56	5.00	1.03	5.67	2.88
Orbiniidae	1.67	0.56	1.00	0.63	3.67	1.12
Phyllodocidae	0.00	0.00	0.00	0.00	0.00	0.00
Pilargidae	0.00	0.00	0.00	0.00	0.17	0.17
Sabellidae	0.00	0.00	0.00	0.00	0.00	0.00
Sigalionidae	0.00	0.00	0.00	0.00	0.17	0.17
Spionidae	0.50	0.34	0.67	0.33	4.33	2.79
Syllidae	0.33	0.21	0.67	0.33	0.33	0.21
2. CRUSTACEANS Order: Amphipoda						
Exoedicerotidae	0.83	0.31	6.17	1.49	22.83	3.80
Ischyroceridae	0.00	0.00	0.00	0.00	0.50	0.34
Oedicerotidae	0.00	0.00	0.00	0.00	0.00	0.00
Phoxocephalidae	0.00	0.00	0.00	0.00	0.00	0.00
Platyischnopidae	0.17	0.17	0.00	0.00	0.00	0.00
Order: Isopoda						
Cirolanidae	0.00	0.00	0.00	0.00	0.33	0.21
Sphaeromatidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Tanaidacea						
Leptocheliidae	0.00	0.00	0.00	0.00	0.33	0.33
Order: Decapooda IOrder Brachyura						
Mictyridae	0.00	0.00	0.00	0.00	0.00	0.00
Crab Larvae (megalopa, zoea)	0.00	0.00	0.67	0.67	0.00	0.00
3. MOLLUSCS Class Gastropoda						
Amphibolidae	0.00	0.00	0.00	0.00	0.00	0.00
Assimineidae	0.00	0.00	0.00	0.00	0.00	0.00
Columbellidae	0.00	0.00	0.00	0.00	0.00	0.00
Hydrobiidae	0.00	0.00	0.00	0.00	0.00	0.00
Nassariidae	0.00	0.00	0.00	0.00	0.17	0.17
Naticidae	0.00	0.00	0.00	0.00	0.00	0.00
Class Bivalva						
Leptonidae	1.17	0.79	0.33	0.33	0.83	0.48
Psammobiidae	0.50	0.22	0.83	0.48	1.33	0.61
Veneridae	0.00	0.00	0.17	0.17	0.00	0.00
4. ECHINODERMS						
Holothuroidea	0.00	0.00	0.17	0.17	0.00	0.00
5. OTHER WORM PHYLA						
Nemertea	0.00	0.00	0.00	0.00	0.33	0.33
Nematoda	0.33	0.21	0.00	0.00	1.00	1.00
Oligochaeta	65.50	39.17	0.00	0.00	0.50	0.34
6. OTHER PHYLA						
Anemone	0.00	0.00	0.00	0.00	0.00	0.00
Summary Statistics						
Number of taxa	6.17	0.48	5.17	0.95	8.17	1.58
Number of polychaete taxa	3.00	0.26	3.00	0.52	4.33	0.76
Number of crustacean taxa	0.83	0.17	1.17	0.17	1.83	0.48
Number of mollusc taxa	1.00	0.37	0.83	0.40	1.33	0.42
Number of individuals	77.67	38.37	16.50	2.40	49.67	7.67
Number of polychaete individuals	9.17	1.99	8.17	1.47	21.50	6.98
Number of crustacean individuals	1.00	0.26	6.83	1.45	24.00	3.71
Number of mollusc individuals	1.67	0.92	1.33	0.80	2.33	1.02

Continued...

Appendix 4: Continued…

	Penrhyn Outer					
	Site 10		Site 11		Site 12	
	Mean	SE	Mean	SE	Mean	SE
1. POLYCHAETES Class Polychaeta						
Capitellidae	0.00	0.00	0.00	0.00	0.00	0.00
Cirratulidae	0.00	0.00	0.00	0.00	0.00	0.00
Glyceridae	0.00	0.00	0.00	0.00	0.00	0.00
Hesionidae	0.00	0.00	0.00	0.00	0.00	0.00
Nephtyidae	0.00	0.00	0.00	0.00	0.00	0.00
Nereididae	0.50	0.34	0.67	0.21	0.00	0.00
Orbiniidae	0.17	0.17	0.00	0.00	0.17	0.17
Phyllodocidae	0.00	0.00	0.00	0.00	0.00	0.00
Pilargidae	0.00	0.00	0.00	0.00	0.00	0.00
Sabellidae	0.00	0.00	0.00	0.00	0.00	0.00
Sigalionidae	0.00	0.00	0.00	0.00	0.00	0.00
Spionidae	0.17	0.17	1.83	0.79	2.33	0.88
Syllidae	0.00	0.00	0.00	0.00	0.00	0.00
2. CRUSTACEANS Order: Amphipoda						
Exoedicerotidae	14.33	7.00	135.33	58.90	3.67	0.80
Ischyroceridae	0.00	0.00	0.00	0.00	0.00	0.00
Oedicerotidae	0.00	0.00	0.00	0.00	0.00	0.00
Phoxocephalidae	0.00	0.00	0.00	0.00	0.00	0.00
Platyischnopidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Isopoda						
Cirolanidae	0.17	0.17	0.33	0.21	0.00	0.00
Sphaeromatidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Tanaidacea						
Leptocheliidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Decapooda IOrder Brachyura						
Mictyridae	0.00	0.00	0.00	0.00	0.67	0.21
Crab Larvae (megalopa, zoea)	0.17	0.17	0.00	0.00	1.50	0.43
3. MOLLUSCS Class Gastropoda						
Amphibolidae	0.00	0.00	0.00	0.00	0.00	0.00
Assimineidae	0.00	0.00	0.00	0.00	0.00	0.00
Columbellidae	0.00	0.00	0.00	0.00	0.17	0.17
Hydrobiidae	0.00	0.00	0.00	0.00	0.00	0.00
Nassariidae	0.00	0.00	0.00	0.00	0.00	0.00
Naticidae	0.00	0.00	0.00	0.00	0.00	0.00
Class Bivalva						
Leptonidae	0.00	0.00	0.00	0.00	0.17	0.17
Psammobiidae	0.00	0.00	0.00	0.00	0.00	0.00
Veneridae	0.00	0.00	0.00	0.00	0.17	0.17
4. ECHINODERMS						
Holothuroidea	0.00	0.00	0.00	0.00	0.00	0.00
5. OTHER WORM PHYLA						
Nemertea	0.00	0.00	0.17	0.17	0.00	0.00
Nematoda	0.00	0.00	0.00	0.00	0.00	0.00
Oligochaeta	0.33	0.21	0.00	0.00	0.00	0.00
6. OTHER PHYLA						
Anemone	0.00	0.00	0.00	0.00	0.00	0.00
Summary Statistics						
Number of taxa	2.33	0.33	2.83	0.48	4.17	0.48
Number of polychaete taxa	0.67	0.33	1.33	0.33	1.17	0.17
Number of crustacean taxa	1.33	0.21	1.33	0.21	2.50	0.22
Number of mollusc taxa	0.00	0.00	0.00	0.00	0.50	0.22
Number of individuals	15.83	7.10	138.33	59.24	8.83	0.87
Number of polychaete individuals	0.83	0.40	2.50	0.92	2.50	0.85
Number of crustacean individuals	14.67	6.95	135.67	58.76	5.83	1.01
Number of mollusc individuals	0.00	0.00	0.00	0.00	0.50	0.22

Continued…

Appendix 4: Continued...

	Penrhyn Inner					
	Site 13		Site 14		Site 15	
	Mean	SE	Mean	SE	Mean	SE
1. POLYCHAETES Class Polychaeta						
Capitellidae	8.17	2.65	0.33	0.21	0.00	0.00
Cirratulidae	0.00	0.00	0.00	0.00	0.17	0.17
Glyceridae	0.00	0.00	0.00	0.00	0.00	0.00
Hesionidae	0.00	0.00	0.00	0.00	0.00	0.00
Nephtyidae	0.00	0.00	0.00	0.00	0.00	0.00
Nereididae	76.83	9.32	10.33	4.51	0.50	0.22
Orbiniidae	3.83	0.75	0.33	0.33	0.00	0.00
Phyllodocidae	0.00	0.00	0.00	0.00	0.00	0.00
Pilargidae	0.00	0.00	0.00	0.00	0.00	0.00
Sabellidae	0.17	0.17	0.00	0.00	0.00	0.00
Sigalionidae	0.00	0.00	0.00	0.00	0.00	0.00
Spionidae	0.17	0.17	4.50	1.82	0.17	0.17
Syllidae	0.17	0.17	0.00	0.00	0.00	0.00
2. CRUSTACEANS Order: Amphipoda						
Exoedicerotidae	1.00	0.52	8.17	2.21	0.50	0.34
Ischyroceridae	0.00	0.00	0.00	0.00	0.00	0.00
Oedicerotidae	0.00	0.00	0.00	0.00	0.00	0.00
Phoxocephalidae	0.00	0.00	0.00	0.00	0.00	0.00
Platyischnopidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Isopoda						
Cirolanidae	0.33	0.33	2.67	0.49	1.83	0.60
Sphaeromatidae	0.00	0.00	0.00	0.00	0.67	0.67
Order: Tanaidacea						
Leptocheliidae	0.00	0.00	0.17	0.17	0.00	0.00
Order: Decapooda IOrder Brachyura						
Mictyridae	0.00	0.00	0.17	0.17	0.00	0.00
Crab Larvae (megalopa, zoea)	1.00	0.52	0.50	0.50	0.00	0.00
3. MOLLUSCS Class Gastropoda						
Amphibolidae	0.17	0.17	0.00	0.00	0.00	0.00
Assimineidae	0.00	0.00	0.50	0.34	1.17	0.83
Columbellidae	0.00	0.00	0.00	0.00	0.00	0.00
Hydrobiidae	0.00	0.00	0.00	0.00	0.17	0.17
Nassariidae	0.17	0.17	0.00	0.00	0.00	0.00
Naticidae	0.00	0.00	0.00	0.00	0.00	0.00
Class Bivalva						
Leptonidae	0.00	0.00	0.67	0.33	0.00	0.00
Psammobiidae	0.00	0.00	0.17	0.17	0.00	0.00
Veneridae	0.00	0.00	0.00	0.00	0.00	0.00
4. ECHINODERMS						
Holothuroidea	0.00	0.00	0.00	0.00	0.00	0.00
5. OTHER WORM PHYLA						
Nemertea	0.00	0.00	0.17	0.17	0.83	0.40
Nematoda	0.17	0.17	0.17	0.17	0.00	0.00
Oligochaeta	0.00	0.00	0.83	0.65	6.17	2.91
6. OTHER PHYLA						
Anemone	0.00	0.00	0.00	0.00	0.00	0.00
Summary Statistics						
Number of taxa	5.17	0.31	6.33	1.17	4.17	0.54
Number of polychaete taxa	3.50	0.22	2.17	0.48	0.83	0.31
Number of crustacean taxa	1.17	0.48	2.50	0.22	1.33	0.33
Number of mollusc taxa	0.33	0.21	1.00	0.52	0.50	0.22
Number of individuals	92.17	10.89	29.67	6.78	12.17	4.04
Number of polychaete individuals	89.33	11.54	15.50	5.51	0.83	0.31
Number of crustacean individuals	2.33	1.23	11.67	2.22	3.00	1.00
Number of mollusc individuals	0.33	0.21	1.33	0.71	1.33	0.80

Continued...

Appendix 4: Continued...

	Total	% Contribution	Rank
1. POLYCHAETES Class Polychaeta			
Capitellidae	180	4.97	5
Cirratulidae	1	0.03	25
Glyceridae	1	0.03	25
Hesionidae	1	0.03	25
Nephtyidae	1	0.03	25
Nereididae	728	20.10	2
Orbiniidae	143	3.95	6
Phyllodocidae	3	0.08	18
Pilargidae	1	0.03	25
Sabellidae	1	0.03	25
Sigalionidae	3	0.08	18
Spionidae	270	7.46	4
Syllidae	10	0.28	13
2. CRUSTACEANS Order: Amphipoda			
Exoedicerotidae	1481	40.90	1
Ischyroceridae	3	0.08	18
Oedicerotidae	3	0.08	18
Phoxocephalidae	1	0.03	25
Platyischnopidae	1	0.03	25
Order: Isopoda			
Cirolanidae	37	1.02	9
Sphaeromatidae	4	0.11	17
Order: Tanaidacea			
Leptocheliidae	3	0.08	18
Order: Decapooda IOrder Brachyura			
Mictyridae	5	0.14	16
Crab Larvae (megalopa, zoea)	26	0.72	11
3. MOLLUSCS Class Gastropoda			
Amphibolidae	1	0.03	25
Assimineidae	10	0.28	14
Columbellidae	1	0.03	25
Hydrobiidae	1	0.03	25
Nassariidae	3	0.08	18
Naticidae	1	0.03	25
Class Bivalva			
Leptonidae	110	3.04	7
Psammobiidae	38	1.05	8
Veneridae	7	0.19	15
4. ECHINODERMS			
Holothuroidea	1	0.03	25
5. OTHER WORM PHYLA			
Nemertea	36	0.99	10
Nematoda	16	0.44	12
Oligochaeta	487	13.45	3
6. OTHER PHYLA			
Anemone	2	0.06	24
Summary Statistics			
Number of taxa	37		
Number of polychaete taxa	13	35%	
Number of crustacean taxa	10	27%	
Number of mollusc taxa	9	24%	
Number of individuals	3621		
Number of polychaete individuals	1343	37%	
Number of crustacean individuals	1564	43%	
Number of mollusc individuals	172	5%	

Appendix 5: Mean (and standard error) percentage of subtidal sediment grains in each size class at each of eighteen sites in Botany Bay, 2002 (n = 2). (ND = no data available for one or both replicates). Laboratory sheets available on request.

	Penrhyn Inner						Penrhyn Outer						Quibray Inner					
	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6		Site 7		Site 8		Site 9	
Grain size (mm)	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
< 0.076 mm	49.00	4.00	41.00	2.00	7.00	3.00	52.50	9.50	5.50	0.50	6.50	0.50	10.00	4.00	5.00	1.00	3.00	2.00
0.076 - 0.150 mm	7.00	0.00	9.00	2.00	2.00	0.00	8.00	1.00	7.00	0.00	4.00	0.00	2.00	0.00	1.00	0.00	2.00	0.00
0.151 - 0.300 mm	25.50	1.50	39.00	1.00	49.50	2.50	15.00	4.00	58.00	0.00	59.50	2.50	23.00	5.00	36.50	2.50	35.50	2.50
0.301 - 0.425 mm	12.00	2.00	8.00	1.00	32.00	1.00	14.00	2.00	23.50	0.50	23.50	0.50	38.50	0.50	42.00	2.00	40.00	1.00
0.426 - 0.600 mm	4.00	1.00	2.00	0.00	8.00	0.00	6.00	1.00	5.00	0.00	5.50	1.50	20.00	2.00	12.00	1.00	16.00	3.00
0.601 - 1.180 mm	2.50	0.50	1.00	0.00	1.50	0.50	4.50	1.50	1.00	0.00	1.00	0.00	6.50	0.50	3.50	0.50	3.50	0.50
> 1.180 mm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Median	0.14	ND	0.16	0.00	0.27	0.01	0.14	ND	0.24	0.00	0.25	0.01	0.35	0.01	0.33	0.01	0.33	0.01

	Quibray Outer						Towra Inner						Towra Outer						
	Site 10		Site 11		Site 12		Site 13		Site 14		Site 15		Site 16		Site 17		Site 18		
Grain size (mm)	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Average (%)
< 0.076 mm	7.50	1.50	10.00	7.00	10.50	0.50	3.50	0.50	67.50	17.50	57.50	6.50	6.50	0.50	3.50	0.50	4.50	2.50	19.47
0.076 - 0.150 mm	2.00	0.00	1.50	0.50	2.50	0.50	1.00	0.00	3.00	2.00	3.50	0.50	0.00	0.00	0.50	0.50	1.00	0.00	3.17
0.151 - 0.300 mm	36.00	0.00	32.00	1.00	34.00	0.00	63.00	2.00	8.00	2.00	11.00	3.00	51.50	0.50	62.00	2.00	53.50	1.50	38.47
0.301 - 0.425 mm	40.00	1.00	40.00	3.00	36.00	1.00	27.50	0.50	8.50	4.50	9.50	1.50	35.00	1.00	28.00	2.00	33.00	3.00	27.28
0.426 - 0.600 mm	11.00	0.00	12.50	1.50	12.50	0.50	4.50	1.50	5.00	3.00	6.50	0.50	6.00	0.00	5.00	1.00	6.50	0.50	8.22
0.601 - 1.180 mm	3.50	0.50	4.00	1.00	4.50	1.50	0.50	0.50	8.00	6.00	12.00	1.00	1.00	0.00	1.00	0.00	1.50	0.50	3.39
> 1.180 mm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Median	0.32	0.00	0.32	0.02	0.32	0.00	0.25	0.00	0.08	ND	ND	ND	0.27	0.00	0.26	0.00	0.27	0.01	0.14

Appendix 6: Mean (and standard error) number of each subtidal invertebrate taxa per core at each of the eighteen sites (n = 6).

	Penrhyn Inner					
	Site 1		Site 2		Site 3	
	Mean	SE	Mean	SE	Mean	SE
1. POLYCHAETES Class Polychaeta						
Capitellidae	46.40	11.43	1099.20	181.63	584.20	207.63
Cirratulidae	0.00	0.00	0.00	0.00	0.00	0.00
Cossuridae	0.00	0.00	0.00	0.00	0.00	0.00
Dorvilleidae	0.00	0.00	0.00	0.00	0.00	0.00
Flabelligeridae	0.00	0.00	0.00	0.00	0.00	0.00
Glyceridae	0.00	0.00	0.00	0.00	0.00	0.00
Goniadidae	0.00	0.00	0.00	0.00	0.00	0.00
Hesionidae	8.00	2.53	4.80	3.20	2.40	0.98
Lumbrineridae	1.60	1.60	0.00	0.00	2.40	1.03
Magelonidae	0.00	0.00	0.00	0.00	0.00	0.00
Maldanidae	0.00	0.00	0.00	0.00	0.00	0.00
Nephtyidae	0.00	0.00	0.00	0.00	0.60	0.24
Nereididae	86.40	17.42	49.60	15.47	281.60	52.80
Onuphidae	0.00	0.00	0.00	0.00	0.00	0.00
Opheliidae	1.60	1.60	0.00	0.00	0.00	0.00
Orbiniidae	0.00	0.00	0.00	0.00	1.60	0.60
Oweniidae	0.00	0.00	0.00	0.00	0.00	0.00
Paraonidae	0.00	0.00	0.00	0.00	0.00	0.00
Pectinariidae	0.00	0.00	0.00	0.00	0.00	0.00
Phyllodocidae	0.00	0.00	0.00	0.00	0.00	0.00
Pilargidae	0.00	0.00	0.00	0.00	0.00	0.00
Polynoidae	0.00	0.00	0.00	0.00	0.00	0.00
Sabellariidae	0.00	0.00	0.00	0.00	0.00	0.00
Sabellidae	22.40	8.91	14.40	3.92	83.60	27.06
Serpulidae	0.00	0.00	0.00	0.00	0.00	0.00
Sigalionidae	0.00	0.00	0.00	0.00	0.00	0.00
Spionidae	457.60	55.16	105.60	26.94	38.20	14.42
Syllidae	0.00	0.00	0.00	0.00	0.20	0.20
Terebellidae	0.00	0.00	0.00	0.00	0.00	0.00
Trichobranchidae	0.00	0.00	0.00	0.00	0.00	0.00
2. CRUSTACEANS Order: Leptostraca						
Nebaliidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Mysidacea						
Mysidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Amphipoda						
Aoridae	0.00	0.00	0.00	0.00	0.00	0.00
Corophiidae	0.00	0.00	0.00	0.00	0.00	0.00
Isaeidae	0.00	0.00	0.00	0.00	0.00	0.00
Ischyroceridae	6.40	4.66	1.60	1.60	5.20	1.36
Liljeborgiidae	0.00	0.00	0.00	0.00	0.00	0.00
Lysianassidae / Lysianassoidea	0.00	0.00	0.00	0.00	0.00	0.00
Melphidippidae / Cheirocratid group	0.00	0.00	0.00	0.00	0.00	0.00
Oedicerotidae	0.00	0.00	0.00	0.00	0.20	0.20
Phoxocephalidae	0.00	0.00	0.00	0.00	0.00	0.00
Podoceridae	0.00	0.00	0.00	0.00	0.00	0.00
Stegocephalidae	0.00	0.00	0.00	0.00	0.00	0.00
Urohaustoriidae	0.00	0.00	0.00	0.00	0.00	0.00
Sub Order: Caprellidea						
Phtisicidae	0.00	0.00	0.00	0.00	0.00	0.00

Continued…

Appendix 6: Continued...

	Penrhyn Inner					
	Site 1		Site 2		Site 3	
	Mean	SE	Mean	SE	Mean	SE
Protellidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Isopoda						
Anthuridae	0.00	0.00	0.00	0.00	0.00	0.00
Arcturidae	0.00	0.00	0.00	0.00	0.00	0.00
Leptanthuridae	0.00	0.00	0.00	0.00	0.00	0.00
Sphaeromatidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Tanaidacea						
Leptochellidae	9.60	7.76	1.60	1.60	1.80	0.66
Order: Cumacea						
Bodotriidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Decapooda IOrder Penaeidea						
Penaeidae	3.20	1.96	0.00	0.00	0.20	0.20
IOrder Caridea						
Alpheidae	0.00	0.00	0.00	0.00	0.00	0.00
Hippolytidae	0.00	0.00	0.00	0.00	0.00	0.00
IOrderThalassinidea						
Callianassidae	0.00	0.00	0.00	0.00	0.00	0.00
IOrder Brachyura						
Goneplacidae	0.00	0.00	0.00	0.00	0.00	0.00
Grapsidae	0.00	0.00	0.00	0.00	0.40	0.40
Hymenosomatidae	0.00	0.00	0.00	0.00	0.00	0.00
Myctiridae	0.00	0.00	0.00	0.00	0.00	0.00
Ocypodidae	0.00	0.00	0.00	0.00	0.00	0.00
Crab Larvae (megalopa, zoea)	0.00	0.00	1.60	1.60	0.20	0.20
Order: Harpacticoida						
Harpacticoida	0.00	0.00	8.00	4.38	0.00	0.00
SubClass Ostracoda Order: Myodocopida						
Cylindroleberidae	0.00	0.00	0.00	0.00	0.00	0.00
3. MOLLUSCS Class Gastropoda						
Amphibolidae	0.00	0.00	0.00	0.00	0.20	0.20
Assimineidae	0.00	0.00	0.00	0.00	0.00	0.00
Batillariidae	0.00	0.00	0.00	0.00	0.00	0.00
Cocculinellidae	0.00	0.00	0.00	0.00	0.00	0.00
Columbellidae	0.00	0.00	0.00	0.00	0.00	0.00
Epitoniidae	0.00	0.00	0.00	0.00	0.00	0.00
Littorinidae	0.00	0.00	0.00	0.00	0.00	0.00
Nassariidae	16.00	5.66	75.20	27.43	9.00	1.79
Naticidae	0.00	0.00	0.00	0.00	0.00	0.00
Pyramidellidae	0.00	0.00	0.00	0.00	0.00	0.00
Rissoidae	0.00	0.00	0.00	0.00	0.00	0.00
Trochidae	0.00	0.00	0.00	0.00	0.00	0.00
Turridae	0.00	0.00	0.00	0.00	0.00	0.00
Vitrinellidae	3.20	1.96	0.00	0.00	0.20	0.20
Gastropod egg mass	0.00	0.00	0.00	0.00	0.00	0.00
SubClass Opisthobranchia Order: Cephalaspidea						
Cylichnidae	0.00	0.00	0.00	0.00	0.00	0.00
Philinidae	0.00	0.00	0.00	0.00	0.00	0.00
Retusidae	0.00	0.00	0.00	0.00	0.00	0.00
Class Bivalva						
Carditidae	0.00	0.00	0.00	0.00	0.00	0.00

Continued...

Appendix 6: Continued...

	Penrhyn Inner					
	Site 1		Site 2		Site 3	
	Mean	SE	Mean	SE	Mean	SE
Galeommatidae	0.00	0.00	0.00	0.00	0.40	0.40
Laternulidae	0.00	0.00	0.00	0.00	0.20	0.20
Leptonidae	9.60	2.99	1.60	1.60	11.00	4.10
Lucinidae	0.00	0.00	0.00	0.00	0.00	0.00
Mactridae	0.00	0.00	0.00	0.00	0.00	0.00
Myochamidae	0.00	0.00	0.00	0.00	0.00	0.00
Pharidae	0.00	0.00	0.00	0.00	0.00	0.00
Psammobiidae	0.00	0.00	0.00	0.00	0.20	0.20
Semelidae	0.00	0.00	0.00	0.00	0.00	0.00
Tellinidae	30.40	7.76	9.60	6.40	2.60	0.93
Veneridae	0.00	0.00	0.00	0.00	0.20	0.20
Class Cephalopoda Order Sepioidea						
Sepiolidae	0.00	0.00	0.00	0.00	0.00	0.00
4. ECHINODERMS						
Asteroidea	0.00	0.00	0.00	0.00	0.00	0.00
Echinoidea	0.00	0.00	0.00	0.00	0.00	0.00
Holothuroidea	0.00	0.00	0.00	0.00	0.00	0.00
Ophiuroidea	0.00	0.00	0.00	0.00	0.00	0.00
5. OTHER WORM PHYLA						
Enteropneusta	0.00	0.00	0.00	0.00	0.00	0.00
Hirudinea	0.00	0.00	0.00	0.00	0.00	0.00
Nematoda	25.60	7.76	880.00	269.17	1.60	1.03
Nemertea	3.20	1.96	1.60	1.60	0.20	0.20
Oligochaeta	1.60	1.60	46.40	14.40	0.00	0.00
Phoronida	0.00	0.00	0.00	0.00	0.00	0.00
Platyhelminthes	0.00	0.00	0.00	0.00	0.00	0.00
Sipuncula: ? family	0.00	0.00	0.00	0.00	0.00	0.00
6. OTHER PHYLA						
Anemone	0.00	0.00	0.00	0.00	0.00	0.00
Ascidiacea	0.00	0.00	0.00	0.00	0.00	0.00
Hydrozoa	0.00	0.00	0.00	0.00	0.00	0.00
Larval fishes	352.00	352.00	0.00	0.00	0.00	0.00
Summary Statistics						
Number of taxa	11.00	0.84	9.00	0.71	14.60	0.51
Number of polychaete taxa	5.20	0.20	4.20	0.37	7.20	0.20
Number of crustacean taxa	1.20	0.58	1.20	0.58	2.60	0.51
Number of mollusc taxa	3.00	0.45	1.40	0.51	4.20	0.37
Number of echinoderm individuals	0.00	0.00	0.00	0.00	0.00	0.00
Number of other worm taxa	1.60	0.24	2.20	0.20	0.60	0.40
Number of other phyla	0.20	0.20	0.00	0.00	0.00	0.00
Number of individuals	732.80	71.13	2300.80	441.06	1028.60	276.12
Number of polychaete individuals	624.00	67.12	1273.60	216.91	994.80	278.16
Number of crustacean individuals	19.20	13.53	12.80	6.50	8.00	1.30
Number of mollusc individuals	59.20	13.76	86.40	29.76	24.00	4.20
Number of echinoderm individuals	0.00	0.00	0.00	0.00	0.00	0.00
Number of other worm individuals	30.40	8.16	928.00	280.86	1.80	1.11
Number of other phyla	352.00	352.00	0.00	0.00	0.00	0.00

Continued...

Appendix 6: Continued...

	Penrhyn Outer					
	Site 4		Site 5		Site 6	
	Mean	SE	Mean	SE	Mean	SE
1. POLYCHAETES Class Polychaeta						
Capitellidae	47.80	4.58	63.20	13.58	103.20	34.76
Cirratulidae	10.20	2.54	2.60	1.03	7.80	3.12
Cossuridae	0.00	0.00	0.00	0.00	0.00	0.00
Dorvilleidae	0.00	0.00	0.00	0.00	0.00	0.00
Flabelligeridae	0.00	0.00	0.40	0.24	0.00	0.00
Glyceridae	0.40	0.24	5.00	0.84	2.40	0.60
Goniadidae	0.80	0.58	1.00	0.55	0.20	0.20
Hesionidae	7.60	1.57	2.20	1.02	10.20	1.53
Lumbrineridae	13.00	1.05	4.00	0.84	8.40	3.60
Magelonidae	0.00	0.00	0.00	0.00	0.00	0.00
Maldanidae	0.00	0.00	0.00	0.00	0.00	0.00
Nephtyidae	4.20	1.59	0.20	0.20	0.40	0.24
Nereididae	21.80	3.31	7.80	1.24	5.20	1.85
Onuphidae	0.00	0.00	0.00	0.00	0.00	0.00
Opheliidae	15.20	3.07	16.60	4.68	3.00	1.05
Orbiniidae	0.20	0.20	0.40	0.24	0.00	0.00
Oweniidae	0.00	0.00	3.00	0.32	0.00	0.00
Paraonidae	0.80	0.37	0.00	0.00	0.00	0.00
Pectinariidae	0.00	0.00	0.20	0.20	0.00	0.00
Phyllodocidae	1.60	0.24	3.60	0.87	0.40	0.40
Pilargidae	0.60	0.40	0.00	0.00	0.00	0.00
Polynoidae	0.00	0.00	0.40	0.24	0.00	0.00
Sabellariidae	2.40	2.40	2.80	2.80	0.00	0.00
Sabellidae	8.60	3.33	6.40	2.44	0.80	0.37
Serpulidae	0.00	0.00	0.00	0.00	0.00	0.00
Sigalionidae	0.00	0.00	0.00	0.00	0.00	0.00
Spionidae	45.80	5.54	27.40	7.42	18.00	10.29
Syllidae	1.20	0.58	1.00	0.45	0.80	0.80
Terebellidae	1.40	0.93	0.00	0.00	0.40	0.40
Trichobranchidae	1.60	0.75	0.20	0.20	0.00	0.00
2. CRUSTACEANS Order: Leptostraca						
Nebaliidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Mysidacea						
Mysidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Amphipoda						
Aoridae	0.00	0.00	0.00	0.00	0.00	0.00
Corophiidae	0.00	0.00	0.00	0.00	0.00	0.00
Isaeidae	0.00	0.00	0.00	0.00	0.20	0.20
Ischyroceridae	4.80	0.86	40.40	9.70	86.80	84.55
Liljeborgiidae	0.20	0.20	1.00	0.32	0.00	0.00
Lysianassidae / Lysianassoidea	0.00	0.00	0.00	0.00	0.00	0.00
Melphidippidae / Cheirocratid group	0.00	0.00	0.00	0.00	0.00	0.00
Oedicerotidae	0.00	0.00	0.20	0.20	0.00	0.00
Phoxocephalidae	0.40	0.24	2.40	0.68	0.40	0.24
Podoceridae	0.00	0.00	0.00	0.00	0.00	0.00
Stegocephalidae	0.00	0.00	0.00	0.00	0.00	0.00
Urohaustoriidae	0.00	0.00	0.00	0.00	0.00	0.00
Sub Order: Caprellidea						
Phtisicidae	0.00	0.00	0.00	0.00	0.00	0.00

Continued...

Appendix 6: Continued...

	Penrhyn Outer					
	Site 4		Site 5		Site 6	
	Mean	SE	Mean	SE	Mean	SE
Protellidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Isopoda						
Anthuridae	0.00	0.00	0.60	0.40	0.20	0.20
Arcturidae	0.00	0.00	0.00	0.00	0.00	0.00
Leptanthuridae	0.00	0.00	0.00	0.00	0.00	0.00
Sphaeromatidae	0.00	0.00	0.00	0.00	0.20	0.20
Order: Tanaidacea						
Leptochellidae	10.00	6.28	32.20	16.01	16.20	9.44
Order: Cumacea						
Bodotriidae	0.20	0.20	0.00	0.00	0.00	0.00
Order: Decapooda IOrder Penaeidea						
Penaeidae	0.40	0.24	0.00	0.00	0.00	0.00
IOrder Caridea						
Alpheidae	0.40	0.24	0.00	0.00	0.00	0.00
Hippolytidae	0.00	0.00	0.00	0.00	0.00	0.00
IOrderThalassinidea						
Callianassidae	0.40	0.40	0.80	0.20	0.80	0.20
IOrder Brachyura						
Goneplacidae	0.00	0.00	0.20	0.20	0.00	0.00
Grapsidae	0.00	0.00	0.20	0.20	0.00	0.00
Hymenosomatidae	0.00	0.00	0.00	0.00	0.40	0.40
Myctiridae	0.00	0.00	0.00	0.00	0.00	0.00
Ocypodidae	1.00	0.55	0.00	0.00	0.00	0.00
Crab Larvae (megalopa, zoea)	0.00	0.00	0.00	0.00	1.40	0.68
Order: Harpacticoida						
Harpacticoida	0.20	0.20	0.00	0.00	0.00	0.00
SubClass Ostracoda Order: Myodocopida						
Cylindroleberidae	0.00	0.00	0.00	0.00	0.00	0.00
3. MOLLUSCS Class Gastropoda						
Amphibolidae	0.20	0.20	0.00	0.00	0.00	0.00
Assimineidae	0.00	0.00	0.00	0.00	0.00	0.00
Batillariidae	0.00	0.00	0.00	0.00	0.00	0.00
Cocculinellidae	0.00	0.00	0.00	0.00	0.00	0.00
Columbellidae	0.00	0.00	0.00	0.00	0.60	0.60
Epitoniidae	0.00	0.00	0.20	0.20	0.00	0.00
Littorinidae	0.00	0.00	0.00	0.00	0.20	0.20
Nassariidae	0.00	0.00	0.00	0.00	0.20	0.20
Naticidae	0.00	0.00	0.00	0.00	0.00	0.00
Pyramidellidae	0.00	0.00	0.00	0.00	0.00	0.00
Rissoidae	0.00	0.00	0.00	0.00	0.00	0.00
Trochidae	0.40	0.24	0.00	0.00	0.20	0.20
Turridae	0.00	0.00	0.60	0.24	1.00	0.77
Vitrinellidae	0.00	0.00	0.00	0.00	0.00	0.00
Gastropod egg mass	0.00	0.00	0.00	0.00	0.00	0.00
SubClass Opisthobranchia Order: Cephalaspidea						
Cylichnidae	0.00	0.00	0.00	0.00	0.00	0.00
Philinidae	0.40	0.40	0.40	0.24	0.00	0.00
Retusidae	0.00	0.00	0.20	0.20	0.00	0.00
Class Bivalva						
Carditidae	0.00	0.00	0.00	0.00	0.20	0.20

Continued...

Appendix 6: Continued...

	Penrhyn Outer					
	Site 4		Site 5		Site 6	
	Mean	SE	Mean	SE	Mean	SE
Galeommatidae	0.00	0.00	0.60	0.24	0.00	0.00
Laternulidae	0.00	0.00	0.00	0.00	0.00	0.00
Leptonidae	0.40	0.40	21.80	6.66	10.00	4.81
Lucinidae	0.00	0.00	0.20	0.20	0.20	0.20
Mactridae	1.40	0.51	0.00	0.00	0.00	0.00
Myochamidae	0.00	0.00	0.20	0.20	0.00	0.00
Pharidae	0.00	0.00	0.00	0.00	0.00	0.00
Psammobiidae	0.00	0.00	0.00	0.00	0.00	0.00
Semelidae	2.60	0.75	0.00	0.00	0.20	0.20
Tellinidae	1.20	0.37	0.40	0.24	0.60	0.24
Veneridae	0.00	0.00	0.20	0.20	0.60	0.40
Class Cephalopoda Order Sepioidea						
Sepiolidae	0.00	0.00	0.20	0.20	15.60	15.60
4. ECHINODERMS						
Asteroidea	0.00	0.00	0.00	0.00	0.00	0.00
Echinoidea	0.00	0.00	0.20	0.20	0.00	0.00
Holothuroidea	0.00	0.00	0.40	0.24	0.00	0.00
Ophiuroidea	0.00	0.00	0.00	0.00	0.00	0.00
5. OTHER WORM PHYLA						
Enteropneusta	0.00	0.00	0.00	0.00	0.00	0.00
Hirudinea	0.00	0.00	0.00	0.00	0.00	0.00
Nematoda	0.80	0.49	0.60	0.40	0.60	0.40
Nemertea	18.80	3.22	11.00	1.58	14.20	6.25
Oligochaeta	1.00	0.55	0.20	0.20	0.40	0.40
Phoronida	0.00	0.00	0.40	0.24	0.20	0.20
Platyhelminthes	0.00	0.00	0.20	0.20	0.20	0.20
Sipuncula: ? family	0.00	0.00	0.00	0.00	0.00	0.00
6. OTHER PHYLA						
Anemone	0.20	0.20	0.00	0.00	0.20	0.20
Ascidiacea	0.00	0.00	0.20	0.20	0.00	0.00
Hydrozoa	0.20	0.20	0.00	0.00	0.00	0.00
Larval fishes	0.00	0.00	0.00	0.00	0.00	0.00
Summary Statistics						
Number of taxa	24.20	1.20	26.40	1.57	20.40	1.63
Number of polychaete taxa	13.80	0.37	13.60	0.24	9.60	0.98
Number of crustacean taxa	4.40	0.51	5.60	0.68	4.60	0.60
Number of mollusc taxa	3.60	0.81	4.20	0.97	4.00	0.95
Number of echinoderm individuals	0.00	0.00	0.60	0.40	0.00	0.00
Number of other worm taxa	2.00	0.32	2.20	0.58	2.00	0.32
Number of other phyla	0.40	0.24	0.20	0.20	0.20	0.20
Number of individuals	230.80	19.32	264.60	37.88	313.20	87.32
Number of polychaete individuals	185.20	9.87	148.40	27.68	161.20	50.14
Number of crustacean individuals	18.00	7.25	78.00	22.69	106.60	93.67
Number of mollusc individuals	6.60	0.93	25.00	6.37	29.60	15.96
Number of echinoderm individuals	0.00	0.00	0.60	0.40	0.00	0.00
Number of other worm individuals	20.60	3.49	12.40	1.44	15.60	6.02
Number of other phyla	0.40	0.24	0.20	0.20	0.20	0.20

Continued...

Appendix 6: Continued...

	Quibray Inner					
	Site 7		Site 8		Site 9	
	Mean	SE	Mean	SE	Mean	SE
1. POLYCHAETES Class Polychaeta						
Capitellidae	31.40	7.01	39.60	16.88	41.60	17.05
Cirratulidae	2.00	1.55	1.40	0.98	12.80	6.50
Cossuridae	0.00	0.00	0.00	0.00	0.00	0.00
Dorvilleidae	1.80	1.56	0.40	0.40	0.00	0.00
Flabelligeridae	1.80	1.56	0.20	0.20	0.00	0.00
Glyceridae	3.60	3.12	2.40	1.60	1.60	1.60
Goniadidae	0.00	0.00	0.00	0.00	4.80	3.20
Hesionidae	0.20	0.20	0.60	0.60	0.00	0.00
Lumbrineridae	1.80	1.56	3.60	1.69	0.00	0.00
Magelonidae	0.00	0.00	0.00	0.00	0.00	0.00
Maldanidae	0.20	0.20	0.00	0.00	0.00	0.00
Nephtyidae	0.00	0.00	1.60	1.60	0.00	0.00
Nereididae	0.00	0.00	0.00	0.00	0.00	0.00
Onuphidae	0.00	0.00	0.00	0.00	0.00	0.00
Opheliidae	0.20	0.20	0.40	0.40	1.60	1.60
Orbiniidae	0.00	0.00	0.20	0.20	0.00	0.00
Oweniidae	0.00	0.00	0.20	0.20	1.60	1.60
Paraonidae	0.00	0.00	0.20	0.20	0.00	0.00
Pectinariidae	0.00	0.00	0.00	0.00	0.00	0.00
Phyllodocidae	0.60	0.60	2.20	1.50	0.00	0.00
Pilargidae	0.00	0.00	0.00	0.00	0.00	0.00
Polynoidae	0.00	0.00	0.00	0.00	0.00	0.00
Sabellariidae	0.00	0.00	0.00	0.00	0.00	0.00
Sabellidae	1.60	1.60	1.00	0.77	0.00	0.00
Serpulidae	0.00	0.00	0.00	0.00	0.00	0.00
Sigalionidae	0.00	0.00	0.00	0.00	0.00	0.00
Spionidae	22.00	9.59	30.40	8.42	24.00	10.73
Syllidae	0.00	0.00	2.40	1.60	0.00	0.00
Terebellidae	0.00	0.00	0.00	0.00	0.00	0.00
Trichobranchidae	0.00	0.00	0.00	0.00	0.00	0.00
2. CRUSTACEANS Order: Leptostraca						
Nebaliidae	0.00	0.00	1.20	1.20	1.60	1.60
Order: Mysidacea						
Mysidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Amphipoda						
Aoridae	1.60	1.60	0.00	0.00	1.60	1.60
Corophiidae	0.00	0.00	0.00	0.00	0.00	0.00
Isaeidae	0.00	0.00	0.80	0.80	0.00	0.00
Ischyroceridae	0.00	0.00	14.60	10.79	0.00	0.00
Liljeborgiidae	0.00	0.00	0.20	0.20	0.00	0.00
Lysianassidae / Lysianassoidea	0.00	0.00	0.40	0.40	0.00	0.00
Melphidippidae / Cheirocratid group	0.00	0.00	3.20	3.20	3.20	1.96
Oedicerotidae	0.00	0.00	0.20	0.20	0.00	0.00
Phoxocephalidae	0.00	0.00	2.00	1.55	0.00	0.00
Podoceridae	0.00	0.00	1.60	1.60	0.00	0.00
Stegocephalidae	0.00	0.00	0.00	0.00	0.00	0.00
Urohaustoriidae	0.00	0.00	0.00	0.00	0.00	0.00
Sub Order: Caprellidea						
Phtisicidae	0.00	0.00	0.00	0.00	0.00	0.00

Continued...

Appendix 6: Continued...

	Quibray Inner					
	Site 7		Site 8		Site 9	
	Mean	SE	Mean	SE	Mean	SE
Protellidae	0.00	0.00	1.40	1.40	1.60	1.60
Order: Isopoda						
Anthuridae	0.00	0.00	0.80	0.80	0.00	0.00
Arcturidae	0.00	0.00	0.20	0.20	0.00	0.00
Leptanthuridae	0.00	0.00	0.00	0.00	0.00	0.00
Sphaeromatidae	0.00	0.00	0.20	0.20	0.00	0.00
Order: Tanaidacea						
Leptochellidae	0.00	0.00	4.40	2.20	1.60	1.60
Order: Cumacea						
Bodotriidae	1.80	1.56	3.60	3.12	1.60	1.60
Order: Decapooda IOrder Penaeidea						
Penaeidae	0.00	0.00	0.00	0.00	0.00	0.00
IOrder Caridea						
Alpheidae	0.00	0.00	1.00	0.77	0.00	0.00
Hippolytidae	0.00	0.00	0.20	0.20	0.00	0.00
IOrderThalassinidea						
Callianassidae	0.00	0.00	0.00	0.00	0.00	0.00
IOrder Brachyura						
Goneplacidae	0.00	0.00	0.00	0.00	0.00	0.00
Grapsidae	0.00	0.00	0.20	0.20	1.60	1.60
Hymenosomatidae	0.00	0.00	0.60	0.60	0.00	0.00
Myctiridae	0.00	0.00	0.00	0.00	0.00	0.00
Ocypodidae	0.00	0.00	0.00	0.00	0.00	0.00
Crab Larvae (megalopa, zoea)	0.00	0.00	0.00	0.00	0.00	0.00
Order: Harpacticoida						
Harpacticoida	0.00	0.00	0.00	0.00	0.00	0.00
SubClass Ostracoda Order: Myodocopida						
Cylindroleberidae	0.00	0.00	0.00	0.00	1.60	1.60
3. MOLLUSCS Class Gastropoda						
Amphibolidae	0.00	0.00	0.00	0.00	0.00	0.00
Assimineidae	0.00	0.00	0.00	0.00	0.00	0.00
Batillariidae	0.00	0.00	0.00	0.00	0.00	0.00
Cocculinellidae	0.00	0.00	0.00	0.00	0.00	0.00
Columbellidae	0.00	0.00	0.00	0.00	0.00	0.00
Epitoniidae	0.00	0.00	0.00	0.00	0.00	0.00
Littorinidae	0.00	0.00	0.00	0.00	0.00	0.00
Nassariidae	5.00	4.75	5.00	3.13	6.40	2.99
Naticidae	0.00	0.00	0.00	0.00	1.60	1.60
Pyramidellidae	0.00	0.00	0.00	0.00	0.00	0.00
Rissoidae	1.60	1.60	0.00	0.00	0.00	0.00
Trochidae	0.00	0.00	0.00	0.00	0.00	0.00
Turridae	0.00	0.00	0.80	0.80	0.00	0.00
Vitrinellidae	0.00	0.00	0.00	0.00	0.00	0.00
Gastropod egg mass	0.00	0.00	0.00	0.00	0.00	0.00
SubClass Opisthobranchia Order: Cephalaspidea						
Cylichnidae	0.00	0.00	0.00	0.00	0.00	0.00
Philinidae	0.00	0.00	0.00	0.00	0.00	0.00
Retusidae	0.00	0.00	0.00	0.00	0.00	0.00
Class Bivalva						
Carditidae	0.00	0.00	0.00	0.00	0.00	0.00

Continued...

Appendix 6: Continued...

	Quibray Inner					
	Site 7		Site 8		Site 9	
	Mean	SE	Mean	SE	Mean	SE
Galeommatidae	0.00	0.00	0.00	0.00	0.00	0.00
Laternulidae	0.00	0.00	0.00	0.00	0.00	0.00
Leptonidae	0.20	0.20	0.60	0.60	0.00	0.00
Lucinidae	1.80	1.56	0.60	0.40	1.60	1.60
Mactridae	0.00	0.00	0.00	0.00	0.00	0.00
Myochamidae	0.00	0.00	0.00	0.00	0.00	0.00
Pharidae	0.00	0.00	0.00	0.00	0.00	0.00
Psammobiidae	0.00	0.00	0.00	0.00	0.00	0.00
Semelidae	0.00	0.00	0.00	0.00	0.00	0.00
Tellinidae	0.00	0.00	1.60	1.60	0.00	0.00
Veneridae	0.00	0.00	0.00	0.00	0.00	0.00
Class Cephalopoda Order Sepioidea						
Sepiolidae	0.00	0.00	0.00	0.00	0.00	0.00
4. ECHINODERMS						
Asteroidea	0.00	0.00	0.00	0.00	0.00	0.00
Echinoidea	0.00	0.00	0.00	0.00	0.00	0.00
Holothuroidea	0.00	0.00	0.40	0.40	0.00	0.00
Ophiuroidea	0.00	0.00	0.00	0.00	0.00	0.00
5. OTHER WORM PHYLA						
Enteropneusta	0.00	0.00	0.20	0.20	1.60	1.60
Hirudinea	0.00	0.00	0.60	0.60	0.00	0.00
Nematoda	8.00	2.53	4.20	1.91	4.80	3.20
Nemertea	11.00	3.26	13.20	5.94	3.20	3.20
Oligochaeta	19.00	6.34	14.40	4.88	0.00	0.00
Phoronida	0.00	0.00	0.20	0.20	1.60	1.60
Platyhelminthes	0.00	0.00	0.20	0.20	0.00	0.00
Sipuncula: ? family	0.00	0.00	0.20	0.20	0.00	0.00
6. OTHER PHYLA						
Anemone	0.00	0.00	0.20	0.20	0.00	0.00
Ascidiacea	0.00	0.00	0.00	0.00	0.00	0.00
Hydrozoa	0.00	0.00	0.00	0.00	0.00	0.00
Larval fishes	0.00	0.00	0.00	0.00	0.00	0.00
Summary Statistics						
Number of taxa	9.00	2.47	16.60	7.55	7.00	1.14
Number of polychaete taxa	4.80	1.69	6.20	2.35	3.20	0.73
Number of crustacean taxa	0.60	0.40	5.20	3.12	1.80	0.58
Number of mollusc taxa	1.20	0.49	1.60	0.68	1.00	0.00
Number of echinoderm individuals	0.00	0.00	0.20	0.20	0.00	0.00
Number of other worm taxa	2.40	0.40	3.20	1.32	1.00	0.32
Number of other phyla	0.00	0.00	0.20	0.20	0.00	0.00
Number of individuals	117.20	24.52	166.00	57.00	123.20	19.03
Number of polychaete individuals	67.20	20.18	86.80	25.58	88.00	15.39
Number of crustacean individuals	3.40	3.16	36.80	22.18	14.40	4.66
Number of mollusc individuals	8.60	4.14	8.60	4.14	9.60	1.60
Number of echinoderm individuals	0.00	0.00	0.40	0.40	0.00	0.00
Number of other worm individuals	38.00	8.34	33.20	12.39	11.20	3.20
Number of other phyla	0.00	0.00	0.20	0.20	0.00	0.00

Continued...

Appendix 6: Continued...

	Quibray Outer					
	Site 10		Site 11		Site 12	
	Mean	SE	Mean	SE	Mean	SE
1. POLYCHAETES Class Polychaeta						
Capitellidae	72.60	19.70	49.60	9.93	25.20	10.19
Cirratulidae	4.80	2.87	9.60	5.88	2.00	1.55
Cossuridae	0.00	0.00	0.00	0.00	0.00	0.00
Dorvilleidae	4.80	4.80	1.60	1.60	3.20	1.96
Flabelligeridae	0.80	0.80	1.60	1.60	0.00	0.00
Glyceridae	2.00	0.84	1.60	1.60	3.00	1.48
Goniadidae	8.20	3.47	1.60	1.60	1.60	1.60
Hesionidae	2.40	1.50	0.00	0.00	0.00	0.00
Lumbrineridae	5.00	3.82	0.00	0.00	1.00	0.77
Magelonidae	10.60	3.71	6.40	2.99	0.80	0.80
Maldanidae	0.00	0.00	0.00	0.00	0.00	0.00
Nephtyidae	0.20	0.20	0.00	0.00	1.00	0.77
Nereididae	0.20	0.20	0.00	0.00	0.00	0.00
Onuphidae	0.00	0.00	0.00	0.00	0.00	0.00
Opheliidae	0.20	0.20	0.00	0.00	0.80	0.80
Orbiniidae	0.00	0.00	0.00	0.00	0.00	0.00
Oweniidae	0.20	0.20	1.60	1.60	0.00	0.00
Paraonidae	0.00	0.00	0.00	0.00	0.00	0.00
Pectinariidae	0.00	0.00	0.00	0.00	0.00	0.00
Phyllodocidae	5.40	1.60	8.00	5.06	1.60	1.60
Pilargidae	0.00	0.00	0.00	0.00	0.00	0.00
Polynoidae	0.00	0.00	1.60	1.60	0.00	0.00
Sabellariidae	0.00	0.00	0.00	0.00	0.00	0.00
Sabellidae	0.00	0.00	1.60	1.60	0.00	0.00
Serpulidae	0.00	0.00	4.80	3.20	0.00	0.00
Sigalionidae	0.00	0.00	0.00	0.00	0.00	0.00
Spionidae	53.80	12.38	76.80	13.99	36.80	13.23
Syllidae	10.20	7.57	38.40	9.93	8.40	4.92
Terebellidae	0.00	0.00	0.00	0.00	0.00	0.00
Trichobranchidae	0.00	0.00	0.00	0.00	0.00	0.00
2. CRUSTACEANS Order: Leptostraca						
Nebaliidae	0.00	0.00	1.60	1.60	0.00	0.00
Order: Mysidacea						
Mysidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Amphipoda						
Aoridae	0.20	0.20	3.20	1.96	0.00	0.00
Corophiidae	0.00	0.00	0.00	0.00	0.80	0.80
Isaeidae	0.00	0.00	0.00	0.00	0.00	0.00
Ischyroceridae	11.60	4.15	72.00	22.49	0.00	0.00
Liljeborgiidae	0.00	0.00	0.00	0.00	0.00	0.00
Lysianassidae / Lysianassoidea	0.00	0.00	0.00	0.00	0.00	0.00
Melphidippidae / Cheirocratid group	0.00	0.00	1.60	1.60	0.00	0.00
Oedicerotidae	0.00	0.00	0.00	0.00	0.80	0.80
Phoxocephalidae	0.60	0.60	3.20	1.96	4.00	3.10
Podoceridae	0.00	0.00	4.80	3.20	0.00	0.00
Stegocephalidae	0.00	0.00	1.60	1.60	0.00	0.00
Urohaustoriidae	0.00	0.00	0.00	0.00	0.00	0.00
Sub Order: Caprellidea						
Phtisicidae	0.00	0.00	1.60	1.60	0.00	0.00

Continued...

Appendix 6: Continued...

	Quibray Outer					
	Site 10		Site 11		Site 12	
	Mean	SE	Mean	SE	Mean	SE
Protellidae	0.00	0.00	3.20	3.20	0.00	0.00
Order: Isopoda						
Anthuridae	0.00	0.00	0.00	0.00	0.00	0.00
Arcturidae	0.00	0.00	0.00	0.00	0.00	0.00
Leptanthuridae	0.00	0.00	0.00	0.00	0.00	0.00
Sphaeromatidae	0.00	0.00	3.20	1.96	0.00	0.00
Order: Tanaidacea						
Leptochellidae	23.80	6.92	88.00	16.59	1.80	1.56
Order: Cumacea						
Bodotriidae	0.80	0.80	0.00	0.00	0.20	0.20
Order: Decapooda IOrder Penaeidea						
Penaeidae	0.00	0.00	1.60	1.60	0.00	0.00
IOrder Caridea						
Alpheidae	0.00	0.00	0.00	0.00	0.00	0.00
Hippolytidae	0.00	0.00	0.00	0.00	0.00	0.00
IOrderThalassinidea						
Callianassidae	0.00	0.00	0.00	0.00	0.00	0.00
IOrder Brachyura						
Goneplacidae	0.00	0.00	0.00	0.00	0.00	0.00
Grapsidae	0.40	0.40	4.80	3.20	0.00	0.00
Hymenosomatidae	0.00	0.00	3.20	3.20	0.00	0.00
Myctiridae	0.00	0.00	0.00	0.00	0.00	0.00
Ocypodidae	0.00	0.00	0.00	0.00	0.00	0.00
Crab Larvae (megalopa, zoea)	0.00	0.00	0.00	0.00	0.00	0.00
Order: Harpacticoida						
Harpacticoida	0.00	0.00	0.00	0.00	0.00	0.00
SubClass Ostracoda Order: Myodocopida						
Cylindroleberidae	0.00	0.00	0.00	0.00	0.00	0.00
3. MOLLUSCS Class Gastropoda						
Amphibolidae	0.00	0.00	0.00	0.00	0.00	0.00
Assimineidae	0.00	0.00	0.00	0.00	0.00	0.00
Batillariidae	0.00	0.00	0.00	0.00	0.00	0.00
Cocculinellidae	0.00	0.00	0.00	0.00	0.00	0.00
Columbellidae	0.00	0.00	0.00	0.00	0.00	0.00
Epitoniidae	0.00	0.00	0.00	0.00	0.00	0.00
Littorinidae	0.00	0.00	0.00	0.00	0.00	0.00
Nassariidae	2.40	2.40	0.00	0.00	1.40	0.87
Naticidae	0.80	0.80	0.00	0.00	0.00	0.00
Pyramidellidae	0.00	0.00	0.00	0.00	0.00	0.00
Rissoidae	0.00	0.00	0.00	0.00	0.00	0.00
Trochidae	1.60	1.60	4.80	4.80	0.00	0.00
Turridae	0.20	0.20	0.00	0.00	0.20	0.20
Vitrinellidae	0.00	0.00	3.20	1.96	0.00	0.00
Gastropod egg mass	0.00	0.00	0.00	0.00	0.00	0.00
SubClass Opisthobranchia Order: Cephalaspidea						
Cylichnidae	0.00	0.00	1.60	1.60	0.00	0.00
Philinidae	0.00	0.00	1.60	1.60	0.00	0.00
Retusidae	0.00	0.00	0.00	0.00	0.00	0.00
Class Bivalva						
Carditidae	0.00	0.00	0.00	0.00	0.00	0.00

Continued...

Appendix 6: Continued…

	Quibray Outer					
	Site 10		Site 11		Site 12	
	Mean	SE	Mean	SE	Mean	SE
Galeommatidae	0.00	0.00	0.00	0.00	0.00	0.00
Laternulidae	0.00	0.00	0.00	0.00	0.00	0.00
Leptonidae	0.00	0.00	1.60	1.60	0.20	0.20
Lucinidae	2.40	1.60	0.00	0.00	0.00	0.00
Mactridae	0.00	0.00	0.00	0.00	0.00	0.00
Myochamidae	0.00	0.00	0.00	0.00	0.00	0.00
Pharidae	0.00	0.00	1.60	1.60	0.00	0.00
Psammobiidae	0.00	0.00	0.00	0.00	0.00	0.00
Semelidae	0.00	0.00	0.00	0.00	0.00	0.00
Tellinidae	2.40	1.60	0.00	0.00	0.00	0.00
Veneridae	0.00	0.00	0.00	0.00	0.00	0.00
Class Cephalopoda Order Sepioidea						
Sepiolidae	0.00	0.00	0.00	0.00	0.00	0.00
4. ECHINODERMS						
Asteroidea	0.40	0.40	0.00	0.00	0.00	0.00
Echinoidea	0.00	0.00	0.00	0.00	0.00	0.00
Holothuroidea	0.00	0.00	0.00	0.00	0.00	0.00
Ophiuroidea	0.00	0.00	0.00	0.00	0.00	0.00
5. OTHER WORM PHYLA						
Enteropneusta	5.80	1.20	6.40	2.99	1.60	1.60
Hirudinea	0.20	0.20	1.60	1.60	0.00	0.00
Nematoda	85.60	32.04	73.60	15.68	22.00	5.87
Nemertea	29.00	8.29	40.00	3.58	15.00	7.47
Oligochaeta	37.40	15.94	35.20	12.03	33.00	5.39
Phoronida	3.40	3.16	0.00	0.00	1.80	1.56
Platyhelminthes	0.00	0.00	0.00	0.00	0.00	0.00
Sipuncula: ? family	0.00	0.00	0.00	0.00	0.00	0.00
6. OTHER PHYLA						
Anemone	0.20	0.20	0.00	0.00	0.00	0.00
Ascidiacea	0.00	0.00	0.00	0.00	0.00	0.00
Hydrozoa	0.00	0.00	0.00	0.00	0.00	0.00
Larval fishes	0.00	0.00	0.00	0.00	0.00	0.00
Summary Statistics						
Number of taxa	18.60	1.99	17.00	1.73	11.20	1.39
Number of polychaete taxa	9.20	1.16	6.40	0.93	5.60	0.68
Number of crustacean taxa	2.80	0.58	5.40	0.60	1.40	0.75
Number of mollusc taxa	1.60	0.68	1.40	0.60	0.80	0.58
Number of echinoderm individuals	0.20	0.20	0.00	0.00	0.00	0.00
Number of other worm taxa	4.60	0.24	3.80	0.37	3.40	0.24
Number of other phyla	0.20	0.20	0.00	0.00	0.00	0.00
Number of individuals	390.60	102.72	569.60	78.36	168.20	36.01
Number of polychaete individuals	181.40	47.89	204.80	25.12	85.40	31.46
Number of crustacean individuals	37.40	9.23	193.60	42.14	7.60	4.31
Number of mollusc individuals	9.80	4.57	14.40	7.33	1.80	1.11
Number of echinoderm individuals	0.40	0.40	0.00	0.00	0.00	0.00
Number of other worm individuals	161.40	56.49	156.80	25.62	73.40	12.13
Number of other phyla	0.20	0.20	0.00	0.00	0.00	0.00

Continued…

Appendix 6: Continued...

	Towra Inner					
	Site 13		Site 14		Site 15	
	Mean	SE	Mean	SE	Mean	SE
1. POLYCHAETES Class Polychaeta						
Capitellidae	38.60	8.08	16.00	2.53	19.20	5.99
Cirratulidae	11.00	3.54	6.40	2.99	27.20	21.26
Cossuridae	0.00	0.00	0.00	0.00	0.00	0.00
Dorvilleidae	0.00	0.00	0.00	0.00	0.00	0.00
Flabelligeridae	0.00	0.00	0.00	0.00	0.00	0.00
Glyceridae	0.00	0.00	0.00	0.00	0.00	0.00
Goniadidae	0.40	0.24	0.00	0.00	0.00	0.00
Hesionidae	3.20	1.02	1.60	1.60	1.60	1.60
Lumbrineridae	0.00	0.00	3.20	1.96	1.60	1.60
Magelonidae	0.00	0.00	0.00	0.00	0.00	0.00
Maldanidae	0.00	0.00	0.00	0.00	0.00	0.00
Nephtyidae	0.00	0.00	3.20	1.96	1.60	1.60
Nereididae	4.20	1.43	0.00	0.00	0.00	0.00
Onuphidae	0.20	0.20	0.00	0.00	0.00	0.00
Opheliidae	0.00	0.00	0.00	0.00	1.60	1.60
Orbiniidae	3.80	0.86	0.00	0.00	0.00	0.00
Oweniidae	0.40	0.24	0.00	0.00	0.00	0.00
Paraonidae	0.00	0.00	0.00	0.00	0.00	0.00
Pectinariidae	0.00	0.00	0.00	0.00	0.00	0.00
Phyllodocidae	0.80	0.37	1.60	1.60	0.00	0.00
Pilargidae	0.00	0.00	0.00	0.00	0.00	0.00
Polynoidae	0.00	0.00	0.00	0.00	0.00	0.00
Sabellariidae	0.00	0.00	0.00	0.00	0.00	0.00
Sabellidae	0.20	0.20	0.00	0.00	0.00	0.00
Serpulidae	0.00	0.00	0.00	0.00	0.00	0.00
Sigalionidae	0.20	0.20	0.00	0.00	0.00	0.00
Spionidae	0.40	0.24	84.80	21.26	51.20	32.06
Syllidae	0.80	0.37	8.00	4.38	4.80	3.20
Terebellidae	0.00	0.00	0.00	0.00	0.00	0.00
Trichobranchidae	0.00	0.00	0.00	0.00	0.00	0.00
2. CRUSTACEANS Order: Leptostraca						
Nebaliidae	0.00	0.00	0.00	0.00	25.60	23.65
Order: Mysidacea						
Mysidae	0.00	0.00	0.00	0.00	1.60	1.60
Order: Amphipoda						
Aoridae	0.00	0.00	0.00	0.00	0.00	0.00
Corophiidae	0.00	0.00	0.00	0.00	0.00	0.00
Isaeidae	0.00	0.00	0.00	0.00	0.00	0.00
Ischyroceridae	0.00	0.00	0.00	0.00	12.80	10.91
Liljeborgiidae	0.00	0.00	0.00	0.00	0.00	0.00
Lysianassidae / Lysianassoidea	0.00	0.00	0.00	0.00	0.00	0.00
Melphidippidae / Cheirocratid group	0.00	0.00	0.00	0.00	4.80	4.80
Oedicerotidae	0.00	0.00	0.00	0.00	0.00	0.00
Phoxocephalidae	0.00	0.00	0.00	0.00	0.00	0.00
Podoceridae	0.00	0.00	0.00	0.00	0.00	0.00
Stegocephalidae	0.00	0.00	0.00	0.00	0.00	0.00
Urohaustoriidae	0.00	0.00	0.00	0.00	0.00	0.00
Sub Order: Caprellidea						
Phtisicidae	0.00	0.00	0.00	0.00	0.00	0.00

Continued...

Appendix 6: Continued...

	Towra Inner					
	Site 13		Site 14		Site 15	
	Mean	SE	Mean	SE	Mean	SE
Protellidae	0.00	0.00	0.00	0.00	1.60	1.60
Order: Isopoda						
Anthuridae	0.00	0.00	0.00	0.00	0.00	0.00
Arcturidae	0.00	0.00	0.00	0.00	0.00	0.00
Leptanthuridae	0.00	0.00	0.00	0.00	0.00	0.00
Sphaeromatidae	0.00	0.00	0.00	0.00	4.80	4.80
Order: Tanaidacea						
Leptochellidae	0.00	0.00	0.00	0.00	1.60	1.60
Order: Cumacea						
Bodotriidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Decapooda IOrder Penaeidea						
Penaeidae	0.00	0.00	0.00	0.00	1.60	1.60
IOrder Caridea						
Alpheidae	0.00	0.00	0.00	0.00	1.60	1.60
Hippolytidae	0.00	0.00	0.00	0.00	0.00	0.00
IOrderThalassinidea						
Callianassidae	0.00	0.00	0.00	0.00	0.00	0.00
IOrder Brachyura						
Goneplacidae	0.00	0.00	0.00	0.00	0.00	0.00
Grapsidae	0.00	0.00	0.00	0.00	1.60	1.60
Hymenosomatidae	0.00	0.00	0.00	0.00	4.80	3.20
Myctiridae	0.00	0.00	0.00	0.00	0.00	0.00
Ocypodidae	0.00	0.00	0.00	0.00	0.00	0.00
Crab Larvae (megalopa, zoea)	0.00	0.00	0.00	0.00	0.00	0.00
Order: Harpacticoida						
Harpacticoida	0.00	0.00	0.00	0.00	0.00	0.00
SubClass Ostracoda Order: Myodocopida						
Cylindroleberidae	0.00	0.00	0.00	0.00	0.00	0.00
3. MOLLUSCS Class Gastropoda						
Amphibolidae	0.00	0.00	0.00	0.00	0.00	0.00
Assimineidae	0.00	0.00	0.00	0.00	0.00	0.00
Batillariidae	0.00	0.00	0.00	0.00	1.60	1.60
Cocculinellidae	0.00	0.00	0.00	0.00	17.60	17.60
Columbellidae	0.00	0.00	0.00	0.00	0.00	0.00
Epitoniidae	0.00	0.00	0.00	0.00	0.00	0.00
Littorinidae	0.00	0.00	0.00	0.00	0.00	0.00
Nassariidae	5.60	1.66	3.20	1.96	6.40	4.66
Naticidae	0.40	0.24	0.00	0.00	0.00	0.00
Pyramidellidae	0.00	0.00	0.00	0.00	0.00	0.00
Rissoidae	0.00	0.00	0.00	0.00	0.00	0.00
Trochidae	0.00	0.00	0.00	0.00	0.00	0.00
Turridae	0.00	0.00	0.00	0.00	0.00	0.00
Vitrinellidae	0.00	0.00	0.00	0.00	9.60	7.76
Gastropod egg mass	0.00	0.00	0.00	0.00	0.00	0.00
SubClass Opisthobranchia Order: Cephalaspidea						
Cylichnidae	0.20	0.20	0.00	0.00	0.00	0.00
Philinidae	0.00	0.00	0.00	0.00	0.00	0.00
Retusidae	0.00	0.00	0.00	0.00	0.00	0.00
Class Bivalva						
Carditidae	0.00	0.00	0.00	0.00	0.00	0.00

Continued...

Appendix 6: Continued...

	Towra Inner					
	Site 13		Site 14		Site 15	
	Mean	SE	Mean	SE	Mean	SE
Galeommatidae	0.00	0.00	0.00	0.00	0.00	0.00
Laternulidae	0.00	0.00	0.00	0.00	0.00	0.00
Leptonidae	1.00	0.45	0.00	0.00	0.00	0.00
Lucinidae	0.00	0.00	0.00	0.00	0.00	0.00
Mactridae	0.20	0.20	0.00	0.00	0.00	0.00
Myochamidae	0.00	0.00	0.00	0.00	0.00	0.00
Pharidae	0.00	0.00	0.00	0.00	0.00	0.00
Psammobiidae	0.00	0.00	0.00	0.00	0.00	0.00
Semelidae	0.00	0.00	0.00	0.00	0.00	0.00
Tellinidae	0.00	0.00	0.00	0.00	0.00	0.00
Veneridae	0.00	0.00	0.00	0.00	0.00	0.00
Class Cephalopoda Order Sepioidea						
Sepiolidae	0.00	0.00	0.00	0.00	0.00	0.00
4. ECHINODERMS						
Asteroidea	0.00	0.00	0.00	0.00	0.00	0.00
Echinoidea	0.00	0.00	0.00	0.00	0.00	0.00
Holothuroidea	0.00	0.00	0.00	0.00	0.00	0.00
Ophiuroidea	0.00	0.00	0.00	0.00	68.80	68.80
5. OTHER WORM PHYLA						
Enteropneusta	0.00	0.00	0.00	0.00	0.00	0.00
Hirudinea	2.20	0.58	0.00	0.00	27.20	23.27
Nematoda	0.00	0.00	0.00	0.00	4.80	1.96
Nemertea	0.40	0.24	0.00	0.00	1.60	1.60
Oligochaeta	0.20	0.20	8.00	6.20	27.20	13.05
Phoronida	0.00	0.00	0.00	0.00	0.00	0.00
Platyhelminthes	0.00	0.00	0.00	0.00	1.60	1.60
Sipuncula: ? family	0.00	0.00	0.00	0.00	0.00	0.00
6. OTHER PHYLA						
Anemone	0.00	0.00	0.00	0.00	0.00	0.00
Ascidiacea	0.00	0.00	0.00	0.00	0.00	0.00
Hydrozoa	0.00	0.00	0.00	0.00	0.00	0.00
Larval fishes	0.00	0.00	0.00	0.00	0.00	0.00
Summary Statistics						
Number of taxa	11.80	0.58	5.20	0.73	10.40	3.23
Number of polychaete taxa	7.80	0.80	4.40	0.68	3.80	0.37
Number of crustacean taxa	0.00	0.00	0.00	0.00	2.80	1.56
Number of mollusc taxa	2.40	0.24	0.40	0.24	1.20	0.73
Number of echinoderm individuals	0.00	0.00	0.00	0.00	0.20	0.20
Number of other worm taxa	1.60	0.24	0.40	0.24	2.40	0.75
Number of other phyla	0.00	0.00	0.00	0.00	0.00	0.00
Number of individuals	74.40	12.64	136.00	31.80	337.60	193.52
Number of polychaete individuals	64.20	11.70	124.80	31.46	108.80	40.05
Number of crustacean individuals	0.00	0.00	0.00	0.00	62.40	41.83
Number of mollusc individuals	7.40	1.81	3.20	1.96	35.20	31.25
Number of echinoderm individuals	0.00	0.00	0.00	0.00	68.80	68.80
Number of other worm individuals	2.80	0.73	8.00	6.20	62.40	37.22
Number of other phyla	0.00	0.00	0.00	0.00	0.00	0.00

Continued...

Appendix 6: Continued...

	Towra Outer					
	Site 16		Site 17		Site 18	
	Mean	SE	Mean	SE	Mean	SE
1. POLYCHAETES Class Polychaeta						
Capitellidae	6.20	3.50	7.40	2.09	5.40	1.60
Cirratulidae	0.20	0.20	3.00	1.41	5.00	4.01
Cossuridae	0.00	0.00	0.00	0.00	0.00	0.00
Dorvilleidae	0.00	0.00	0.00	0.00	0.00	0.00
Flabelligeridae	0.00	0.00	0.00	0.00	0.00	0.00
Glyceridae	0.00	0.00	0.20	0.20	0.00	0.00
Goniadidae	0.00	0.00	0.00	0.00	0.00	0.00
Hesionidae	0.00	0.00	0.40	0.24	0.00	0.00
Lumbrineridae	0.00	0.00	0.20	0.20	0.00	0.00
Magelonidae	0.40	0.40	0.00	0.00	0.00	0.00
Maldanidae	0.00	0.00	0.00	0.00	0.00	0.00
Nephtyidae	9.80	5.26	0.20	0.20	1.60	1.12
Nereididae	0.60	0.24	1.80	1.11	0.20	0.20
Onuphidae	0.00	0.00	0.00	0.00	0.00	0.00
Opheliidae	0.00	0.00	0.00	0.00	0.00	0.00
Orbiniidae	0.40	0.24	2.60	1.29	1.40	0.87
Oweniidae	0.80	0.58	0.00	0.00	0.80	0.37
Paraonidae	0.00	0.00	0.00	0.00	0.00	0.00
Pectinariidae	0.00	0.00	0.00	0.00	0.00	0.00
Phyllodocidae	3.00	1.90	0.20	0.20	0.00	0.00
Pilargidae	0.00	0.00	0.00	0.00	0.00	0.00
Polynoidae	0.00	0.00	0.00	0.00	0.00	0.00
Sabellariidae	0.00	0.00	0.00	0.00	0.00	0.00
Sabellidae	0.80	0.58	0.00	0.00	0.20	0.20
Serpulidae	0.00	0.00	0.00	0.00	0.00	0.00
Sigalionidae	0.00	0.00	0.00	0.00	0.00	0.00
Spionidae	0.20	0.20	0.40	0.24	0.40	0.24
Syllidae	0.20	0.20	0.00	0.00	0.80	0.49
Terebellidae	0.00	0.00	0.00	0.00	0.00	0.00
Trichobranchidae	0.00	0.00	0.00	0.00	0.00	0.00
2. CRUSTACEANS Order: Leptostraca						
Nebaliidae	0.40	0.40	1.20	0.97	0.00	0.00
Order: Mysidacea						
Mysidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Amphipoda						
Aoridae	0.20	0.20	0.00	0.00	0.00	0.00
Corophiidae	0.20	0.20	0.00	0.00	0.00	0.00
Isaeidae	0.00	0.00	0.00	0.00	0.00	0.00
Ischyroceridae	0.20	0.20	2.60	1.60	0.40	0.24
Liljeborgiidae	0.20	0.20	0.00	0.00	0.00	0.00
Lysianassidae / Lysianassoidea	0.00	0.00	0.00	0.00	0.00	0.00
Melphidippidae / Cheirocratid group	0.20	0.20	0.00	0.00	0.00	0.00
Oedicerotidae	0.00	0.00	0.40	0.40	0.00	0.00
Phoxocephalidae	0.00	0.00	0.00	0.00	0.00	0.00
Podoceridae	0.00	0.00	0.00	0.00	0.00	0.00
Stegocephalidae	0.00	0.00	0.00	0.00	0.00	0.00
Urohaustoriidae	0.00	0.00	8.00	5.59	1.20	0.58
Sub Order: Caprellidea						
Phtisicidae	0.00	0.00	0.00	0.00	0.00	0.00

Continued...

Appendix 6: Continued...

	Towra Outer					
	Site 16		Site 17		Site 18	
	Mean	SE	Mean	SE	Mean	SE
Protellidae	0.40	0.40	0.40	0.24	0.00	0.00
Order: Isopoda						
Anthuridae	0.00	0.00	0.00	0.00	0.00	0.00
Arcturidae	0.00	0.00	0.00	0.00	0.00	0.00
Leptanthuridae	0.00	0.00	0.00	0.00	0.00	0.00
Sphaeromatidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Tanaidacea						
Leptochellidae	3.20	3.20	1.40	0.87	5.60	4.63
Order: Cumacea						
Bodotriidae	0.00	0.00	0.00	0.00	0.00	0.00
Order: Decapooda IOrder Penaeidea						
Penaeidae	0.20	0.20	0.00	0.00	0.20	0.20
IOrder Caridea						
Alpheidae	0.20	0.20	0.00	0.00	0.00	0.00
Hippolytidae	0.00	0.00	0.00	0.00	0.00	0.00
IOrderThalassinidea						
Callianassidae	0.00	0.00	0.00	0.00	0.00	0.00
IOrder Brachyura						
Goneplacidae	0.00	0.00	0.00	0.00	0.00	0.00
Grapsidae	0.20	0.20	0.20	0.20	0.80	0.80
Hymenosomatidae	0.00	0.00	0.00	0.00	0.40	0.40
Myctiridae	0.40	0.40	0.00	0.00	1.60	0.87
Ocypodidae	0.00	0.00	0.00	0.00	0.20	0.20
Crab Larvae (megalopa, zoea)	0.20	0.20	0.20	0.20	0.20	0.20
Order: Harpacticoida						
Harpacticoida	0.00	0.00	0.00	0.00	0.00	0.00
SubClass Ostracoda Order: Myodocopida						
Cylindroleberidae	0.00	0.00	0.00	0.00	0.00	0.00
3. MOLLUSCS Class Gastropoda						
Amphibolidae	0.20	0.20	0.00	0.00	0.00	0.00
Assimineidae	0.00	0.00	0.20	0.20	0.00	0.00
Batillariidae	0.00	0.00	0.00	0.00	0.00	0.00
Cocculinellidae	0.00	0.00	0.00	0.00	0.00	0.00
Columbellidae	0.00	0.00	0.00	0.00	0.00	0.00
Epitoniidae	0.00	0.00	0.00	0.00	0.00	0.00
Littorinidae	0.00	0.00	0.00	0.00	0.00	0.00
Nassariidae	1.00	0.77	6.20	2.08	0.00	0.00
Naticidae	0.60	0.40	1.00	0.55	0.00	0.00
Pyramidellidae	0.00	0.00	0.40	0.24	0.00	0.00
Rissoidae	0.00	0.00	0.00	0.00	0.00	0.00
Trochidae	0.40	0.40	0.00	0.00	0.40	0.24
Turridae	0.00	0.00	0.40	0.40	0.00	0.00
Vitrinellidae	0.00	0.00	0.00	0.00	0.00	0.00
Gastropod egg mass	0.00	0.00	0.00	0.00	0.00	0.00
SubClass Opisthobranchia Order: Cephalaspidea						
Cylichnidae	0.00	0.00	0.00	0.00	0.00	0.00
Philinidae	0.00	0.00	0.00	0.00	0.00	0.00
Retusidae	0.00	0.00	0.00	0.00	0.00	0.00
Class Bivalva						
Carditidae	0.00	0.00	0.00	0.00	0.00	0.00

Continued...

Appendix 6: Continued...

	Towra Outer					
	Site 16		Site 17		Site 18	
	Mean	SE	Mean	SE	Mean	SE
Galeommatidae	0.00	0.00	0.00	0.00	0.00	0.00
Laternulidae	0.60	0.60	0.00	0.00	0.00	0.00
Leptonidae	1.60	0.68	2.20	1.36	1.40	0.87
Lucinidae	0.00	0.00	0.00	0.00	0.00	0.00
Mactridae	0.00	0.00	0.40	0.24	0.20	0.20
Myochamidae	0.00	0.00	0.00	0.00	0.00	0.00
Pharidae	0.00	0.00	0.00	0.00	0.00	0.00
Psammobiidae	0.00	0.00	0.40	0.40	0.00	0.00
Semelidae	0.00	0.00	0.00	0.00	0.00	0.00
Tellinidae	0.80	0.58	0.00	0.00	0.20	0.20
Veneridae	0.20	0.20	0.60	0.40	0.00	0.00
Class Cephalopoda Order Sepioidea						
Sepiolidae	0.00	0.00	0.00	0.00	0.00	0.00
4. ECHINODERMS						
Asteroidea	0.00	0.00	0.00	0.00	0.00	0.00
Echinoidea	0.00	0.00	0.00	0.00	0.00	0.00
Holothuroidea	0.00	0.00	0.00	0.00	0.00	0.00
Ophiuroidea	0.00	0.00	0.00	0.00	0.00	0.00
5. OTHER WORM PHYLA						
Enteropneusta	0.00	0.00	0.00	0.00	0.00	0.00
Hirudinea	0.00	0.00	0.20	0.20	0.00	0.00
Nematoda	0.00	0.00	0.20	0.20	0.00	0.00
Nemertea	1.80	1.20	1.60	0.51	0.60	0.40
Oligochaeta	0.80	0.49	0.00	0.00	1.40	1.17
Phoronida	0.00	0.00	0.00	0.00	0.20	0.20
Platyhelminthes	0.00	0.00	0.00	0.00	0.00	0.00
Sipuncula: ? family	0.00	0.00	0.00	0.00	0.00	0.00
6. OTHER PHYLA						
Anemone	0.00	0.00	0.00	0.00	0.00	0.00
Ascidiacea	0.00	0.00	0.00	0.00	0.00	0.00
Hydrozoa	0.00	0.00	0.00	0.00	0.00	0.00
Larval fishes	0.00	0.00	0.00	0.00	0.00	0.00
Summary Statistics						
Number of taxa	10.20	4.85	12.60	1.75	10.00	1.48
Number of polychaete taxa	4.20	1.85	4.60	0.93	4.40	1.08
Number of crustacean taxa	2.60	2.11	3.00	0.84	3.40	0.51
Number of mollusc taxa	2.60	1.08	3.80	0.58	1.20	0.37
Number of echinoderm individuals	0.00	0.00	0.00	0.00	0.00	0.00
Number of other worm taxa	0.80	0.49	1.20	0.49	1.00	0.00
Number of other phyla	0.00	0.00	0.00	0.00	0.00	0.00
Number of individuals	36.80	20.26	44.60	1.12	30.80	7.41
Number of polychaete individuals	22.60	12.25	16.40	4.27	15.80	5.16
Number of crustacean individuals	6.20	5.46	14.40	5.16	10.60	5.41
Number of mollusc individuals	5.40	2.16	11.80	3.14	2.20	0.86
Number of echinoderm individuals	0.00	0.00	0.00	0.00	0.00	0.00
Number of other worm individuals	2.60	1.66	2.00	0.71	2.20	0.97
Number of other phyla	0.00	0.00	0.00	0.00	0.00	0.00

Continued...

Appendix 6: Continued...

	Total	% Contribution	Rank
1. POLYCHAETES Class Polychaeta			
Capitellidae	11494	30.97	1
Cirratulidae	530	1.43	11
Cossuridae	0	0.00	91
Dorvilleidae	59	0.16	32
Flabelligeridae	24	0.06	49
Glyceridae	111	0.30	23
Goniadidae	93	0.25	24
Hesionidae	226	0.61	17
Lumbrineridae	229	0.62	16
Magelonidae	91	0.25	24
Maldanidae	1	0.00	91
Nephtyidae	124	0.33	22
Nereididae	2297	6.19	4
Onuphidae	1	0.00	91
Opheliidae	206	0.56	18
Orbiniidae	55	0.15	33
Oweniidae	43	0.12	37
Paraonidae	5	0.01	77
Pectinariidae	1	0.00	91
Phyllodocidae	145	0.39	21
Pilargidae	3	0.01	77
Polynoidae	10	0.03	56
Sabellariidae	26	0.07	48
Sabellidae	708	1.91	10
Serpulidae	24	0.06	49
Sigalionidae	1	0.00	91
Spionidae	5369	14.47	3
Syllidae	386	1.04	12
Terebellidae	9	0.02	62
Trichobranchidae	9	0.02	62
2. CRUSTACEANS Order: Leptostraca			
Nebaliidae	158	0.43	19
Order: Mysidacea			
Mysidae	8	0.02	62
Order: Amphipoda			
Aoridae	34	0.09	45
Corophiidae	5	0.01	77
Isaeidae	5	0.01	77
Ischyroceridae	1299	3.50	5
Liljeborgiidae	8	0.02	62
Lysianassidae / Lysianassoidea	2	0.01	77
Melphidippidae / Cheirocratid group	65	0.18	30
Oedicerotidae	9	0.02	62
Phoxocephalidae	65	0.18	30
Podoceridae	32	0.09	45
Stegocephalidae	8	0.02	62
Urohaustoriidae	49	0.13	35
Sub Order: Caprellidea			
Phtisicidae	8	0.02	62

Appendix 6: Continued...

	Total	% Contribution	Rank
Protellidae	43	0.12	37
Order: Isopoda			
Anthuridae	8	0.02	62
Arcturidae	1	0.00	91
Leptanthuridae	0	0.00	91
Sphaeromatidae	42	0.11	39
Order: Tanaidacea			
Leptochellidae	1014	2.73	7
Order: Cumacea			
Bodotriidae	41	0.11	39
Order: Decapooda IOrder Penaeidea			
Penaeidae	38	0.10	44
IOrder Caridea			
Alpheidae	16	0.04	53
Hippolytidae	1	0.00	91
IOrderThalassinidea			
Callianassidae	10	0.03	56
IOrder Brachyura			
Goneplacidae	1	0.00	91
Grapsidae	52	0.14	34
Hymenosomatidae	47	0.13	35
Myctiridae	10	0.03	56
Ocypodidae	6	0.02	62
Crab Larvae (megalopa, zoea)	19	0.05	52
Order: Harpacticoida			
Harpacticoida	41	0.11	39
SubClass Ostracoda Order: Myodocopida			
Cylindroleberidae	8	0.02	62
3. MOLLUSCS Class Gastropoda			
Amphibolidae	3	0.01	77
Assimineidae	1	0.00	91
Batillariidae	8	0.02	62
Cocculinellidae	88	0.24	26
Columbellidae	3	0.01	77
Epitoniidae	1	0.00	91
Littorinidae	1	0.00	91
Nassariidae	715	1.93	9
Naticidae	23	0.06	49
Pyramidellidae	2	0.01	77
Rissoidae	8	0.02	62
Trochidae	39	0.11	39
Turridae	16	0.04	53
Vitrinellidae	81	0.22	27
Gastropod egg mass	0	0.00	91
SubClass Opisthobranchia Order: Cephalaspidea			
Cylichnidae	9	0.02	62
Philinidae	12	0.03	56
Retusidae	1	0.00	91
Class Bivalva			
Carditidae	1	0.00	91

Appendix 6: Continued...

	Total	% Contribution	Rank
Galeommatidae	5	0.01	77
Laternulidae	4	0.01	77
Leptonidae	317	0.85	14
Lucinidae	34	0.09	45
Mactridae	11	0.03	56
Myochamidae	1	0.00	91
Pharidae	8	0.02	62
Psammobiidae	3	0.01	77
Semelidae	14	0.04	53
Tellinidae	249	0.67	15
Veneridae	9	0.02	62
Class Cephalopoda Order Sepioidea			
Sepiolidae	79	0.21	28
4. ECHINODERMS			
Asteroidea	2	0.01	77
Echinoidea	1	0.00	91
Holothuroidea	4	0.01	77
Ophiuroidea	344	0.93	13
5. OTHER WORM PHYLA			
Enteropneusta	78	0.21	28
Hirudinea	160	0.43	19
Nematoda	5562	14.99	2
Nemertea	832	2.24	8
Oligochaeta	1131	3.05	6
Phoronida	39	0.11	39
Platyhelminthes	11	0.03	56
Sipuncula: ? family	1	0.00	91
6. OTHER PHYLA			
Anemone	4	0.01	77
Ascidiacea	1	0.00	91
Hydrozoa	1	0.00	91
Larval fishes	1760	4.74	-
Summary Statistics			
Number of taxa	108		
Number of polychaete taxa	29	26.85	
Number of crustacean taxa	33	30.56	
Number of mollusc taxa	30	27.78	
Number of echinoderm individuals	4	3.70	
Number of other worm taxa	8	7.41	
Number of other phyla	4	3.70	
Number of individuals	37110		
Number of polychaete individuals	22280	60.04	
Number of crustacean individuals	3153	8.50	
Number of mollusc individuals	1746	4.70	
Number of echinoderm individuals	351	0.95	
Number of other worm individuals	7814	21.06	
Number of other phyla	1766	4.76	