APPENDIX G

AQUATIC ECOLOGY IMPACT ASSESSMENT REPORT
(THE ECOLOGY LAB)

Report to:

GHD Pty Ltd

Proposed Extension of Shipping Channels, Port of Newcastle

Assessment of Aquatic Ecology

FINAL

August 2003

Report prepared by:

The Ecology Lab Pty Ltd

Proposed Extension of Shipping Channels, Port of Newcastle

Assessment of Aquatic Ecology

August 2003

Report Prepared for:

GHD Pty Ltd
10 Bond Sreet
Sydney, NSW, 2000

Report Prepared by:

The Ecology Lab Pty Ltd
4 Green Street
Brookvale, NSW, 2100
Phone: (02) 9907 4440

Report Number - 34/0001 A
Report Status - Final , 11/08/03

Table of Contents

SUMMARY

Introduction

Newcastle Port Corporation (NPC) is developing a Master Plan for dredging the South Arm of the Hunter River, with the ultimate goal of expanding the port facilities in this region. Dredging would extend east of Tourle Street Bridge for a distance of 3 km adjacent to Kooragang Island and would increase the depth of the river bed from 1-3 m to approximately 15.2 m. Contaminated dredge sediments would be remediated on the disused BHP steel site and buried on site, while clean sediments would be either reused at various land sites or disposed to an approved offshore dump ground. The consultant GHD has been engaged by NPC to prepare an Environmental Impact Statement (EIS) for the proposed works. The Ecology Lab Pty Limited was commissioned as sub-consultant to assist with the ecological studies for the proposed dredging. The proposed dredging would require the removal of estuarine sediment and wetland vegetation, including a stand of mangrove trees and saltmarsh.

The ecological value of the mangrove forest and the impacts of dredging on the fauna of the South Arm were assessed and impacts of proposed works on aquatic ecology were predicted. The study aims were to:

- Review existing information on the aquatic ecology of the lower Hunter River and assess impacts on marine habitats, fisheries, threatened species and sediment toxicity.
- Map wetland habitat, study and assess impacts of proposed dredging on mangrove habitat and benthic invertebrates communities of the mangrove.
- Study and assess impacts of proposed dredging on demersal fish and mobile invertebrates in the lower Hunter River.

NSW Fisheries has a policy of 2:1 habitat compensation for any removal of degradation of wetland habitat, hence it was important to measure the area of wetland to be removed. To better assess the conservation value of the mangrove forest at the dredge site, it was compared to mangrove forest in other locations within the Hunter River.

Existing Information

The Hunter River is classed as a moderately filled barrier lagoon, permanently open to the sea by training walls and requiring regular dredging for port navigation. It is relatively unusual in that its aquatic habitat is dominated by mangroves, which cover 50% of the water area and to a lesser extent saltmarshes, which cover 17% of the water area. There is no seagrass occurring along the main river channels. Although large areas of mangrove have been destroyed for industrial and port development, the overall extent of mangroves has increased since 1954, while the area of saltmarsh has decreased. Seventy-two species of fish and twenty-six species of crustaceans have been identified from the Hunter River estuary. This is similar to assemblages sampled in rivers from mid-northern NSW and all show great temporal variability. The lower Hunter supports an extensive industrial base in addition to extensive urban and commercial areas. Consequently many of the soft sediments are contaminated with pollutants including heavy metals, polycyclic aromatic hydrocarbons.

The major commercial fishery of the Hunter is the estuary prawn trawl fishery, while the Hunter finfish fishery in the ninth largest in NSW, and the oyster industry which is based in the North Arm of the river, is small but viable.

The proposed works would require significant dredging to increase existing channel depth. Approximately 11.35 million cubic metres of material would be dredged and excavated. The materials to be dredged from the bed and bank of the South Arm range from silty clays near the surface (21%), followed by sands (50%), clay (10.6%), and rock near the bottom (16.7%) and fill (1.3%). Activities involved in the process may include the following:

- Establishment of dredging equipment on site and installation of sediment containment measures include sheet pile wall around the contaminated area and silt screen around other sections of the dredge site.
- Dredging and extraction of South Arm sediments and banks requires earthmoving equipment followed by river based dredging. Soft clays would be removed using a trailing suction hopper dredger and disposed at sea. Clean sand would be removed and pumped onshore using a cutter suction dredger. A grab and backhoe dredger would be used to break up hard clays, rock and rock like material. Some blasting of rock may also be required.
- Dredge materials would be temporarily stockpiled. Clean sands would be transported along the proposed transport corridor to Tomago Industrial estate for processing. Uncontaminated materials that cannot be beneficially reused, such as fine river bed sediments, clays, soft rock and hard rock would be disposed of at sea.
- An estimated 250,000 m^3 of soft sediment located immediately adjacent to the BHP site is contaminated and requires remediation on land prior to disposal. Contaminants present in sediments include polycyclic aromatic hydrocarbons, total petroleum hydrocarbons and heavy metals. These sediments would be remediated on the BHP closure site using either cement stabilisation, thermal desorption technology, or appropriate equivalent approved by NSW EPA.
- Bank stabilisation of riverbeds in the vicinity of the dredge site.
- The appropriate management of all dredge waters returning the Hunter River to an acceptable level of quality.
- The disposal of the remaining sediments to an approved offshore dump ground. The permitting of the offshore component of the work is being processed under a separate application to Environment Australia.

Field Studies

The mangrove forest east of Tourle Street Bridge covers an area of approximately 9.7 ha. The forest is dominated by mature trees of *Avicennia marina* and patches of saltmarsh (*Sarcocornia quinqueflora* and *Suaeda australis*). An area of saltmarsh of approximately 1.3 ha is situated between the bridge and mangrove forest. It is dominated by tall grasses and the introduced *Juncus acuta*. Reference locations were selected to provide a context for assessing the importance of the mangroves east of Tourle St. Bridge. These were east of Ironbark Creek in the South Arm and east of Hexham Bridge in the North Arm. These mangrove forests were composed of mature *A. marina* and occasional *Aegicera corniculatum*.

Existing physical damage to mangrove forest was measured along transects at Tourle Street Bridge and the two reference locations during a survey done in September 2002. Most damage was composed of fallen branches, logs and tree stumps and occasional rubbish. Although statistically less forest was damaged at the dredge location (20%), compared to reference locations (30%), recent storms and natural forest processes would cause more branches to fall. Human sources of disturbance do not appear to have caused much of the physical damage. The forest at the proposed dredge site appeared to be representative of the range of conditions found in mangrove forest of the Hunter estuary.

Habitat components of the forest were measured along transects and in quadrats at three sites at each location. Mud was the most abundant cover along transects followed by pneumatophores (peg roots) and *A. marina* trees. Statistical analysis found no difference in type of cover among locations. Mud was the dominant habitat component in quadrats followed by pneumatophores, leaf litter, saplings and algae. Analysis of individual habitat components indicated that significantly more saplings occurred at the North Arm reference location compared to the dredge and other reference location. Previous research has found that the growth of saplings is affected by forest topography. It was concluded that mangrove forest habitat at the dredge location was typical and representative of other forest in the Hunter estuary.

Animals living in the sediment (benthos) of the mangrove forest were sampled at each location. Thirty-nine taxa were identified including species of crabs, amphipods, isopods, gastropods, bivalves, insects and families of polychaete worms. The gastropod genus *Tatea* sp. accounted for over 50% of abundance at each location. Significant differences among locations were found in the abundance and number of individual taxa. However the entire assemblage did not differ among locations. Hence the benthic assemblage at the dredge location was representative of other mangrove forests of the Hunter Estuary.

A survey of fish and mobile invertebrates was done to determine if fish at the proposed dredge site were similar to other areas of the estuary, including deeper waters. Twenty-six species of fish and invertebrates were collected throughout the Hunter River estuary during sampling in late October, 2002. Twenty-one species were considered of economic importance with nine species of this category being caught at the proposed dredge area in the South Arm. No threatened or endangered species were caught. Species such as mulloway, school prawns and luminous bay squid were characteristic of the deeper water sites, whereas tarwhine, yellowfin bream and silver biddy were more common in shallow waters. This suggests that depth may be an important factor in structuring the types of species found within these areas. Assemblages caught in the proposed dredge area were highly variable compared to those of other locations. Therefore it is difficult to draw definite conclusions on patterns occurring in the dredge area from one sampling time. However, it is predicted that fish species will be different after dredging, but will comprise an assemblage with species of commercial and recreational value, including prawns and mulloway.

Threatened species legislation was reviewed and the green sawfish and black cod which spend some of their life in estuaries were further assessed. However since no known population or critical habitat of these fish exist in the Hunter River, no further consideration was required.

Assessment of Impacts

The proposed works could have a number of long term and short term effect on the aquatic ecology of the Hunter Estuary. These are summarised below:

- Loss of mangroves and replacement with wharf structure. Hard surfaces provides habitat for invertebrate communities different to those found in soft-sediments.
- Loss of shallow subtidal habitat and creation of deep subtidal habitat. Research on benthic communities in areas dredged for the third runway in Botany Bay found recolonisation of dredged sites occurred within months. Recovery, defined as restoration to natural levels of variation in faunal assemblages took around two years.
- Changes to fish passage and connectivity. Local increases in flow velocity by a factor of 1.5 caused by the sheet pile wall and a turbidity gradient formed by sediments suspended in the waterway during dredging could temporarily inhibit fish passage. The proposed increase in depth of the channel would affect the type of fishes inhabiting this area.
- Effects of rock blasting on fish: Sound waves created during rock blasting can affect the swim bladder of fish and cause fish mortality and/or avoidance depending on the intensity and distance of the blasting.
- Potential changes in the existing hydrodynamics and salinity structure of the estuary. Any upstream movement of the salt wedge could affect the extent and types of wetland vegetation in the estuary. Modelling of the hydrodynamics and salinity structure in the South Arm following dredging indicated negligible change.
- The displacement of water by the bow waves of vessels could cause erosion of river banks, wetlands and riparian vegetation.
- Impacts oyster cultivation: No oyster cultivation occurs in the South Arm and the proposed dredging is unlikely to affect commercial oyster leases in the North Arm.
- Effects on commercial and recreational fishing: The South Arm is one of seven areas used regularly by prawn trawlers. Sediments resuspended during dredging and loss of habitat could affect fish and prawns feeding in the dredge area. Dredging will take between 12 and 24 months therefore it is not possible to restrict dredging to the winter months when prawns are least abundant and the trawling season is closed. Therefore, there would be some short-term inconvenience to fishes.
- Effects of dredging on sediment toxicity: High levels of PAHs and heavy metals were found in sediments at the proposed dredge site. PAHs have been found to bioaccumulate in wild oysters at the disused BHP site. Dredged sediments have lower levels of contaminants compared to undredged sediments. Hence it can be expected after dredging is completed, that the river bed sediments may be less polluted.
- Effects of dredging on water quality (turbidity, DO): A turbidity gradient formed from sediment suspension in waterway could inhibit fish passage. Reduced dissolved oxygen concentrations in deeper waters could affect organisms.
- Transport and deposition of dredge sediments: Modelling shows that muddy sediments will deposit along fringing mangroves upstream as far as Ironbark Creek.

Excessive sedimentation can have negative effect on mangrove plants smothering peg roots and affect forest communities.

- Effect of land disposal on the leaching of PAH, heavy metals and acid sulphates: Land disposal and the treatment of contaminated sediments can result in the seepage of contaminants into the environment during dewatering operation. Remediation measures include the use of geotextile bags and treatment of return waters to EPA acceptable levels.

Conclusions

The proposed works requires the removal of approximately 9.7 ha of mangrove forest or equivalent to 0.6 % of existing mangrove habitat in the Hunter Estuary. Also, approximately 1.3 ha of saltmarsh would be removed, equivalent to 0.29% of existing saltmarsh habitat in the Hunter Estuary. These amounts are relatively small, hence it is unlikely that their removal would have significant impacts on the ecology of the Hunter Estuary. The transport and deposition of sediments could affect upstream mangrove forest and mitigation measures would be required to minimise impacts. It is predicted that fish species found in the water column and benthic communities living in sediments will change after dredging works. Benthic invertebrates would colonise the dredged area within months, but recovery to a stable system would take in thee order of 2 years. Impacts to fish from blasting could be significant and would require appropriate mitigation.

Recommendations and Monitoring

Sediment containment devices such as silt curtains and sheet pile wall should be used during dredging to minimise the transport of sediments and contaminants from the dredge site to upstream wetland areas, in particular Kooragang wetland. Given the timeframe required for dredging, it will likely coincide with the prawn trawling season, hence financial compensation to prawn fisherman for loss of earnings could be considered. Strategies to minimise impacts to fish from blasting include employing fish avoidance devices to reduce fish abundance in the area affected and to conduct blasting in ways that minimise the magnitude of the shock waves produced. Appropriate measures should be taken to minimise the seepage of acid sulphate leachate into the water column. Habitat compensation measures could include the creation of artificial wetlands in Throsby Creek, planting riparian vegetation along the South Arm foreshore and supporting existing wetland rehabilitation projects such as the Hexham Swamp and Kooragang wetland projects. The environmental management plan to be implemented post-works could include the monitoring of fish, benthos, wetland habitat and water quality over time. This would provide vital information on natural variation and long term effects of dredging.

CHAPTER 1. INTRODUCTION

1.1 Background and Aims

The Port of Newcastle is one of Australia's largest tonnage ports, accommodating over 3,000 shipping movements per year. The Port is managed by the Newcastle Port Corporation (NPC), which is responsible for providing and maintaining navigation services to commercial shipping. NPC is developing a Master Plan for dredging the South Arm of the Hunter River, with the ultimate goal of expanding the port facilities in this region. Dredging would extend from the proposed Kooragang number 7 berth upstream to the Tourle Street Bridge, a distance of approximately 3 km. The proposed works include the dredging of sediments, the removal of wetland vegetation east of Tourle Street Bridge, and the remediation and disposal of dredged sediments. The consultant GHD has been engaged by NPC to prepare an Environmental Impact Statement (EIS) for the proposed works in the South Arm. The Ecology Lab Pty Limited, a private consultancy firm specialising in marine and freshwater research, was commissioned as sub-consultants to do studies of aquatic habitats for the EIS.

The estuarine environment is complex and it is acknowledged by specialists that the diversity of assemblages and their interactions are not fully understood. The ecological studies undertaken to assess impacts of the proposed dredging have therefore contributed to the on-going understanding of the marine environment. The scope of works was identified from relevant marine ecological issues. The direct ecological effects of dredging in the South Arm would include the loss of wetland habitat, the loss and modification to subtidal benthic communities and potential impacts on fish and mobile invertebrates that live on and feed in the subtidal zone and the water column. A number of indirect effects of the proposal on aquatic ecology are discussed in later chapters. The following components were considered essential and were selected for detailed study:

- Review existing information on the aquatic ecology of the lower Hunter River and assessment of impacts on marine habitats, fisheries, threatened species and sediment toxicity;
- Map wetland habitat, study and assess impacts of proposed dredging on mangrove habitat and benthic invertebrates communities of the mangrove; and
- Study and assess impacts of proposed dredging on demersal fish and mobile invertebrates in the lower Hunter River.

No specific study on ecological impacts of remediation and disposal of dredge material off-shore and onto land sites was included in our scope of works. However this issue was discussed briefly in the assessment of impacts. Neither was an assessment of potential impacts of proposed works on terrestrial flora and fauna (including water birds and waders) included, as this was covered by other specialist.

1.2 Report Structure

Existing literature on the aquatic ecology of the Hunter River is reviewed in Chapter 2. This includes the following:

- Review of historical changes to wetland vegetation in the Hunter River;
- Description of commercial and recreational fishing;
- Review of sediment toxicity and bioaccumulation studies, findings from previous studies on marine habitats in the Hunter River; and
- Assessment of threatened species legislation with regards to marine listed species.

The methods and results of field investigations done as part of this report are described in Chapter 3. Field studies included the assessment of damage in wetland habitat, the study of benthic invertebrate communities and the survey of fish and demersal invertebrates. Impacts of the proposal on aquatic ecology were discussed in Chapter 4. Finally, mitigation measures and recommendations are discussed in Chapter 5. Assessment requirements identified by statutory agencies including NSW Planning (formerly Dept of Urban Affairs and Planning) and NSW Fisheries are summarised in Table 1 and referred to throughout the report.

CHAPTER 2. REVIEW OF EXISTING INFORMATION

2.1 Aquatic Habitats

The Hunter River is a major waterway on the mid coast of New South Wales. Within the lower estuarine portion of the river, Kooragang Island divides the waterway into two arms, the South Arm and the North Arm (Figure 1). The South Arm is characterised by extensive human development: port infrastructure and the former BHP steelworks fringe the river downstream of Tourle Street Bridge, whilst upstream of the bridge there is light industrial development, residential development and a sewage treatment plant and outlet at Ironbark Creek. The North Arm is far less developed, with some industry at the southern end of Kooragang Island., residential development, Stockton Bridge and oyster cultivation.

The Hunter Estuary is classed as a moderately filled barrier lagoon, kept permanently open to the sea by training walls and regular dredging for port navigation (West *et al.* 1985). The estuary is of moderate size (map water area = 30.42 km^2) and is relatively unusual in that its aquatic habitat is dominated by mangroves and to a lesser extent saltmarshes but contains very little seagrass (Ruello, 1976; West *et al.* 1985; Williams *et al* 2000; and The Ecology Lab unpublished data). Based on amounts of aquatic habitat obtained by West *et al* (1985), mangroves covered over 50% of the map water area of the Hunter, compared to 19% in Port Stephens, 8% in Botany Bay and 1.8% in Port Jackson, while saltmarsh covered 17%, 6%, 3% and 0,1% of area in the Hunter, Port Stephens, Botany Bay and Port Jackson, respectively. The seagrass reported to be present at the time of study by West and his co-workers was *Ruppia* spp., which grew in lagoons on Kooragang Island., with no seagrass occurring along the main river channel (West *et. al.* 1985). Thus, mangroves form a very large part of the aquatic environment in the Hunter Estuary, and there is evidence that the size of this habitat is increasing (Williams *et al.* 2000).

Mangroves currently cover a total area of 17 km^2 within the Hunter Estuary and are most extensive in the North Arm and Fullerton Cove (Figure 1; West *et al.* 1985, Williams *et al.* 2000). Although substantial amounts of mangrove habitat have been destroyed for industrial and port developments, the overall extent of mangroves in the Hunter River has increased since 1954 (Williams *et al.* 2000). The steady increase in mangroves is correlated with a decrease in saltmarsh habitat and may be due to changes in tidal flushing (Williams *et al.* 2000). In 1985, saltmarsh communities in the Hunter estuary covered an area of 5 km^2 and were found on Kooragang Island between South and North Arm junctions and the South Arm Rail Bridge (West *et al.* 1985). The dominant species are *Sarcocornia quinqueflora* and *Sporobolus virginicus*. In a survey of the vegetation of Kooragang Island, Outhred and Buckney (1983) described the extent of mangroves and saltmarsh on the island and reported that no rare or endangered species were found. The Kooragang Wetland Rehabilitation Project was initiated in 1993 in recognition of the role played by estuarine wetland in supporting food chains, modifying hydrological events and maintaining water quality (Williams *et al.* 2000).

By far the largest unvegetated aquatic habitat in the Hunter estuary comprises the soft sediments, which include intertidal and large subtidal regions. Few studies have examined the fauna that live in soft sediments in the Hunter Estuary and those that have been done have focussed on the fauna of the intertidal mangrove habitats. Hutchings (1983) sampled the mudflats, saltmarshes and mangroves of Fullerton Cove and concluded that there were relatively few species, but that some were extremely abundant and speculated that this may be due to the large ranges in salinity. Hodda and Nicholas (1986) sampled nematodes in various soft sediment habitats in the Hunter estuary. They found a great diversity of nematodes in polluted regions of the South Arm relative to unpolluted areas (Hodda and Nicholas 1986).

2.2 Fish and Crustaceans

In the last sixteen years, there have been only three quantitative studies on fish and crustaceans in the lower reaches of the Hunter Estuary. Shepherd (1994) sampled fish in Ironbark Creek and Moscheto Creek, Williams *et al.* (1995) sampled various small channels on Kooragang Island and Gibbs *et al.* (1999) sampled several locations in the North Arm, South Arm and in Ironbark Creek using seine nets. The work of Gibbs *et al.* (1999) is the most comprehensive and most relevant to the proposed dredging project. Each location was sampled nine times between March 1996 and December 1997. The study provided a list of species found in the lower reaches of the Hunter and compared assemblages among the Hunter River and other NSW estuaries. They found that the fish and invertebrate assemblages in the Hunter River appeared similar to assemblages sampled in the Macleay, Nambucca, Wallamba and Manning Rivers. Importantly, great temporal variability in the numbers and types of species was identified. There was, however, a limited number of samples taken from the proposed dredging area.

As part of a study on bioaccumulation, The Ecology Lab sampled fish and crustaceans in the South Arm and had no difficultly catching a diverse range of species, including large numbers of prawns (The Ecology Lab, 1997, 1998). Although no quantitative data were collected, the study demonstrated that large numbers of fish and crustaceans occurred in the proposed dredging area. NSW Fisheries is currently surveying fish assemblages in estuary along the NSW coast (per. comm. Rob Williams).

There are no seagrasses in the main channels of the Hunter River, but *Ruppia* sp. has been found in small channels on Kooragang Island (West *et al.* 1985, SPCC 1986, Williams *et al.* 2000). It has been suggested that the more common species of seagrass (*Zostera* and *Posidonia*) have not been present in the Hunter for at least 30 years (Williams *et al.* 2000).

2.3 Sediment Contamination and Bioaccumulation

The lower Hunter supports one of Australia's most extensive industrial bases in addition to extensive urban and commercial areas and consequently many of the soft sediments are contaminated with pollutants. Birch *et al.* (1997) detected the greatest concentrations of heavy metals in Throsby Creek, followed by sections of Newcastle Harbour and the southern section of the South Channel. Levels of many metals exceeded the draft Commonwealth guidelines for contaminated sediments. Cursory studies indicated that levels of organochlorines and pesticides in Throsby Creek were quite high, whereas in the South Channel they were low. In areas of the Harbour that are dredged regularly, sediments were described as being homogeneous olive-grey muds with low levels of metal contamination. It was postulated that this pattern of contamination was due to the dredged areas being filled by relatively uncontaminated fine sediments that get flushed from upper reaches of the river. In areas that are not dredged, sediments are highly enriched in heavy metals and organic contaminants (Birch *et al.* 1997).

Trace metals, or heavy metals, and polycyclic aromatic hydrocarbons (PAHs) occur naturally in most environments, but above certain concentrations they will become deleterious to biota. Trace metals occur in low concentrations in seawater, but marine organisms accumulate them in soft tissues to concentrations well above ambient levels, a process termed bioaccumulation (Phillips 1977). Oysters, fish and crustaceans have been used in various studies of bioaccumulation (primarily of trace metals and organochlorines) in the Hunter River over the past decade. In 1992, concentrations of many trace metals and organochlorines in oysters collected from the South Arm of the Hunter River exceeded Commonwealth guidelines for seafood (EPA 1994). Copper and zinc were detected in particularly high concentrations. Levels of contaminants in fish did not generally exceed the health guidelines, although high levels of chlordane and deldrin were detected in some mullet and bream (EPA 1994).

Studies of concentrations of trace metals in oysters, fish and crustaceans in the South Arm of the Hunter River in 1997 and 1998 found elevated levels of lead in wild oysters on intertidal rocks adjacent to the BHP Steelworks (The Ecology Lab, 1997, 1998). At all sites, even those distant from the BHP Steelworks, concentrations of lead were above the health guidelines for seafood, indicating estuary-wide effects. High concentrations of copper and zinc were also detected in oysters; concentrations of copper were greatest downstream of BHP and levels of zinc were generally high at all sites. Concentrations of phenols were generally low at all sites. No prawns, crabs or fish sampled had unacceptable concentrations of contaminants.

Recent ecotoxicological tests of dredged sediment from Newcastle Harbour done by the CSIRO Centre for Advanced Analytical Chemistry (Simpson *et al.* 2001) detected elevated and toxic levels of polycyclic aromatic hydrocarbons (PAHs) and heavy metals from sediments from the dredge site in front of the BHP steelworks closure area. Total PAHs from the most contaminated sediments tested were lethal to both algae (*Entomoneis puntulata*) and amphipod (*Corophium* sp.) after a 24 hour and 10 day exposure, respectively (Simpson *et al.* 2001).

Although concentrations of heavy metals including acid-soluble zinc, lead, mercury and nickel in river sediments exceeded ANZECC (1998) guideline, their toxicity rating was low (Simpson *et al.* 2001).

2.4 Commercial Fishing Industry

The major commercial fishery in the Hunter is the estuary prawn trawl fishery. The total value of the Hunter River estuarine fishery in 1998-1999 was $750,000 (NSW Fisheries 2000). The total value of the prawn trawl fishery in 1997-1998 was $322,261 (NSW Fisheries 1999a). The Hunter River is one of only 4 estuaries in the state where trawling for prawns is permitted, the others being the Clarence, Hawkesbury, and Port Jackson. A fifth estuary, Botany Bay, was closed to all commercial fishing during 2002. Commercial prawn trawling is currently permitted throughout the South Arm of the Hunter River from October to May between 6 am and 6 pm, however these vary yearly depending on catch. The entire estuary is divided in to sections (of which the South Arm is the largest) and sections are open to trawling only if the prawns being caught are sufficiently large.

School prawns (*Metapenaeus macleayi*) make up the vast majority of landings by trawlers in the Hunter River (57,781 kg in 1997-1998), whereas the landings of eastern king prawns (*Peneaus plebejus*) are very small (2,447 kg in 1997-1998). The opposite pattern of catch occurs for Port Jackson and previously in Botany Bay, but it has been suggested that this reflects differences in fishing operations between the regions, rather than differences in species composition (NSW Fisheries 1999a). The prawn trawlers in the Hunter River operate during the day when school prawns are likely to be caught, whereas trawlers in Port Jackson and previously Botany Bay tend to operate during the evening.

The average landings of school prawns in the Hunter River have ranged between 40,000 and 70,000 kg per year over the last 15 years, but, in comparison to some other estuaries, these landings are relatively constant (NSW Fisheries 1999a). Landings of eastern king prawns have consistently been less than 4,000 kg per year. The trawling effort for prawns in the Hunter has been relatively stable over the last 15 years and the catch rates for school prawns and eastern king prawns have increased steadily over the last 10 years (NSW Fisheries 1999a). In contrast, catch rates in the Clarence River, Port Jackson and Botany Bay have been decreasing over this time (NSW Fisheries 1999a).

It has been demonstrated that increases in freshwater result in seasonal movements of school prawns (*Metapenaeus macleayi*) from the Hunter estuary to oceanic waters where they breed (Ruello 1973). The consequence of this is that, in the following year, the abundance of juvenile prawns will increase. Prolonged dry weather results in smaller prawn population. Juvenile prawns remain in the river during autumn-winter, then grow rapidly in spring (September). By October, the larger maturing individuals move downstream and out to sea to breed.

No trawling for finfish is permitted in the Hunter River, but all other forms of fishing such as mesh netting are important industries. The Hunter River finfish fishery is the 9th largest in NSW, supplying just over 140,000 kg of fish per year (NSW Fisheries 2000). Data from 1998- 1999 indicate that sea mullet are by far the most important contributors (by weight) to the Hunter River fishery (67,262 kg), followed by hairtail (16,090) river eels (15,131 kg), sand mullet (12,896 kg), bream (8,050 kg), dusky flathead (6,819 kg), fantail mullet (6,617 kg) and silver biddy (1,153 kg) (NSW Fisheries 2000).

The oyster industry in the Hunter River is no longer as profitable as it once was. Ruello (1976) provides an account of the changes to the industry during the 20th century. He explains that in the early 1900s, oysters were an important resource in the Newcastle region because they were collected for food (both manually and by dredging) and dead oyster shells were collected and burnt for their lime. During this time, the oyster industry thrived in the Hunter and leases existed in the north and south channels of the lower reaches. In 1914, more than 4% of the state's oysters were produced in the Hunter River (Ruello 1976). By the 1920s, however, the development of the harbour works had begun destroying several oyster leases and by the mid 1960s, commercial oyster production in the Hunter River ceased (Ruello 1976). It is unclear for how long commercial oyster production halted, but it has been a viable (but small) industry since 1980 (Terry Jones, President Oyster Farmers Association, pers. comm.). The Hunter River Sydney rock oyster industry was valued at $190,159 in 1999 - 2000 and was ranked 24th in the NSW (NSW Fisheries 2001).

Currently there are around 20 oyster leases in the Hunter River, all of which are located in the North Arm between Stockton Bridge and Fullerton Cove. These leases are grow out areas only; the spat are brought from Port Stephens. There is a ban on the collection of oysters (and mussels) from the South Arm due to the risk of contamination. Oysters settle and grow on rocky rubble, artificial seawalls and concrete and brick crane stands in the South Channel of the Hunter River. In general, the number of oysters in the Hunter River is unusually small for a NSW estuary and it has been suggested that this is a consequence of high siltation and turbidity in the Hunter combined with pollution (Ruello 1976).

2.5 Wading Birds

The wetlands in the Hunter estuary, and Kooragang Island in particular, are renowned as bird watching areas. It has been suggested that the mud flats around Kooragang Island and Fullerton Cove are important feeding and breeding grounds for resident and migratory wading birds (Maddock 1983).

CHAPTER 3. FIELD STUDIES

3.1. Survey of Mangrove Habitat

3.1.1 Introduction

Wetland habitats have high conservation value, due to their apparent importance for coastal fisheries (e.g. Bell *et al.*, 1984; Robertson & Duke; Morton, 1990) and usage by migratory birds (Adam, 1984). Human-induced alterations such as damage to vegetation, erosion, compaction of the sediment and changes to drainage patterns could modify the conservation value of wetlands. In light of the proposed dredging and removal of much of the wetland east of Tourle Street Bridge, it was decided to map the area of mangrove, assess its biodiversity and abundance of fauna and determine the extent of existing damage to the wetland. The mangrove forest at the proposed dredge site was compared to mangrove forests in other parts of the lower Hunter Estuary to distinguish any existing unique characteristics of the site and hence assess its conservation value. Mapping the existing area of wetland habitat provided information for addressing habitat compensation measures.

As part of the assessment of mangrove condition and conservation value, the abundance and distribution of animals living in soft-bottom sediment (benthos) of the mangrove forest east of Tourle Street Bridge were examined and compared to reference locations to provide an indicator of spatial variability. Benthos plays an important role in the bioturbation of sediments and recycling of nutrients (Morrisey, 1995). Many factors including variations in larvae, food or oxygen supply can alter the diversity and abundance of benthic organisms. Therefore, studying the benthic communities living in sediments of the mangrove forest provided an estimate of mangrove forest condition.

3.1.2 Sampling Sites and Methods

The methodology described is based on a procedure modified from Skilleter (1996). It involves a rapid assessment technique to examine physical damage in urban mangrove forests. Mangrove forests at three locations were selected within the Hunter Estuary (Figure 2). They included:

- The mangrove forest at the proposed dredging east of Tourle Street Bridge;
- The forest south of Ironbark Bridge (South Arm reference location); and
- The forest east of Hexham Bridge (North Arm reference location).

Reference locations provided an indication of the normal range of habitat and conditions in the Hunter estuary. The mangrove forest at the entrance to Fullerton Cove, near Sandy Island was dismissed as a potential reference location because the trees appeared devoid of leaves and the forest was severely damaged.

Locations were sampled at low tide from 18 - 20 September 2002. There had been heavy rain and strong winds for 2 days prior to the sampling and consequently the water was very turbid. At each location, damage to mangrove forests and habitat cover was estimated along six transects.

3.1.2.1 Estimating Damage

The sampling design for the estimate of damage and biota components consisted of three random locations spaced approximately 3 to 6 kilometres apart, three random sites nested at each location spaced 100 m apart and two random transects nested in each site spaced 10 m apart (Figure 3). The two replicate transects were marked with a measuring tape from the bottom of the shore, where the pneumatophores (i.e. peg roots) ended to the top of the mangrove forest or to a maximum distance of 150 m. Along each transect and within a 30 cm band on either side, the total length of each habitat was measured and the position of each of four categories of damage was recorded (Table 2). These categories were used to estimate the relative amount of existing damage and were independent of any measure of abundance or diversity of plants and animals (Skilleter 1996).

3.1.2.2 Habitat Component of Mangrove Forest

Along each transect, the total length of each of the following habitat components was measured by determining the habitat component at 1 m intervals:

- species of mangrove and their level of maturity (e.g. mature tree, juvenile tree or sapling);
- saltmarsh species;
- pneumatophores;
- algae;
- oysters; and
- combined leaf litter and mud criteria denoted as mud.

3.1.2.3 Fauna and Density of Habitat Components

The sampling design for this study consisted of the same locations, sites and transects used in the study of damage and habitat components with another level of spatial replication, that of quadrats. Along each nested transect, 4 randomly selected quadrats (0.1 m^2) were sampled (Figure 4). In each quadrat, the number of mangrove saplings, seeds, crab holes and pneumatophores were counted. The percent cover of leaf litter, algae, saltmarsh plants and trash was estimated by a point-intercept method (using 100 points per quadrat). All leaf litter and the upper half centimeter layer of sediment were spooned into a labelled plastic bag. In the laboratory, the contents of each bag were washed over a 1 mm sieve and any animals present were removed, identified and counted.

3.1.2.4 Analysis of Data

The statistical procedures used in the analysis are detailed in Appendix 1 and the experimental designs are shown in Figures 3 and 4.

Each category of damage was analysed using univariate nested analysis of variance procedures to distinguish significant differences in damage among locations, sites and transects. Prior to univariate analyses, data was tested for homogeneity of variance using Cochran's test and transformed were necessary. SNK tests where done on significant ANOVA results (Appendix 1). Differences in abundance or percent cover of habitat components measured in quadrats were examined using univariate nested ANOVA procedures. Multivariate procedures were used to examine habitat structure of mangrove forests by comparing percent cover data along transects at different locations and sites.

Multivariate procedures (ANOSIM) were also used to examine difference in the abundance of benthic taxa among locations and sites. Following analysis, habitat structure and benthos results were plotted using Multidimensional Scaling (MDS) to diagrammatically represent the similarities among every pair of samples. Taxa accounting for the most dissimilarity amongst locations were selected using SIMPER. The abundance of these taxa and species richness and abundance of crustaceans, molluscs and polychaete worms were selected for nested ANOVA analysis. These analyses examined differences in the abundance and number of taxa between transects, among sites and among locations to elicit small and larger scale variations.

3.1.3 Results

3.1.3.1 Description of Surveyed Wetlands

The wetland vegetation at the proposed dredge site east of Tourle Street Bridge was mapped on the aerial photograph of the South Arm (Figure 5), (refer to Appendix 2 for GPS coordinates). The wetland comprised a mangrove forest of approximately 800 m in length and ranging in width between 115 to 140 m. The area of mangrove forest was estimated at 9.7 ha, equivalent to 0.6% of existing mangrove habitat in the Hunter Estuary. The area of saltmarsh located between the mangrove forest and Tourle Street Bridge was estimated at 1.3 ha, representing 0.29% of existing saltmarsh habitat in the Hunter Estuary. A number of individual trees located east of the mangrove forest were not included in the mapping; neither were the Casuarina trees located near the EnergyAustralia windmill. The saltmarsh east of the bridge and behind the mangrove forest was dominated by dense patches of rushes (primarily the introduced species *Juncus acuta*) and tall grasses (Plate 1). Towards the edge of the road were invasive weeds such as bitou bush *Chrysanthemoides monilifera.*

The lower reaches of the South Arm of the Hunter River are developed and subject to a variety of human disturbances. The channel consists of fine soft sediments and is quite shallow along the northern edge in the proposed dredging site, but far deeper along the southern side. Much of the southern shoreline consists of artificial walls, whereas east of the mangroves forest, sandy intertidal areas, a few small mangrove plants, casuarina trees and artificial rock rubble dominate the northern shoreline (Figure 5). These habitats are very patchy and extend from the Energy Australia windmill downstream to the alumina berth and bulk terminal.

3.1.3.1.1 Tourle Street Bridge Dredge Location

During the survey, people were seen fishing from the sandy beaches on the Kooragang Island side of the South Arm. The habitat components consisted of a narrow and abrupt mud flat 0 to 2 m wide (Plate 2). This was followed by a dense mangrove forest of mature grey mangroves *(Avicennia marina)* (Plate 2) and occasional river mangroves (*Aegiceras corniculatum*). Between 70 and 90 m from the river was a section of saltmarsh comprising the samphire *Sarcocornia quinqueflora* and bushes of *Suaeda australis* (Plate 3). The forest ended with a dense cover of grey mangrove. The estuarine barnacle *Elminius covertus* occurred on the trunks of *A. marina* on the lower shore (Plate 3). The steep embankment was covered with *Sporobulus virginicus* grass, other unidentified grasses and occasional pig face, *Carpobrotus glaucescens* and samphire *S. quinqueflora*.

Oysters are possibly the most abundant epi-benthic animal along the northern shoreline, and in fact, along much of the South Arm of the Hunter River. They grow on the pneumatophores (together with epiphytic algae) and occur on most of the rocks in the intertidal region. Small gastropods (*Bembicium auratum*) and limpets (*Patelloida mimula*) were common amongst the oysters.

Seagulls were the most common seabirds and there were also a number of egrets foraging in the shallows of the mangroves. Pelicans and cormorants were also seen in the mangroves and along other parts of the northern shoreline.

3.1.3.1.2 South Arm Reference

Located upstream of Tourle Street Bridge on the south bank of the South Arm, adjacent to Newcastle General Cemetery, this mangrove forest is almost 300 m wide. At this point sampling occurred only from the river's edge back to 150 m into the forest. The mangrove forest adjoins a narrow and vertical embankment with no distinct mudflat. The forest is characterised by a continuous cover of mature *Avicennia marina*, occasional patches of dead branches and patches of juvenile *Avicennia marina*. A number of small tidal creeks meander through the forest (Plate 4). Juvenile *A. marina* became more common beyond 200 m. The mangrove forest ends with narrow a band of saltmarsh grasses.

3.1.3.1.3 North Arm Reference

The North Arm reference was located east of Hexham Bridge (Plate 5). The mangrove forest ranged in width from 80 to 140 m. A narrow mud flat approximately 2 m wide adjoined the forest. The mangrove forest was characterised by a continuous dense cover of mature *A. marina* with occasional trees of *Aegicera corniculatum*. The cover of *A. marina* saplings appeared thicker than at previous locations. Wetland grasses and a creek formed the landward boundary of the mangrove forest.

3.1.3.2 Mangrove Forest Biota and Damage

3.1.3.2.1 Estimating Damage

Damage was evident at all three locations (Table 3). The average cover of undamaged forest (Category D) was over 80% of transects at Tourle Street Bridge, and over 70% of transects at each reference location. Some proportions of transects were classified as slightly damaged (category C: <19%) and partially damaged (Category B: <10%). The few instances (<1%) where category A damage (complete damage) was recorded, were accounted for by metal scrapes and a car tyre.

ANOVA revealed significant differences among location in the extent of undamaged forest (Table 4). Student-Newman-Keuls (SNK) tests identified significantly more undamaged forest at Tourle Street Bridge compared with each reference locations. The extent of slight damage (Category C) did not differ significantly among sites or locations. The extent of partial damage (Category B) differed among locations, however SNK comparisons did not differentiate means (Table 4).

Most of the damage observed was from dead mangrove branches, logs and stumps. There were only occasional sightings of plastics, glass and metal scraps.

3.1.3.2.2 Habitat Components

The habitat components of the three mangrove forests, as determined by percent cover along transects, are summarised in Table 3. At all transects approximately 40% of the forest was covered with mud. Pneumatophores were the next most abundant cover accounting for between 22 and 27% of cover. *A. marina* saplings covered between 6 and 12% of transects, while *A. marina* trees covered between 7% and 13% of transects. Most of the other habitat components including algae covered less than 5% of transects.

ANOSIM detected significant differences among locations in the habitat components along transects (Table 5). Pairwise comparisons were unable identify any significant differences due to limited numbers of permutations. The relatively large R values produced by the pairwise tests of locations suggested that Tourle Street Bridge was separated from the reference locations (Clarke and Gorley, 2001). The results of the ANOSIM are well reflected in the nMDS (Figure 6). The dissimilarity of the locations was not strongly attributed to anything particular; rather the contribution of each habitat component was generally even (Table 3).

3.1.3.2.3 Habitat Densities

At the small scale of quadrats, most of the percent cover within quadrats was mud (49-91%), followed by smaller covers of leaf litter and algae (Table 6). The abundances of habitat components per 0.1 m^2 quadrat ranged as follows: crab holes (0 to 24), pneumatophores (12 to 89) and mangrove saplings (0 to 16).

ANOVA comparing factors for major habitat components (percent cover of leaf litter, mud, algae, and number of pneumatophores, saplings and crab holes) revealed significant differences among locations only for the abundance of saplings (Table 7). SNK comparisons detected significantly greater numbers of saplings at the North Arm Reference compared to the South Arm Reference and Tourle Street Bridge locations. There were significant small scale differences in the number of pneumatophores (Table 7).

3.1.3.3 Soft Sediment Benthos

Means and standard errors for each benthic taxa identified are presented in Appendix 4. A total of 39 taxa from 6 phyla were identified (Appendix 5). The most abundant taxa was the gastropod *Tatea* spp. accounting for more than 50% of individuals collected at each location (Appendix 7; Table 8). Taxa accounting for the most dissimilarity between locations are presented in Table 9. Other abundant taxa included polychaete worms from the families Capitellidae and Nereididae, oligochaete worms, Hyalidae amphipods, the gastropod *Salinator solida* and insect larvae. The total abundance of benthos was 8,800 individuals at the North Arm Reference compared to 3,400 and 3,200 individuals at Tourle Street Bridge and the South Arm Reference, respectively.

3.1.3.3.1 Analysis of Assemblages

The one-way ANOSIM comparing locations revealed that benthic assemblages did not differ significantly between Tourle Street Bridge and each reference location, while some difference was detected between reference locations (Table 9). Two-dimensional representation of the relationship between all 72 samples is shown in Figure 6. The plot indicates that samples from the same location do not group together. Hence, locations do not differ significantly.

3.1.3.3.2 Analysis of Populations

Locations differed significantly in their total abundance, number of polychaete taxa, molluscs taxa, crustacean taxa, total abundance of polychaetes and molluscs, abundance of *Tatea* gastropods, nereididae polychaetes and insect larvae (Table 8). The North Arm Reference had significantly greater total abundance, abundance of molluscs, abundance of *Tatea* and numbers of polychaete taxa and mollusc taxa than other locations sampled. Tourle Street Bridge had significantly fewer polychaetes and significantly more of crustacean taxa than other locations sampled (Table 11). Significant small-scale variation was detected in the crustacean abundance among sites at Tourle Street and South Arm reference locations. The abundance of Hyalid sp. 1 (an amphipod) varied significantly among sites at the North Arm reference location (Table 11).

3.1.4 Discussion

3.1.4.1 Mangrove Condition

The three mangrove forests sampled in the lower Hunter River showed some degree of damage with mangroves forests at Tourle Street Bridge having the least damage. It was difficult to distinguish natural from anthropogenic types of damage because much of the damage was composed of branches and logs and only occasional rubbish. Branches fall during natural forest processes or from dieback due to anthropogenic disturbances. Strong winds on days previous to sampling would have caused a large number of dead branches to fall onto the forest floor. No damage to pneumatophores, saplings or mangrove trees was apparent, except at the South Arm Reference where compacted sediments along the foreshore suggested trampling caused the disturbance. Mats of algae found amongst pneumatophores, and algal assemblages attached to them are typical of mangrove forests, and could represent an important source of nitrogen for the ecosystem (King *et al.* 1990). The Tourle Street Bridge location was further downstream compared to the two reference locations and possibly subject to different tidal conditions. Differences in levels of physical damage amongst mangroves most probably reflects the range of conditions existing in the Hunter River.

3.1.4.2 Mangrove Habitat

There were a significantly more saplings and more river mangroves at the North Arm Reference, which is situated furthest upstream compared to other locations.

Minchinton (2001) found that mangrove saplings in NSW are more abundant on mounds in gaps in the canopy, while the distribution of seedlings (the early stages of life history) is driven by habitat structure. Long-term survival of seedlings and their development into saplings may depend both on light availability in gaps and on sediment disturbance resulting from the creation of mounds. The causative agent, crabs, may therefore be critical for regeneration of mangrove forests (Minchinton 2001).

Further studies are required to examine the processes influencing the distribution of mangrove habitat components. All three locations were likely representative of the natural range of habitat condition existing in the Hunter River, and no specific habitat characteristics of Tourle Street Bridge location distinguished it as more unique from the other locations.

3.1.4.3 Mangrove Benthos

The benthic fauna sampled at Tourle Street Bridge and reference locations were typical of taxa collected previously in Fullerton Cove (Hutching 1983) and other nearby estuaries (Hutching *et al.* 1977). Variation in the diversity and abundance of benthic macroinvertebrates collected in the present study were detected over several spatial scales. Benthic taxa at Tourle Street Bridge accounted for only 3 of the significant differences among locations. The greater crustacean diversity at Tourle Street Bridge could be due to the likely higher salinity at this location compared to the reference locations situated further upstream. Three species of crabs are commonly found in mangrove forests of southern Australia (Chapman and Underwood 1995). Two of these common species were collected in the present study including the purple shore crab *Paragrapsus laevis.* This species is very common especially in the mid to seaward area of mangrove forests, however it moves around extensively. The red-clawed crab *Sesarma erythrodactyla* is a wide ranging scavenger that feeds on the algae growing on pneumatophores (Chapman and Underwood 1995).

The presence of the barnacle *Elminius covertus* on the bark of *Avicenna marina* at Tourle Street Bridge indicated that the forest receives adequate tidal flushing and hence recruitment of larvae. The cyprids (barnacle larvae) recruit during high tides and mostly at night (Ross 2001). The significantly greater abundance of polychaetes, molluscs, *Tatea* spp. and insect larvae at the North Arm reference location could be related to the habitat structure at this location. For example, algae and pneumatophores are important resources for the gastropod *Ophicardelus* (Kaly 1988). Another study found littorinid snails and *Bembicium auratum* were more abundant on the Sydney rock oyster *Saccostrea commercialis,* than other substrata (pneumatophores, mud and on the trunks of trees) (Underwood & Barrett, 1990). Similar relationships between the gastropod *Tatea* spp. and structural components of the mangrove forest could exist, however, few studies have been done in this area. It is likely that differences in salinity or tidal flow would influence species richness and their abundance. The disturbed nature of the lower Hunter River could also affect species diversity.

The present study found 39 benthic taxa in the Hunter River while 51 taxa were found in similar mangrove forests of the Hawkesbury River (Lasiak and Underwood 2002) and 26 taxa were found in Fullerton Cove mangroves (Hutchings 1983). Unfortunately, each study used different sized sieves; hence differences in the number of taxa could be due to more animals being retained in smaller sieves. Specific locational characteristics could also influence the number of taxa. Without replication through time, temporal variations in abundance and diversity cannot be understood. Hence, the effects of anthropogenic disturbances cannot be distinguished from natural variation. Hutching (1983) found the abundance of *Tatea, Ophicardelus* and *Paragrapsus laevis* in Fullerton Cove decreased significantly between 1976 and 1977 but could not explain why. Further sampling would be necessary to examine what factors determine the observed abundance and diversity of taxa in mangrove forest of the Hunter River.

Although some benthic taxa differed significantly between locations, total species richness (total number of taxa) and benthic assemblages (refer to multivariate results) did not differ. Hence, the benthos at the Tourle Street Bridge location is not unique and is similar to that found in other mangrove forests of the lower Hunter River.

3.2 Demersal Fish and Mobile Invertebrate Survey

3.2.1 Introduction

Previous studies have found that fish from the Hunter River appeared similar to assemblages found in other NSW estuaries (Gibbs *et al.*, 1999). However it is not known if bottom dwelling (demersal) fish are similar at different depths. The proposed dredging works would significantly deepen the South Arm channel. The aim of the fish survey was to determine if demersal fish and mobile invertebrates at the proposed dredge site of the Hunter River were similar to those at other locations in the South Arm and North Arm including deeper waters of the estuary.

3.2.2 Sampling Sites and Methods

Demersal fish and invertebrates were sampled by trawling in subtidal areas of the Hunter River estuary using the 28-foot prawn-trawling vessel, "*Megan*".

Trawling was done at two sites within the South Arm, representing the proposed dredge area, two sites within the North Arm representing shallow water subtidal habitat (1-4 m) and two sites (one each in both the South Arm and North Arm) representing deeper water subtidal habitat (9-16 m) (Figure 2).

Four replicate 5-minute trawls were done at each site. Care was taken that each replicate trawl did not considerably overlap another replicate. The trawl net, consisting of an 11 m headline, mesh size of 41 mm and a cod-end, was towed by boat over a distance of approximately 700 m at an average boat speed of 3 - 4 knots (Plate 6). Depth, time and GPS co-ordinates were recorded at the start and end of each trawl (Appendix 6). Sampling was conducted on the 29 and 30 October 2002 during the day.

All fish and invertebrates collected were counted and identified to species where possible. Fork length of economically important fishes was also recorded. Care was taken to minimise damage to biota, and all fish and invertebrates were returned to the water after identification.

To ensure the water quality was similar at each site, temperature (°C), turbidity (ntu), dissolved oxygen (mg/L and % saturation), pH and salinity (ppt) were recorded at both the surface and bottom using a Yeokal 611 water quality probe (Appendix 7).

3.2.3 Analysis of Data

In terms of the design used to analyse demersal fish and invertebrate data, sites were grouped into habitat categories (Figure 9). Category was a fixed orthogonal factor with three levels (proposed dredge area, North Arm shallow water and deep water). Site was a random factor nested within category, with two sites representing each category. There were four replicate trawls taken per site.

Data were analysed using both univariate and multivariate techniques. ANOSIM was used to test for differences in demersal fish and invertebrate assemblages among categories and sites within categories, and a two dimensional nMDS plot was constructed to graphically represent these differences. The SIMPER procedure was used to determine the taxa that contributed most to any differences among categories. A nested ANOVA was used to test for differences in total abundance, number of taxa and the abundance of selected taxa among categories and sites within categories. Results from SIMPER were used to determine the individual taxa that were analysed by ANOVA. The five species that contributed most to differences between at least two categories were used.

3.2.4 Results

Due to large amounts of green weed present at the Tourle Street Bridge site within the proposed dredge area (Plate 6), two replicate trawls were aborted approximately half way through each trawl. However, three replicate trawls were successfully completed at this site. The data from the two aborted replicates were combined to provide the fourth replicate.

Multivariate analyses were originally performed on all data obtained. However, a nMDS plot revealed that the 3rd replicate from the Tourle Street Bridge site differed greatly from all other replicates, due to the capture of a single sea hare (*Aplysia* sp.) which was not caught in any other replicate. This resulted in a highly distorted nMDS plot, making any patterns that may have occurred impossible to differentiate. Therefore, data from this replicate was not used and multivariate analyses redone on the revised data set. When performing univariate analyses, however, the entire data set was used to maintain a balanced sampling design.

3.2.4.1 Analysis of Assemblages

A total of 24 trawls were taken throughout the Hunter River estuary. In total, 342 fish and invertebrates were collected, composing 26 species (22 and 4 species of fish and invertebrates, respectively). Twenty-one species were considered of economic importance, with 9 of these being caught at the proposed dredge area. No threatened or endangered species were caught at any site throughout the study period. The most abundant species were yellowfin bream (*Acanthopagrus australis*, 35% of total abundance), luminous bay squid (*Loliolus noctiluca*, 20%), school prawn (*Metapenaeus macleayi*, 13%), mulloway (*Argyrosomus japonicus*, 6%), tarwhine (*Rhabdosargus sarba*, 5%), sandy sprat (*Hyperlophus vittatus*, 4%) and silver biddy (*Gerres subfasciatus*, 3%). Captures were generally considered small, due to relatively clear water following an extended dry period (Rob Hyde, pers. comm.) (Plate 7).

The assemblages of demersal fish and invertebrates appeared to differ to varying degrees among some categories. ANOSIM results (Table 12) and the nMDS plot (Figure 10) showed the assemblages within the North Arm shallow water category were different from those of the other categories. Also, there was greater variability in assemblages within the proposed dredge area compared with those of the other two categories (Figure 10).

SIMPER analysis indicated that yellowfin bream, tarwhine, mulloway, silver biddy, sandy sprat, school prawn and luminous bay squid were the species that contributed most to differences among categories (Table 13).

3.2.4.2 Analysis of Populations

The abundance of mulloway was significantly greater in the deep water category (Table 14; Figure 11). Although the variances for this taxon could not be stabilised with a suitable transformation, the abundance of this species was still found to be significant at the reduced α level of 0.01. All mulloway caught were classified as small juveniles (Table 15).

The abundance of yellowfin bream, silver biddy, school prawns and luminous bay squid were not significantly different among categories, however, there were significantly more of these species caught at particular sites within categories compared with others (Table 14; Figure 12).

The abundance of yellowfin bream was highest at the shallow water site located upstream of the Stockton Bridge (Table 14; Figure 12). All but one yellowfin bream caught at this site were regarded as juveniles (Table 15). Most fish of this species caught in the proposed dredge area were considered small juveniles (Table 15).

The windmill site at the proposed dredge area had the highest abundance of silver biddy, however, this species was absent from both deep water sites (Table 14; Figure 12). All silver biddy caught were classified as either large juveniles or adults (Table 15).

The abundance of school prawns and luminous bay squid were greatest at the South Arm deep site and the North Arm deep site, respectively (Table 14; Figure 12). No data on lengths of these species were obtained.

ANOVA results showed the deep water category had significantly more taxa than the other habitat categories. (Table 14; Figure 11).

3.2.5 Discussion

Demersal fish and invertebrate assemblages showed differences among some habitat categories. Assemblages in both the deep water sites appeared different from those in other sites. Species such as mulloway, school prawns and luminous bay squid were characteristic of the deep water sites, whereas yellowfin bream, tarwhine and silver biddy were more common in shallow water. This suggests that depth is an important factor in structuring the types of species found within these areas. The greater species diversity observed in the deep water category could be due to less variability in water conditions, such as temperature and salinity, compared to those of shallow waters. Although there are negligible, projected changes to water flow or morphological characteristics of the South Arm (Patterson Britton and Partners 2003), depth is expected to increase from the current 2-3 m to 15 m, which will affect the type of fishes inhabiting this area.

Assemblages caught in the proposed dredge area were highly variable compared to those of other sites. Although the lower South Arm of the Hunter River is highly modified and disturbed, it is thought that this variability is due to large amounts of green weed present at the Tourle Street Bridge site in the proposed dredge area, possibly limiting the effectiveness of the sampling method and/or the occurrence of species during the survey. Therefore, it is difficult to draw definite conclusions on patterns occurring in this area from one sampling occasion.

CHAPTER 4. ASSESSMENT OF IMPACTS

4.1 Brief Description of The Proposal

This description is based on documentation provided to The Ecology Lab by GHD on 27/3/2003.

Newcastle Harbour is a large industrial port. Recently a number of industries have shown interest in having more port facilities and greater access to deepwater berths. The Hunter River South Arm has been identified as the most suitable location for port expansion. Future development of the port facilities will be dependant upon the provision of a dredged navigation channel, swinging basin and berthing trenches designed to accommodate Panamax and Cape Class vessels.

The proposal to create a navigation channel and swinging basin would involve three main work elements:

- Dredging and excavation;
- Treatment of contaminated sediments; and
- Disposal of materials.

At present the bed of the South Arm immediately east of Tourle Street Bridge comprises a shallow sedimentary channel. Significant dredging will be required to increase existing depth from approximately 1 - 3 m to the expected 15.2 m according to the chart datum. Approximately 11.35 million cubic metres of material would be dredged and excavated. The materials to be dredged from the bed and bank of the South Arm range from soft silty clays near the surface (21%), followed by sands (50%), stiff clay (10.6%), and rock near the bottom (16.7%) and fill (1.3%). Activities involved in the process may include the following:

- Establishment of dredging equipment on site and installation of sediment containment measures include sheet pile wall around the contaminated area and silt screen around other sections of the dredge site.
- Dredging and extraction of South Arm sediments and banks requires earthmoving equipment followed by river based dredging. Clean sand would be removed and pumped onshore using a cutter suction dredger; Grab and backhoe dredger would be used to break up hard clays, rock and rock like material. Some blasting of rock may also b required.
- Dredge materials would be temporarily stockpiled. Clean sands would be transported along the proposed transport corridor to Tomago Industrial estate for processing. Uncontaminated materials that cannot be beneficially reused such as fine river bed sediments, clays, soft rock and hard rock would be disposed of at sea.
- An estimated 250,000 m^3 of soft sediment located immediately adjacent to the BHP site is contaminated and requires remediation on land prior to disposal. Contaminants present in sediments include polycyclic aromatic hydrocarbons, total petroleum hydrocarbons and heavy metals. These sediments would be remediated on the BHP closure site using cement stabilisation, thermal desorption technology, or appropriate equivalent approved by NSW EPA.

- Bank stabilisation of riverbeds in the vicinity of the dredge site.
- The appropriate management of all dredge waters returning the Hunter River to an acceptable level of quality.
- The disposal of the remaining sediments to an approved offshore dump ground. The permitting of the offshore component of the work is being processed under a separate application to Environment Australia.

4.2 Relevant Issues

The assessment of environmental impacts for the proposed dredging of the South Arm of the Hunter River considers issues described under the various acts and policies of NSW State legislation. Matters relating to impacts of the proposal on both the built environment, and social, heritage and economic values of the locality would be assessed by other specialists, as would matters relating to air, noise and water pollution, sediment toxicity and terrestrial ecology. Here, assessment of impacts pertain to issues of aquatic biology and ecology, including the direct removal of vegetation and river sediment from dredging the South Arm, and the indirect impacts of environmental disturbance on the aquatic biology and ecology of the lower Hunter River. Table 1 summarises the matters of significance for the assessment of aquatic ecology impacts of the proposal as detailed in NSW State environmental legislation. These include issues raised in the Director General's requirements for the proposed dredging and issues relevant under the NSW Fisheries Management Act 1994 and NSW Fisheries policies for Aquatic Habitat Management and Fish Conservation (NSW Fisheries 1999b).

The proposed works could have a number of long term and short term effect on the aquatic ecology of the Hunter Estuary. These are summarised below:

- Loss of mangroves and replacement with wharf structure: Hard surfaces provides habitat for invertebrate communities different to those found in soft-sediments.
- Loss of shallow subtidal habitat and creation of deep subtidal habitat: Research on benthic communities in areas dredged for the third runway in Botany Bay found recolonisation of dredged sites occurred within months. Recovery, defined as restoration to natural levels of variation in faunal assemblages took around two years (Wilson 1998).
- Changes to fish passage and connectivity: Local increases in flow velocity by a factor of 1.5 caused by the sheet pile wall (Patterson Britton and Partners 2003) and a turbidity gradient formed by sediments suspended in the waterway during dredging could temporarily inhibit fish. The proposed increase in depth of the channel would affect the type of fishes inhabiting this area;
- Effects of rock blasting on fish: Sound waves created during rock blasting can affect the swim bladder of fish and cause fish mortality and/or avoidance depending on the intensity and distance of the blasting.
- Potential changes in the existing hydrodynamics and salinity structure of the estuary: Any upstream movement of the salt wedge could affect the extent and types of wetland vegetation in the estuary. The length and duration of flooding in the vicinity of Kooragang Wetlands and Hexham swamps could also be affected.

Modelling of water levels in the South Arm following dredging indicated negligible change (Patterson Britton and Partners 2003).

- The displacement of water by the bow waves of vessels could cause erosion to the river banks, wetlands and riparian vegetation.
- Impacts oyster cultivation: No oyster cultivation occurs in the South Arm and the proposed dredging is unlikely to affect commercial oyster leases in the North Arm.
- Effects on commercial and recreational fishing: The South Arm is one of seven areas used regularly by prawn trawlers. Sediments resuspended during dredging and loss of habitat could affect fish and prawns feeding in the dredge area. Dredging will take between 12 and 24 months therefore it is not possible to restrict dredging to the winter months when prawns are least abundant and the trawling season is closed. Therefore, there would be some short-term inconvenience to fishes.
- Effects of dredging on sediment toxicity: High levels of PAH and heavy metals were found in sediments at the proposed dredge site. Dredged sediments have lower levels of contaminants compared to undredged sediments. Hence it can be expected after dredging is completed, that the river bed sediments may be less polluted.
- Effects of the oyster industry: PAH have been found to bioaccumulate in wild oysters at the disused BHP site.
- Effects of dredging on water quality (turbidity, DO): A turbidity gradient formed from sediment suspension in waterway could inhibit fish passage. Reduced dissolved oxygen concentrations in deeper waters could affect organisms.
- Transport and deposition of dredge sediments: Modelling shows that muddy sediments will deposit along fringing mangroves upstream as far as Ironbark Creek (Patterson and Britton 2003).
- Effect of land disposal on the leaching of PAH, heavy metals and acid sulphates: Land disposal and the treatment of contaminated sediments can result in the seepage of contaminants into the environment during dewatering operation. Remediation measures include the use of geotextile bags and treatment of return waters to EPA acceptable levels.

Each issue above is discussed in detail in the following section.

4.3. Assessment of Impacts

4.3.1 Aquatic Habitats

The major aquatic habitats in the South Arm of the Hunter Estuary are the shallow river bed, the water column, artificial hard surfaces and the intertidal mangrove and saltmarshes. Less common habitats include muddy shores and sand flats. No seagrass occurs in the main channel (Williams *et al.* 2000). Habitats to be removed during proposed dredging works include the foreshore of mangroves, saltmarsh, sand flats and the shallow subtidal river bed. The removal of mangroves will require a permit in accordance with S205 of the Fisheries Management Act 94. There could be short term and long term effects of the proposed dredging on the water column environment and existing hard surfaces. After the completion of proposed works, there will be an increase in deep subtidal habitat and artificial hard surfaces. The major changes to aquatic habitats and their associated fauna are discussed further below.

4.3.1.1 Mangroves

Mangrove habitat is the most dominant aquatic vegetation of the Hunter Estuary (Chapter 2). The loss of mangrove habitat at the proposed dredge location was estimated at 9.7 ha. This represents 0.6% of the existing mangrove habitat of the Hunter Estuary. Hence this loss of wetland is unlikely to have a significant ecological impact on the Hunter Estuary system.

The intertidal mangrove habitats on Kooragang Island are also vulnerable to disturbance from dredging. These habitats may be impacted by the transport from the dredge site and deposition of a predicted 3 to 4 cm of sediments along fringing mangroves upstream to Ironbark Creek (Patterson Britton and Partners 2003). Altered patterns of water flow could lead to erosion of muds and sands. While mangroves flourish on sedimentary shorelines, excessive input of sediment to mangroves can cause death of trees owing to root smothering (Ellison 1999). Short-term natural sedimentation rates of up to 1 cm per year have been found along the east coast of Australia (Ellison 1999).

Under the Fisheries Management Act, a permit is required if any loss or damage to mangroves is likely to occur, as these habitats are considered to have great ecological importance (NSW Fisheries 1999b). Muddy sediments suspended during the dredging process could be transported as far upstream as Ironbark Creek and deposit on mangroves smothering the small peg roots (pneumatophores) (Patterson Britton and Partners 2003). The use of best practice dredging methods including the use of sheet pile wall and silt curtains whilst dredging would be implemented to minimise impacts.

4.3.1 2 Subtidal Sediments

The proposed works would result in the loss of shallow subtidal habitat and the creation of deep subtidal habitat. The sediments are likely to be contaminated by various industrial pollutants but nevertheless they support a variety of benthic invertebrates and fish. Dredging of this habitat would cause complete removal of the existing channel bed, removal of bottom-dwelling fauna and would create a turbid sediment plume. A permit for the dredging would be required from NSW Fisheries (NSW Fisheries, 1999). It is likely that benthic organisms have already been disturbed by activities such as previous dredging further downstream and contaminated sediments from industrial sources. No studies have, however, sampled benthic invertebrates in the South Arm, so it is not known what species occur there, or whether they may have been impacted by past disturbances. Nevertheless, there is little doubt that dredging would initially affect or destroy them in the dredged area. Once an area has been dredged, benthic macroinvertebrates would recolonise the area. Studies of invertebrates in dredged areas indicate that the assemblages may change greatly after being dredged (Kaplan *et al.* 1975, Jones 1986, De Grave and Whitaker 1999). Research on benthic communities in areas dredged for the third runway in Botany Bay found recolonisation of dredged sites occurred within months. However, recovery, defined as restoration to natural levels of variation in faunal assemblages, took at least two years (Wilson 1998). Other studies suggested that recovery may start after just a couple of months (Jones 1986), whilst another has detected no recovery after 11 months (Kaplan *et al.* 1975). It is important to understand, however, that the dredged area will be deeper than was initially and consequently any assemblages of animals that colonize the dredged areas are likely to be different from those that existed in shallower areas prior to dredging. Moreover the types of benthos and rate of recolonisation will often depend on the source of the benthos. The dominant fish species presently found along the shallow river bed will likely change after dredging. In this study (Chapter 3) yellowfin bream, silver biddy and tarwhine were most abundant in shallow waters while mulloway, luminous bay squid and school prawns were most abundant in deeper waters of the Hunter Estuary.

4.3.1.3 Saltmarsh

The small area of saltmarsh occurring behind the mangrove forest west of Tourle Street Bridge would be affected by large-scale dredging, although it is not clear how much of this habitat would be removed. Although saltmarshes occur relatively high on the shore, they may be affected by altered patterns of water flow and by the removal of mangroves which form a buffer between saltmarsh and the South Arm. Large areas of saltmarshes have been lost from the Hunter River over the past 50 years and various government organisations (e.g. National Parks and NSW Fisheries) are implementing strategies to halt their disappearance. Impacts to saltmarsh from changes in hydrology are likely to be minimal as the final dredging profile does little to alter the tidal hydrodynamics of the Hunter estuary (Patterson Britton and Partners 2003). Although sediment could deposit along the foreshore upstream up to Ironbark Creek, this is unlikely to affect saltmarsh habitat generally located above mangroves.

4.3.1.4 Hard Artificial Surfaces

Hard artificial surfaces provide habitat for invertebrate communities different to those found in soft-sediments. Encrusting animals such as oysters and barnacles dominate hard surfaces while benthic infauna (e.g. polychaete worms, amphipods) dominates soft sediments (refer to Chapter 3). The loss of mangroves and replacement with hard structures would result in a different assemblage of organisms colonising theses surfaces. Little information exists on the rate of colonisation of bare hard surfaces, however its extent and timing would depend on the recruitment of larvae from the water column. Increased turbidity of the water column during dredging could result in a short term loss of organisms on existing hard surfaces. However, given that biota within the Hunter River are subjected to large scale natural disturbances due to flooding, impacts here are expected to be within the range of natural variability.

4.3.1.5 Water Column

Disturbances to the water column during dredging could include increased turbidity, noise and blasting sock waves. The abundance of fish and crustaceans living in the water column may be affected by dredging works. In general, increases in turbidity may affect the foraging behaviour of fish and suspended sediments may abrade the protective mucus coats on fish, thereby increasing their susceptibility to disease, or clog gill filaments and suffocate the fish (Johnstone 1981). Proposed dredging methods including the cutter suction and grab would generate noise during operation and this could disorientate fish. Shock waves generated during rock blasting could kill fish depending on the distance and intensity of the blast.

Although there are no projected long term changes to water flow or morphological characteristics of the South Arm (Patterson Britton and Partners 2003), depth is expected to increase from the current 1-3 m to 15.4 m, which will affect the type of fishes inhabiting this area (Chapter 3). A turbidity gradient formed from sediment suspension in the waterway could inhibit fish passage, although given that large-scale flood events occur in the Hunter, such effects are predicted to be minor. The use of a sheet pile wall to contain resuspended contaminated sediments during dredging could increase local flow velocities by a factor of about 1.5 (Patterson Britton and Partners 2003). Moreover this is unlikely to be a significant issue as it would be a temporary impediment and there exist an alternative passage through the north arm.

4.3.2 Fishing Industry

The proposed dredging may have impacts on the prawn trawling industry as the South Arm is one of the seven areas used regularly by trawlers. Prawns are bottom dwelling animals and so may be directly influenced by the dredging. Animals may be removed and their habitat will certainly be disturbed greatly in the dredged area. Moreover, prawns are benthic feeders and so could potentially accumulate any contaminants that are mobilized by the dredging process. Juvenile prawns enter the Hunter River and travel upstream to the less saline regions between December and April. They remain upstream until September when they start to move into the main channels of the river (Ruello 1973) and the prawn trawling season opens from October-December to May, however this varies yearly depending on catches (per. comm. NSW Fisheries). Given the scale of the project, however, dredging may be required year round, in which case there will certainly be impacts on the prawn trawling industry. School prawns were caught along the proposed dredge site (Chapter 3). The development of an environmental management plan in collaboration with the prawn trawlers to minimise affects to the industry could be considered.

Given that all the commercial oyster leases in the Hunter are in the North Arm, between Stockton Bridge and Fullerton Cove, is probably unlikely that the dredging activities would directly affect this industry. Modelling of sediment transport from the proposed dredge area indicates no transport of sediments into the north arm of the Hunter River. Most sediment deposits will occur within the dredge area and upstream along the foreshore to Ironbark Creek (Patterson Britton and Partners 2003). The collection of oysters from the South Arm is currently banned and so any risks of humans eating potentially contaminated oysters should be minimal.

No trawling for finfish is permitted in the Hunter River, but all other forms of fishing such as mesh netting are important industries and are permitted all year round. Little information exists on the fish of the South Arm, particularly concerning temporal variability in abundances. Thus, it is difficult to predict the possible effects or suggest when dredging could be done to minimise any potential impacts on this industry. Ruello (1976) suggested that dredging "...destroys or damages many benthic organisms..." and the discoloured or contaminated water that results from dredging "...frequently drives fish and prawns away from the area and commonly imparts an unpleasant taste to cooked crustaceans and fishes...and... may stop the influx of young or adult fish to the estuary." Therefore, there are likely to be impacts on commercial and recreational fishing in the South Arm during dredging.

4.3.3 Impacts of Rock Blasting on Fish

Sound waves created during rock blasting can affect the swim bladder of fish depending on the intensity of the blasting. Blasting shock wave can cause fish mortality. The size of the charge and distance from detonation are the two most important factors in determining fish mortality. Depth of water, type of substratum, and the size and species of fish present also affect the number of fish killed by underwater explosions. Specific data exist on the effects of distance and charge size on fish mortality rates in the United States for US fish species. This issue needs to be considered in an Environmental Management Plan for the project and addressed in detail at the design stage.

4.3.4 Water Quality and Sediment Toxicity

Dredging would re-suspend sediments and increase the turbidity of the water in the South Arm. Although this may not occur for long periods of time, there may still be short-term effects of increased turbidity on aquatic biota. The Hunter River is typically very turbid and it has been suggested that the small number of oysters in the river is a consequence of this (Ruello 1976). Thus, increased turbidity during dredging may have adverse effects on oysters. In particular, it is important to consider the potential for contaminants in the sediments to be accumulated by oysters and other marine invertebrates. The Ecology Lab (1999) has investigated the potential bioaccumulation of contaminants by oysters during a dredging operation in Newcastle Harbour and found that, although contaminants were accumulated by oysters in dredged areas and reference areas, there was no evidence that dredging significantly increased the bioaccumulation of contaminants. Recent ecotoxicological tests of dredged sediment from Newcastle Harbour done by the CSIRO Centre for Advanced Analytical Chemistry (Simpson *et al.* 2001) detected elevated and toxic levels of polycyclic aromatic hydrocarbons (PAHs) from sediments from the dredge site. Seepage of these chemicals back into the water could have effects on aquatic biology, hence would need to be carefully managed. It is proposed that sediments be remediated on the BHP closure site using cement stabilisation and thermal desorption technology, or appropriate equivalent approved by NSW EPA.

Although concentrations of heavy metals including acid-soluble zinc, lead, mercury and nickel in river sediments exceeded ANZECC (1998) guideline, their toxicity rating was low (Simpson *et al.* 2001). A previous study found consistently higher levels of PAHs bioaccumulated in oysters sampled adjacent to the BHP site compared to sites downstream (The Ecology Lab 1998). During the same study, PAHs were not detected in fish and crustacean. Fish and crustaceans are mobile animals hence their time of exposure to contaminants is likely less than oysters located adjacent to the BHP site. Re-suspension of contaminant in the water column during dredging could increase their level of toxicity to organisms living in the water column.

4.4 Possible Effects of Spoil Disposal

4.4.1 Offshore Spoil Disposal

Assessment of offshore disposal is not part of the scope-of-works for this study, however it is noted that any proposal to dispose of dredge material at sea would need to apply for a permit under the Environment Protection (Sea Dumping) Act 1981. The National Ocean

Disposal Guidelines for dredge material (2002) describe in detail the procedures which are to be followed in sampling, testing and assessing the suitability of material to be disposed at sea and evaluating and monitoring of disposal sites.

4.4.2 Land Disposal

It is proposed that some dredged sediments be remediated on the former BHP steelworks site located on the south bank of the South Arm and buried on site as part of the overall closure plan. The disused BHP site is an industrial estate with little natural vegetation. High levels of PAH and heavy metals were measured in sediments at the dredge site (Simpson *et al.* 2001). Possible impacts of spoil burial on land can include the seepage of heavy metal, PAH and acid sulphate leachates into the Hunter River. It is proposed that all return waters will be treated to acceptable standards and licenced by the EPA.

4.5 Threatened Species Assessment

4.5.1 Introduction

There are provisions in both State and Commonwealth legislation to ensure that Threatened species, populations and communities and threatening processes are considered in relation to proposed developments. Threatened species legislation examined included the Environment Protection and Biodiversity Conservation Act 1999, Threatened Species Conservation Act 1995 and the Fisheries Management Act 1994. Threatened species, populations, ecological communities and threatening processes listed in the legislation likely to occur in the lower Hunter Estuary were described. Where appropriate, 8-part tests were done and recommendations made regarding the need for any Species Impact Statements (SISs) or further specific management action. Impacts were assessed and recommendations made to minimise or avoid, where possible all negative effects.

4.5.2 General Assessment

Many of the animals listed in threatened species legislation are unlikely to occur in the Hunter Estuary, while listed species inhabiting freshwater are not relevant to the project. Marine mammals such the blue whale, sperm whale, Sei whale, fin whale, Australian fur seal and long-snouted spinner dolphin tend to occur in coastal or oceanic waters and rarely enter estuaries hence will not be affected by the proposed dredging works in the Hunter Estuary. Threatened species such as the green turtle, the eastern blue devil and the giant Queensland grouper do not occur along this stretch of the NSW coast hence are not relevant. A number of species have been observed in south-east Australian waters including the southern right whale, humpback whale, loggerhead turtle, leatherback turtle and hawksbill turtle, however none were observed within the Hunter Estuary, particularly within the South Arm (NSW NPWS Atlas 2002). The ocean entrance to Newcastle Harbour is narrow, rendering passage of large animals difficult and the disturbed foreshore of the South Arm would make it most unlikely to be used as a nesting area for turtles. Grey nurse sharks would occur most commonly on rocky headlands at the entrance to the harbour and along the coastline to the north and south of the bay. They occasionally occur in embayments, however it is unlikely that the proposed dredging works would disturb their habitat or disrupt their lifecycle. Great white sharks are coastal dwelling sharks that travel large distances. Although they do occasionally swim into bays and estuaries it is highly unlikely that the proposed dredging works would disturb their habitat or disrupt their lifecycle. Whilst these coastal species are likely to be affected by the proposed works within the Hunter Estuary, there may be effects related to offshore disposal. It is suggested that, when seeking approval for spoil disposal, coastal species be re-considered.

Threatened species that do spend some of their life in estuaries and require further consideration include the green sawfish and the black cod, and are discussed below.

Two key threatening processes could occur during proposed dredging works, discussed as follows:

1. Degradation of native vegetation along New South Wales water courses.

The proposed dredging works requires the removal of significant amounts of mangrove vegetation east of Tourle Street Bridge. The habitat structure and conservation value of these mangroves are assessed in Chapter 3. The area of existing wetland habitat was mapped and discussed in Chapter 3. NSW Fisheries has a policy of no net habitat loss (NSW Fisheries Policy and Guidelines 1999) therefore the proposal should consider some form of environmental compensation, such as rehabilitation works in the catchment or the creation of compensatory habitat elsewhere. The issue of habitat compensation although outside the scope of works for this project, is discussed briefly in Chapter 5.

2. Installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams.

There are no projected long term changes to flow morphology characteristics of the estuary as a result of the project (Patterson Britton and Partners 2003). Hence there should be no new physical hindrance to fish migrations along the estuary resulting from the proposed works. During construction, increased turbidity and noise could form a barrier to fish movement. Additionally, use of a sheet pile wall partially across the South Arm could also create a partial barrier to movement and increase flow velocity by a factor of 1.5 (Patterson Britton and Partners 2003). This issue is further discussed in section 4.3.

4.5.3 Specific Assessments

The following two species may potentially occur within the lower reaches of the Hunter Estuary, hence 8-part tests are warranted. The outcome of each test is described as follows.

4.5.3.1 Green Sawfish (*Pristis zijsron*)

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 marine or estuarine habitats as are found in the Hunter River estuary. 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 the Hunter Estuary. 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 the estuary, potentially within the North Arm and Fullerton Cove.

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 the Hunter Estuary 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 an amount of habitat that could be utilised by green sawfish would be altered by the proposed dredging, this is not considered to be significant for green sawfish, as there is extensive alternative habitat available.

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.*

There will be a permanent fish passage available along the South Arm after proposed dredging works. Access to the South Arm around Kooragang Island from the North Arm would remain undisturbed. In the event that green sawfish did occur within the study area, access to other parts of the South Arm would remain.

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, some of the shoreline sections of the Solitary Islands Marine Park and possibly within Towra Point Aquatic Reserve (Botany Bay). 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 dredging is not recognised as a threatening process with respect to green sawfish.

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 Hunter River estuary 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.

Conclusion: The proposed Hunter River dredging is unlikely to disturb green sawfish since no population of this species is recognised from the area and hence no SIS or any special management measures are recommended.

4.5.3.2 Black Cod (*Epinephelus daemelii*)

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 and occasionally enter estuaries. 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 the Hunter Estuary black cod may occur on natural reef and on artificial breakwaters and rock walls. Although artificial subtrata occur on both shores of the South Arm, 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 dredging is not recognised as a threatening process with respect to black cod.

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

The Hunter River 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 dredging of the Hunter River South Arm does not represent any significant threat to black cod, hence no SIS is recommended, nor any special management required.

5.0 RECOMMENDED MITIGATION MEASURES

The South Arm of the lower Hunter River is a highly disturbed environment. However, the extensive nature of proposed dredging works and proximity to important wetlands such as Kooragang Island and the removal of significant amounts of mangrove forest east of Tourle Street Bridge require appropriate mitigation and compensation measures. The following section discusses actions to minimise impacts on marine environment during and after proposed works. These include controlling the transport of sediments during dredging, minimising contaminant leaching during remediation and minimising the effects of rock blasting on fish. Post construction habitat compensation measures are discussed as well as long term monitoring programs.

5.1 Maintaining Water Quality and Protecting Foreshore Vegetation

Following are recommendations to minimise the impacts of dredging, reclamation and land filling on water quality and foreshore vegetation.

- Where feasible, maintain a vegetated buffer zone along the foreshore to minimise the erosion and runoff of sediments into the estuary.
- Appropriate use of sheet pile wall and turbidity curtains to minimise sediment transport during dredging operations. In particular, to reduce the transport of sediments to upstream mangroves including Kooragang Island Reserve.
- Minimise the transport of sediments contaminated with PAHs and heavy metals resuspended in the water column during dredging.
- Exposed acid sulphate soils should be treated to minimise the seepage of acid sulphate into the river.
- Appropriate measures should be taken to minimise the seepage of PAHs and heavy metals from land disposal sites into the river. It is proposed that sediments be remediated on the BHP closure site using cement stabilisation and thermal desorption technology.

5.2 Methods to Reduce Impacts to Fish from Blasting

Strategies to minimise impacts to fish from blasting include employing fish avoidance devices to reduce fish abundance in the area affected and to conduct blasting in ways that minimise the magnitude of the shock waves produced (US Army Corps of Engineers 1997).

- Fish avoidance techniques include the use of strobe lights. Many fish exhibit strong avoidance responses to underwater strobe lights. However avoidance is species specific and varies with other factors such as current velocity and turbidity.
- High frequency sounds were affective in excluding fish. Pulsed broad band high frequency sounds were affective in excluding fish from the half of experimental cages exposed to the higher sound frequencies.
- Bubble curtains reduce the pressure wave experienced by fish by essentially creating an energy-absorbing volume of air within the water column. Bubble curtains are vertical walls of air bubbles within the water column which are intentionally

produced using various types of air diffusers placed on the bottom. Bubble curtains appear to be extremely effective at reducing fish mortality (US Army Corps of Engineers 1997).

5.3 Protecting Fisheries Resources

Given that dredging would be required year round there will certainly be impacts on the prawn trawling and finfish industries. Develop an environmental management plan in collaboration with the prawn trawlers to minimise affects to the fishery.

5.4 Habitat Compensation

The proposed works requires the removal of approximately 9.7 ha of mangrove forest or equivalent to 0.6% of existing mangrove habitat in the Hunter Estuary. Also approximately 1.3 ha of saltmarsh would be removed, equivalent to 0.29% of existing saltmarsh habitat in the Hunter Estuary. The removal of mangroves and saltmarsh require a permit from NSW Fisheries in accordance with S205 of the Fisheries Management Act 1994. NSW Fisheries encourages habitat restoration wherever past environmental damage can be repaired. Where a development must proceed, and wetlands, such as mangroves, are destroyed, NSW Fisheries has a policy of environmental compensation. Restoration of previously degraded mangrove habitat may compensate for the loss of mangrove forests intended for development. This would normally require the creation of new habitat, and on a 2:1 basis to account for the indirect as well as direct impacts (NSW Fisheries 1999).

Mangrove saplings can easily be transplanted when they are no more than 18 months old and have no peg root development. Adult trees cannot be readily transplanted. Transplanting has been successful along reclaimed foreshore formerly occupied by mangrove or as fringing strip along retaining walls (SPCC undated).

Following discussion with the NSW Fisheries Conservation Manager for Central NSW, Roland Bow, a number of possible areas of compensation were proposed. These include creating an artificial wetland in Throsby Creek. This creek is located near the mouth of the Hunter River in a highly urbanised setting. Creating a wetland in Throsby Creek would be a strategically important location as no other wetlands exist in the area.

Secondly, funding could be provided to wetland rehabilitation projects already existing in the lower Hunter River including the Hexham Swamp Rehabilitation Project coordinated by the Hunter Catchment Management Trust. The Trust in partnership with private landholders, industry groups, local community and State and Federal Government agencies is to rehabilitate Hexham Swamp. Hexham Swamp is the Hunter's largest wetland covering an area of 3,800 hectares and most biologically diverse. But after thirty years of limited tidal exchange between the swamp and river, brought on by the operation of floodgates at the mouth of Ironbark Creek, the wetland has changed from an estuarine to freshwater habitat with significant losses in biodiversity. The Trust has purchased 440 hectares of private grazing land in the swamp and is negotiating the purchase of the remaining land that may become inundated when the floodgates are re-opened to allow salt-water intrusion and flushing into the swamp to restore previous ecological processes.

Thirdly, NSW Fisheries, Public Works Department, Newcastle City Council and the Hunter Catchment Management Trust, are jointly involved in the rehabilitation of 200 hectares of saltmarsh and mangroves on Kooragang Island in the Hunter Estuary. This Wetland

Compensation Project launched in 1993, aims to restore mangrove habitat to compensate for large scale wetland losses of previous reclamations. The project will provide valuable information for developing and improving techniques for restoration, creation and rehabilitation of mangroves. Additional funding to this project would allow for the better protection of a nationally significant wetland.

Finally, trial seagrass planting programs could be developed in cooperation with NSW Fisheries the Hunter River estuary. Seagrasses provide significant habitat for commercially important fish and invertebrates and is present in most estuaries of NSW. Although there are no recorded sightings of seagrass in the main channels of the Hunter River estuary, its absence could be due to poor water quality, in particular water clarity. This is the most important factor in determining the growth of seagrass (Doherty and Scanes 1998). Introducing cleaner technology in industry would assist in improving water quality.

5.5 Monitoring Program

Long term management could include purpose built constructed wetlands to provide waste water treatment, flood mitigation, improve water management and enhance nutrient removal. Issues to consider when building wetlands include the need for gross pollutant traps, flow regulation, recirculation and planting appropriate species (Sainty and Jacob 1994). The remediation of contaminated sediments at Bicentennial Park, Homebush Bay is an example of environmentally successful remediation. Remediation of the Haslams Creek South site won a Gold Award for Waste Service NSW at RiverCare 2000 awards.

Baseline data on the abundance and distribution of benthic taxa and fish species was collected in the present study. Because the abundance of most species is known to vary greatly over time, it would be essential to have at least two sampling periods before dredging commences. Similarly, any test for impact would require additional sampling periods during and after dredging and these could be integrated in an environmental management plan. The abundance and species of fish varies throughout estuaries. Future surveys should consider a number of locations including the north and south arms and shallow and deep areas to provide information on spatial variability. To assess long-term changes in aquatic vegetation, it is recommended that the distribution of mangrove and saltmarsh habitat upstream of the dredge site is mapped periodically. Long term water quality measures such as upstream salinity, turbidity and changes in temperature and dissolved oxygen in the dredged section could be included in a long term monitoring program.

6.0 ACKNOWLEDGEMENTS

This report was written by Sophie Diller, Brendan Alderson, Dr Marcus Lincoln Smith and Dr Tim Glasby. Greig Campbell, Lana Assaf, Belinda Parkes, Charmaine Read and Katryna Denning sorted samples. Sophie Diller and Brendan Alderson prepared the figures and did the statistical analyses. The following people assisted with field work: Lana Assaf, Karen Judd, Paul Godfrey, Brendan Alderson, Marcus Lincoln Smith, Kane Organ and Sophie Diller. A special thanks to Robert Hyde for the use of his boat during the fish trawling survey.

7.0 REFERENCES

Adam P. 1984. Towards a wetland conservation strategy. Wetlands (Australia) 4 pp 33-48.

Bell J,D, Pollard D.A., Burchmore J.J, Pease B.C and Middleton M.J. 1984. Structure of a fish community in a temperate tidal mangrove creek in Botany Bay, New South Wales. Australian Journal of Marine and Freshwater Research, 35 pp33-46.

Birch, G., Ingleton, T. and Taylor, S. (1997). Environmental implications of dredging in the world's second largest coal exporting harbour, Port Hunter, Australia. *Journal of Marine Environmental Engineering.* **4**, pp. 133-145.

Clarke P., 1994. Baseline studies of temperate mangrove growth and reproduction; demographic and litterfall measures of leafing and flowering. Australian Journal of Botany, 42:1, pp 37-48.

DeGrave, S. and Whitaker, A. (1999). Benthic community re-adjustment following dredging of a muddy-maerl matrix. *Marine Pollution Bulletin* **38**, pp. 102-108.

Ellison, J.C. (1999). Impacts of sediment burial on mangroves. *Marine Pollution Bulletin* **37**, pp. 420-426.

Environment Protection Authority, N. S. W. (1992). *Port Kembla Dredge Spoil Report: The Environmental Effects of Spoil Disposal off Port Kembla Following Construction of the Grain Terminal.* Prepared for: Public Works Department.

Environment Protection Authority, N.S.W. (1994). *Contaminants in Fish and Oysters from Newcastle Waters.* Prepared for: NSW Environment Protection Authority. NSW Environment Protection Authority, Bankstown NSW.

Gibbs, P., McVea, T. and Louden, B. (1999). *Utilisation of Restored Wetlands by Fish and Invertebrates.* NSW Final Report Series No.16, FRDC Project No. 95/150. NSW Fisheries, Pyrmont.

Hutchings, P. (1983). The wetlands of Fullerton Cove, Hunter River, New South Wales. *Wetlands* **3**, pp. 12-21.

Johnston, S. A. (1981). Estuarine dredge and fill activities: a review of impacts. *Environmental Management* pp. 427-440.

Jones, A. R. (1986). The effects of dredging and spoil disposal on macrobenthos, Hawkesbury Estuary, N.S.W. *Marine Pollution Bulletin* **17 No.1**, pp. 17-20.

Kaly, U.L., 1988. Distribution, abundance and size of mangrove and saltmarsh gastropods. Ph.D. thesis, University of Sydney.

Kaplan, E. H., Welker, J. R., Kraus, M. G. and McCourt, S. (1975). Some factors affecting the colonization of a dredged channel. *Marine Biology* **32**, pp. 193-204.

Lasiak T.A. and Underwood A.J, 2002. Baseline survey of the benthic invertebrate assemblages associated with fringing mangroves in the Brooklyn region of the Hawkesbury River. Draft Report, Centre for Research on Ecological Impacts of Coastal Cities.

Last, P. R. and Stevens, J. D. (1994). Sharks and Rays of Australia. CSIRO, Australia, 513 pp.

Maddock, M. (1983). Hunter Valley wetland birds raise conservation issues. *Wetlands* **3**, pp. 71-80.

Minchinton T.E., 2001. Canopy and substratum heterogeneity influence recruitment of the mangrove Avicennia marina. Journal of Ecology, 89: 5.

Morrisey D. 1995. Estuaries, in: Coastal Marine Ecology of Temperate Australia, edited by A.J Underwood & M.J. Chapman. UNSW Press.

Morton R.M. 1990. Community structure, density and standing crop of fishes in a subtropical Australian mangrove area. Marine Biology 105 pp 385-394.

NSW Fisheries (1999a). *Status of Fisheries Resources 1998/1999.* NSW Fisheries Institute.

NSW Fisheries (1999b). *Policy and Guidelines: Aquatic Habitat Management and Fish Conservation* (1999 Update). Smith, A. K. and Pollard, D. A. (eds). NSW Fisheries, Port Stephens.

NSW Fisheries (2000). Commercial Fisheries Statistics 1998/1999. Tanner, M. and Liggins G.W. (eds). NSW Fisheries.

NSW Fisheries (2001). Aquaculture production report 1999/2000. NSW Fisheries.

Patterson Britton and Partners (2003). Potential Impacts of Proposed Dredging of South Arm on Tidal Hydrodynamics, Flooding and Water Quality, Issue No. 1, March, for GHD.

Phillips, D. J. H. (1977). The use of biological indicator organisms to monitor trace metal pollution in marine and estuarine environments - a review. *Environmental Pollution* **13**, pp. 281-317.

Robertson A.I and Duke N.C, 1987. Mangrove as nursery sites: comparisons of the abundance and species composition of fish and crustaceans in mangroves and other nearshore habitats in tropical Australia, Marine Biology, 96 pp 193-205.

Ross P.M., 2001. Larval supply, settlement and survival of barnacles in a temperate mangrove forest. Marine Ecology Progress Series, 215 pp. 237-249.

Ruello, N. V. (1976). Environmental and biological studies of the Hunter River. *Operculum* pp. 76-83.

Saintilan N., 1998. Relationship between height and girth of mangrove and soil-water conditions in the Mary and Hawkesbury. Australian Journal of Ecology, 23:4, pp

322-328.

Sainty G. and Jacobs S.W., 1995. Waterplants in Australia. CSIRO.

Shepherd, M. (1994). *A report to the Ecosystem Group of Ironbark Creek Catchment Management Committee on the Effects of Flood Mitigation Structures of Ironbark Creek on the Fish and Prawn Populations of the Mangrove Swamp Community.* Prepared for: Ironbark Creek Catchment Management Committee. Macquarie University, Sydney, NSW.

Simpson S., Adams M., Stauber J. and Batley G., 2001. Relationships between chemical contaminants and ecotoxicological effects for dredged Newcastle Harbour sediments. CSIRO Centre for Advanced Analytical Chemistry, Energy and Technology.

SPCC State Pollution Control Commission (no date). A Guide to Mangrove Transplanting, SPCC.

State Pollution Control Commission (1986). *Dredge Spoil From Port Kembla - Summary Report on the Environmental Effects of Ocean Disposal.* SPCC, Sydney, Australia.

The Ecology Lab Pty Ltd (1997). *Investigation of Bioaccumulation in Estuarine Fauna, South Arm of the Hunter River.* Prepared for: CMPS & F. The Ecology Lab Pty Ltd, Sydney, NSW.

The Ecology Lab Pty Ltd (1998). *Bioaccumulation in Aquatic Fauna from the Hunter River - Final Report.* Prepared for: CMPS & F. The Ecology Lab Pty Ltd, Sydney, NSW.

Underwood A.J, and Barrett G., 1990. Experiments on the influence of oysters on the distribution, abundance and size of the gastropod Bembicium auratum in a mangrove swamp in New South Wales, Australia.

US Army Corp of Engineers, undated. Chapter 13, Assessment of Impacts Associated with Rock Blasting for the Delaware River Deepening EIS. Web site: www.nap.usace.army.mil.

West, R. J., Thorogood, C. A., Walford, T. R. and Williams, R. J. (1985). *An Estuarine Inventory for New South Wales, Australia.* Division of Fisheries, NSW Department of Agriculture, Sydney, Australia.

Williams, R. J., Hannan, J., F. A. and Balashov, V. (1995). *Kooragang Wetland Rehabilitation Project: Fish, Decapod Crustaceans and Their Habitats.* NSW Fisheries First Interim Report. NSW Fisheries, Cronulla, NSW.

Williams, R. J., Watford, F. A. and Balashov, V. (2000). *Kooragang Wetland Rehabilitation Project: History of Changes to Estuarine Wetlands of the Lower Hunter River.* NSW Fisheries Final Report Series, No. 22. NSW Fisheries, Cronulla, NSW.

PLATES

Plate 1: Tourle Street Bridge Location. Upper: Saltmarsh area west of mangrove forest. Lower: Mature mangrove forest of *Avicennia marina*.

Plate 2: Tourle Street Bridge Location. Upper: Foreshore of mangrove forest, view east. Lower: View west.

Plate 3: Tourle Street Bridge Location. Upper: Large patch of saltmarsh vegetation, *Sarcocornia quinqueflora* and *Suaeda australis*, in mangrove forest. Lower: Estuarine barnacle *Elminius* sp. growing on *A. marina* tree.

Plate 4: South Arm Reference Location: Upper: *A. marina* forest and dead branches. Lower Creek draining mangrove forest.

Plate 5: North Arm Reference Location: Upper: Foreshore of juvenile *A. marina* trees. Lower: Mature *A. marina* mangrove forest with dense cover of saplings and pneumatophores. Note the quadrat sampling unit in foreground.

Plate 6: Upper: Trawl net entering the water. Lower: large amounts of green weed caught at the Tourle Street Bridge site.

Plate 7: Upper: Fish caught during one trawl from the shallow water site upstream of Stockton Bridge.

Plate 1: Upper:. Saltmarsh near Tourle Street Bridge location. Lower: Mature mangrove forest of *Avicennia marina* at Tourle Street Bridge location. Note dense cover of pneumatophore.

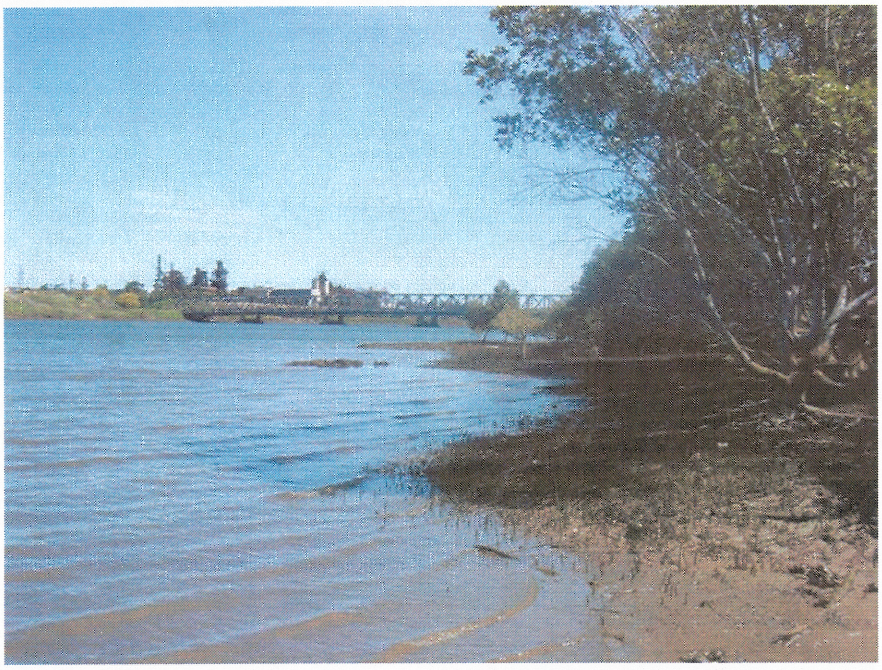

Plate 2: Upper: Foreshore of mangrove forest at Tourle Street Bridge location, view east. Lower: view west.

Plate 3: Tourle Street Bridge location. Upper:. Large patch of saltmarsh vegetation (*Sarcocornia quinqueflora* and *Suaeda australis*) in mangrove forest. Lower: Estuarine barnacle *Elminius* sp. growing on *A. marina* tree.

Plate 4: South Arm Reference: Upper: Mature *A..marine* forest and dead branchs. Lower: Creek draining *A. marina* forest.

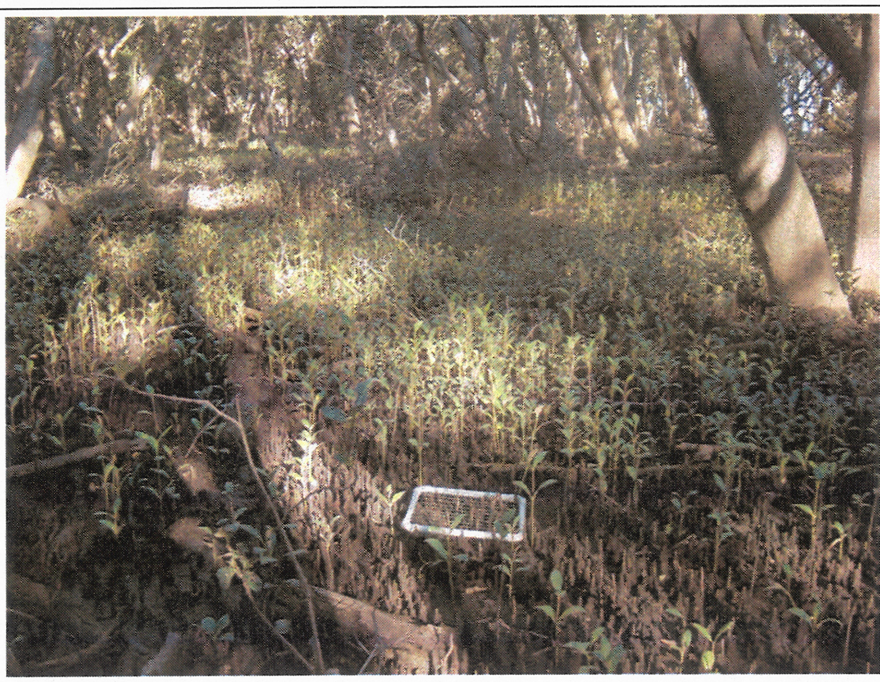

Plate 5: North Arm Reference Location: Upper: Foreshore with *A. marina* juvenile trees. Lower: Mature *A. marina* mangrove forest with dense cover of saplings and pneumatophores . Note: Quadrat sampling unit in foreground.

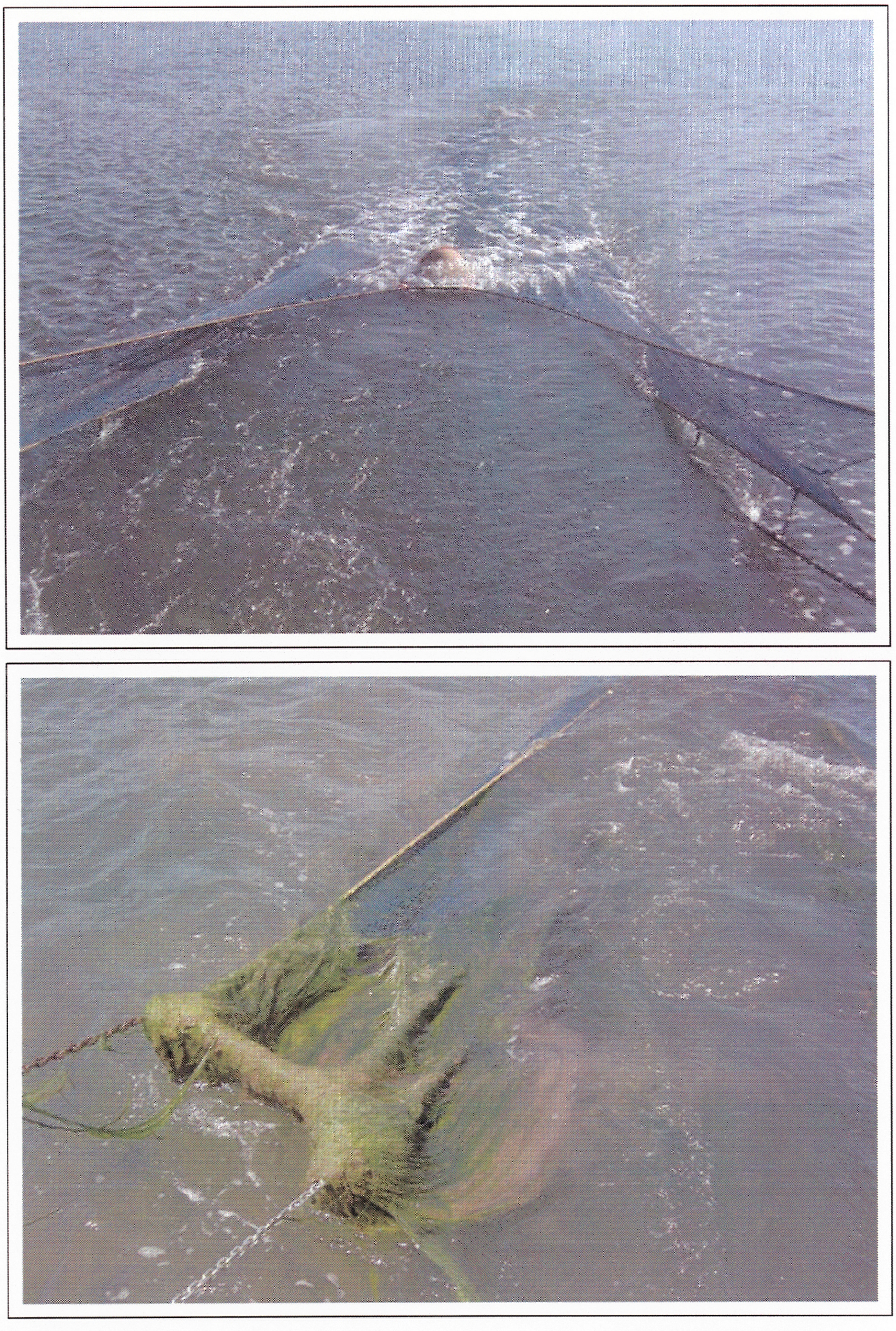

Plate 6: Upper: Trawl net entering the water. Lower: Large amounts of green weed caught at the Tourle Street Bridge site.

Plate 7: Fish caught from the shallow water site upstream of Stockton Bridge.

TABLES

Table 1: Summary of Director General requirements and other requirements identified by statutory agencies for the assessment of aquatic ecology impacts of the proposed dredging of the Hunter River South Arm.

Impact Assessment Requirement (relevant Act)	**Relevant section of Report**
Wetland Vegetation:	
• Location and extent of habitat removal or modification.	3.1.3.1
• Area of wetland vegetation to be removed and impacts of proposal on wetland habitat.	4.4.1.1
• Degraded aquatic habitats should be rehabilitated to repair past environmental damage.	5.3
• Environmental compensation integrated into the planning process (NSW Fisheries).	5.3
• Impacts of inundation of Hexham Swamp (DG requirements).	4.4.13. and 5.3
• High conservation value wetlands about 1.5 km upstream from the proposed dredge limit have been identified as possible additions to Kooragang Nature Reserve. Changes in tidal regime through activities such as dredging may exacerbate subsidence effects and encourage mangrove rather than saltmarsh rehabilitation (NPWS).	5.1 and 4.4.1.1
• Methods and location of transplanting activities or disposal of marine vegetation (NSW Fisheries).	5.3
• Permit to harm marine vegetation required under section 204 and 205 of the Fisheries Management Act 1994.	5.3
• Terrestrial areas adjoining estuary carefully managed to minimise land-use impacts: Recommendation As a precautionary approach, foreshore buffer zones at least 50 m wide should be established an maintained with natural vegetation preserved (NSW Fisheries).	5.1

Table 1 continued.	
Fish:	
• Length of time fish passage is to be restricted (during dredging and any deployment of silt contaminant devices. Timing of proposed restriction.	4.4.1.5
• Threatened Species Assessment and relevant 8-part test (NSW Fisheries).	2.7
• Consider protected areas and critical fish habitat (NSW Fisheries).	2.7
• Alien, exotic or introduced fish species should not be released into estuary (NSW Fisheries).	2.7
Water Quality:	
• Description of remediation work.	5.2
• Location of land disposal and runoff.	4.5.2
• Impacts of proposed dredging on water quality (DG requirements).	4.4.3
• Identification of point source and diffuse pollutant discharge. Prevention or minimisation of discharge. Effective treatment of any continuing discharge. Disposal of waste to alternative land sites (NSW Fisheries).	4.4.3 and 5.2
Monitoring:	
• Environmental monitoring program to determine if assessment of impacts were accurate. Include multiple control sites and surveys over time to monitor change in biological indicators (NSW Fisheries).	5.4 and Chapter 3
Miscellaneous:	
• Impacts of off-shore dumping on the coastal processes.	Not part of scope-of-works
• Ensure no net loss of wader habitat (NPWS).	

Table 2: Categories used to estimate damage in mangrove forests. Source: Skilleter (1996).

Category	Type of Damage
A - completely damaged	rocks (>15 cm), urban debris (fridge, car bodies, tyre), large pieces of flotsam.
B - partially damaged	large branches and stumps from nearby dead trees, household garbage, small rocks.
C - slightly damaged	occasional rubbish, small branches, light flotsam.
d - undamaged	no visual signs of external damage.

Table 3: Average (±SE) percent cover of habitat components and percent damage in mangrove forest from the Hunter River sampling locations. N= 2 replicate transects.

	Tourle Street Bridge						South Arm Reference			
	Site 1		Site 2		Site 3		Site 4		Site 5	
	Average	SE	Average	SE	Average	SE	Average	SE	Average	SE
Habitat										
Pneumatophore	22.88	1.24	22.52	4.83	20.98	0.26	27.90	7.23	27.77	1.77
A. corniculatum tree	1.06	1.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A. corniculatum juvenile	0.35	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A. corniculatum sapling	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A. marina tree	5.52	2.69	8.14	0.45	6.26	0.95	13.09	1.09	16.06	0.72
A. marina juvenile	3.73	3.73	4.27	1.20	3.11	1.31	6.05	1.38	8.02	2.65
A. marina sapling	14.26	2.91	9.28	2.25	8.03	0.82	6.03	1.30	7.02	2.32
Mud	50.03	6.00	38.70	8.23	44.20	0.05	38.91	3.09	36.12	0.79
Algae	0.37	0.37	6.24	4.70	3.60	2.71	8.02	5.32	5.02	1.69
Oysters	0.00	0.00	1.16	0.38	0.45	0.45	0.00	0.00	0.00	0.00
Log or branch	0.73	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C. glaucescens	0.00	0.00	0.77	0.77	0.00	0.00	0.00	0.00	0.00	0.00
S. quinqueflora	0.00	0.00	5.04	0.43	8.01	2.61	0.00	0.00	0.00	0.00
S. australis	1.06	1.06	3.88	0.03	5.37	0.94	0.00	0.00	0.00	0.00
Damage										
Category D	84.70	1.12	80.25	1.78	80.76	5.08	68.15	4.82	72.91	1.58
Category C	11.31	1.38	15.10	2.60	13.40	1.01	25.14	3.52	18.38	2.95
Category B	3.99	0.26	4.66	0.81	5.39	3.62	6.70	1.30	8.70	1.37
Category A	0.00	0.00	0.00	0.00	0.45	0.45	0.00	0.00	0.00	0.00

	South Arm		North Arm Reference					
	Site 6		Site 7		Site 8		Site 9	
	Average	SE	Average	SE	Average	SE	Average	SE
Habitat								
Pneumatophore	26.20	1.38	30.78	4.35	20.82	3.71	20.63	3.13
A. corniculatum tree	0.00	0.00	0.00	0.00	1.39	0.49	3.13	0.63
A. corniculatum juvenile	0.00	0.00	0.00	0.00	0.00	0.00	1.88	0.63
A. corniculatum sapling	0.00	0.00	0.00	0.00	0.00	0.00	1.88	1.88
A. marina tree	11.92	2.26	11.02	3.17	9.14	3.48	8.75	1.25
A. marina juvenile	11.20	0.86	5.50	1.93	10.96	4.36	5.63	1.88
A. marina sapling	5.93	0.97	8.79	4.06	13.02	4.91	16.88	1.88
Mud	40.55	0.83	40.41	4.59	38.24	0.50	35.63	9.38
Algae	4.20	0.06	3.49	0.79	5.98	0.32	3.75	3.75
Oysters	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Log or branch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C. glaucescens	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S. quinqueflora	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S. australis	0.00	0.00	0.00	0.00	0.45	0.45	1.88	0.63
Damage								
Category D	79.75	1.81	72.92	0.06	72.21	6.17	68.75	2.50
Category C	11.14	3.34	16.88	4.74	13.45	3.54	24.38	1.88
Category B	9.11	1.53	10.20	4.80	13.45	3.54	6.88	4.38
Category A	0.00	0.00	0.00	0.00	0.90	0.90	0.00	0.00

Table 4: ANOVA results of percent damage in mangrove forest among three sites and three locations. N=2 replicate transects.

a) No damage — Cochran's Test: C = 0.3675 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Location	373.6	2	186.8	6.25	**0.0342**	si(lo)
Site (location)	179.4	6	29.91	1.30	0.3474	Residual
Residual	207.2	9	23.02			
SNK	Tourle > Ref1 = Ref2				Transform: none	

b) Category C damage — Cochran's Test: C = 0.2794 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Location	98.43	2	49.21	0.88	0.4621	si(lo)
Site (location)	335.4	6	55.91	3.13	0.0608	Residual
Residual	160.8	9	17.87			
					Transform: none	

c) Category B damage — Cochran's Test: C = 0.2469 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Location	92.78	2	46.39	5.38	**0.0459**	si(lo)
Site (location)	51.77	6	8.628	0.52	0.7789	Residual
Residual	148.73	9	16.53			
SNK	Tourle = Ref1 = Ref2				Transform: none	

Table 5: Results of ANOSIM examining habitat components along transects among location. N=4

Location		
Global R: 0.51; P=0.007		
	R statistic	*P*
Tourle Street - South Arm Reference	0.82	0.1
Tourle Street - North Arm Reference	0.59	0.1
South Arm Reference - North Arm Reference	0.26	0.2

Summary - locations overlapping but clearly different.

Table 6: Mean (±S.E.) percent cover and abundance of habitat components per $0.1m^2$ quadrat at transects from the three locations sampled in the Hunter River. N = 4.

Location	Tourle Street Bridge Location												South Arm Reference Location					
Site	Site 1				Site 2				Site 3				Site 4				Site 5	
Transect	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5		Transect 6		Transect 7		Transect 8		Transect 9	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Percent Cover																		
Leaf Litter	8.00	2.04	9.75	2.66	21.25	15.64	14.50	10.63	22.00	16.07	7.50	2.78	7.25	2.29	17.75	4.21	15.25	5.51
Algae	1.25	0.95	1.00	0.71	18.50	19.85	2.00	2.31	13.75	7.51	12.50	11.21	10.00	10.00	34.75	20.30	3.75	3.75
Trash	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
Bare mud	90.50	1.55	89.25	3.22	60.25	22.06	83.50	9.89	64.25	13.31	80.00	11.55	82.75	11.12	47.50	17.44	81.00	4.34
Abundance																		
Pneumatophores	50.75	8.58	45.50	12.42	47.75	16.90	37.00	14.73	16.25	6.50	38.25	10.08	35.50	6.30	36.75	1.11	39.75	4.31
Crab hole	7.50	3.18	5.25	2.06	3.25	1.28	3.75	2.37	5.50	3.07	3.25	1.25	7.00	5.74	3.50	2.84	1.25	1.25
Mangrove Saplings	0.25	0.25	0.50	0.29	0.25	0.29	0.00	0.00	0.25	0.25	1.00	0.71	0.00	0.00	0.00	0.00	0.00	0.00
Mangrove Seeds	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.29	0.00	0.00	0.25	0.25	0.00	0.00	0.75	0.75	0.50	0.50

Location	South Arm Reference Location						North Arm Reference Location											
Site	Site 5		Site 6				Site 7				Site 8				Site 9			
Transect	Transect 10		Transect 11		Transect 12		Transect 13		Transect 14		Transect 15		Transect 16		Transect 17		Transect 18	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Percent Cover																		
Leaf Litter	13.25	4.13	15.75	5.02	15.75	1.18	9.00	1.73	6.25	2.29	22.75	4.27	12.25	5.31	21.75	4.61	16.00	7.82
Algae	10.00	6.12	3.50	3.50	17.50	17.50	3.75	3.75	2.25	1.60	3.00	3.00	3.75	2.39	17.50	6.75	15.00	7.82
Trash	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	1.75	1.75
Bare mud	76.75	4.13	80.75	4.13	66.75	18.59	87.25	4.96	91.50	2.18	74.25	3.12	84.00	7.58	60.75	9.40	67.25	6.80
Abundance																		
Pneumatophores	36.00	6.36	32.75	3.90	44.25	6.86	40.75	8.42	75.00	6.68	37.25	5.98	59.25	12.05	32.50	2.02	61.50	11.65
Crab hole	3.50	1.71	4.50	3.57	1.25	0.95	1.50	0.87	4.00	0.71	1.75	0.85	5.00	0.71	0.25	0.25	3.00	1.22
Mangrove Saplings	0.00	0.00	0.00	0.00	0.50	0.29	2.25	1.03	3.75	1.11	4.00	1.73	3.00	1.47	4.00	0.71	6.00	3.56
Mangrove Seeds	0.00	0.00	0.25	0.25	0.00	0.00	0.25	0.25	0.00	0.00	0.25	0.25	0.75	0.48	0.00	0.00	0.25	0.25

Table 7: ANOVA results for the a) to c) percent cover and d) to f) abundance of habitat components per quadrat in mangrove forest from two transects at three sites and at three locations. N = 4. Significant terms are in bold print. A indicates that the term was pooled (P > 0.25).

a) Leaf Litter — Cochran's Test: C = 0.238 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Location	1.876	2	0.938	0.47	0.628	Pooled
Site (location)[A]	12.83	6	2.138	1.07	0.628	Pooled
Transect[A]	14.07	9	1.564	0.78	0.628	Pooled
Residual[A]	111.3	54	2.060			

Transform: Sqrt (X+1)

b) Mud — Cochran's Test: C =0.2006 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Location	426.2	2	213.1	0.32	0.729	Pooled
Site (location)[A]	5084	6	847.4	1.29	0.322	Pooled
Transect[A]	4804	9	533.8	1.32	0.249	Residual
Residual	21834	54	404.3			

Transform: none

c) Algae — Cochran's Test: C = 0.2740 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Location	470.5	2	235.3	0.71	0.496	Pooled
Site (location)[A]	2590	6	431.7	1.3	0.268	Pooled
Transect[A]	2261.1	9	251.2	0.76	0.656	Pooled
Residual[A]	18036	54	334.0			

Transform: none

d) Pneumatophore — Cochran's Test: C = 0.1590 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Location	2604	2	1301.9	2.17	0.149	Pooled
Site (location)[A]	2451	6	408.5	0.68	0.668	Pooled
Transect[A]	6546	9	727.3	2.43	**0.021**	Residual
Residual	16168	54	299.4			

Transform: none

(Continued)

Table 7: Continued.

e) Crab burrow — Cochran's Test: C = 0.2313 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Location	2.814	2	1.407	1.75	0.182	Pooled
Site (location)[A]	3.172	6	0.529	0.66	0.685	Pooled
Transect[A]	6.216	9	0.691	0.86	0.566	Pooled
Residual[A]	46.15	54	0.855			
				Transform:Sqrt(X+1)		

f) Sapling — Cochran's Test: C = 0.5897 ($P < 0.01$)

Source	SS	DF	MS	F	P	F versus
Location	208.9	2	104.4	24.61	**0.000**	Pooled
Site (location)[A]	18.67	6	3.111	0.73	0.625	Pooled
Transect[A]	16.38	9	1.819	0.43	0.915	Pooled
Residual[A]	257.8	54	4.773			
SNK	Tourle Street= Ref 1 < Ref 2			Transform: none		

Table 8: Total abundance and percent abundance of benthos taxa identified from quadrats at transects from three locations sampled in the Hunter River.

	Total Abundance			Percent Abundance		
Location	Tourle St	S. Arm Ref	N. Arm Ref	Tourle St	S. Arm Ref	N. Arm Ref
POLYCHAETES						
Capitellidae	127	100	0	3.7	3.1	0.0
Cirratulidae	1	0	0	0.0	0.0	0.0
Nephtyidae	1	0	0	0.0	0.0	0.0
Nereididae	82	384	622	2.4	11.9	7.1
Orbiniidae	1	0	0	0.0	0.0	0.0
Sabellidae	3	0	0	0.1	0.0	0.0
Spionidae	93	32	0	2.7	1.0	0.0
CRUSTACEANS						
Aoridae	1	0	1	0.0	0.0	0.0
Hyalidae (hyalid sp 1)	202	171	692	5.9	5.3	7.9
Hyalidae (hyalid sp 2)	0	0	7	0.0	0.0	0.1
Lysianassidae	0	0	1	0.0	0.0	0.0
Sphaeromatidae sp1	3	3	1	0.1	0.1	0.0
Sphaeromatidae sp2	8	0	0	0.2	0.0	0.0
Leptocheliidae	26	0	0	0.8	0.0	0.0
Macrobrachium intermedium	2	0	0	0.1	0.0	0.0
Helographsus haswellianus	6	0	0	0.2	0.0	0.0
Paragrapsus laevis	6	3	1	0.2	0.1	0.0
Sesarma erythrodactyla	69	10	20	2.0	0.3	0.2
Diogenidae	1	0	0	0.0	0.0	0.0
Australoplax tridentata	18	11	0	0.5	0.3	0.0
Juvenile crabs	139	25	12	4.1	0.8	0.1
Megalopa larvae	5	0	2	0.1	0.0	0.0
Cirripedia (barnacle sp.1)	1	0	0	0.0	0.0	0.0
MOLLUSCS						
Salinator solida	239	264	249	7.0	8.2	2.8
Assiminea buccinoides	36	12	41	1.1	0.4	0.5
Ophicardelus ornatus	67	8	198	2.0	0.2	2.3
Ophicardelus quoyi	5	5	62	0.1	0.2	0.7
Ophicardelus sulcatus	6	1	70	0.2	0.0	0.8
Tatea spp	1995	1682	5116	58.4	52.0	58.2
Arthritica helmsi	32	13	0	0.9	0.4	0.0
Glauconome plankta	1	1	0	0.0	0.0	0.0
Hiatella australis	1	0	0	0.0	0.0	0.0
Bembicium auratum	2	0	0	0.1	0.0	0.0
OTHER PHYLA						
Oligochaeta	140	455	857	4.1	14.1	9.8
Nematoda	12	2	2	0.4	0.1	0.0
Mugilogobius paludis	5	0	0	0.1	0.0	0.0
Arachnida	2	0	0	0.1	0.0	0.0
Insect larvae	77	50	829	2.3	1.5	9.4
Adult insects	3	0	1	0.1	0.0	0.0
Total abundance	3418	3232	8784			

Table 9: Results of ANOSIM examining benthos assemblages in quadrats among location . N=4

Location		
Global R: 0.309; P=0.004		
	R statistic	*P*
Tourle Street - South Arm Reference	0	0.6
Tourle Street - North Arm Reference	0.26	0.1
South Arm Reference - North Arm Reference	0.63	0.1
Summary - locations barely separable		

Table 10: SIMPER results comparing the relative contribution of benthic macroinvertebrate taxa to the dissimilarity of the assemblages at each location. Cut-off for low contributions 90.00%. SAR = South Arm reference, NAR = North Arm reference, TSB = Tourle Street Bridge

a) TSB and SAR

Taxon	Av. Abundance TSB	Av. Abundance SAR	Av. Diss	Diss/SD	Contrib%	Cum%
Tatea spp	83.13	70.08	32.91	1.34	42.87	42.87
Oligochaeta	5.83	18.96	9.42	0.72	12.27	55.14
Nereididae	3.42	16.00	8.39	0.87	10.92	66.06
Salinator solida	9.96	11.00	5.90	1.01	7.68	73.74
Hyalidae (hyalid sp 1)	8.42	7.13	5.35	0.69	6.96	80.71
Capitellidae	5.29	4.17	2.67	0.50	3.48	84.19
Juvenile crabs	5.79	1.04	2.22	0.78	2.89	87.08
Insect larvae	3.21	2.08	1.88	0.75	2.45	89.53
Spionidae	3.88	1.33	1.49	0.70	1.94	91.47

Average Dissimilarity = 76.78

b) TSB and NAR

Taxon	Av. Abundance TSB	Av. Abundance NAR	Av. Diss	Diss/SD	Contrib%	Cum%
Tatea spp	83.13	213.17	36.72	1.64	47.50	47.50
Oligochaeta	5.83	35.71	7.93	0.81	10.26	57.76
Insect larvae	3.21	34.54	7.34	0.95	9.50	67.26
Hyalidae (hyalid sp 1)	8.42	28.83	6.76	1.06	8.74	75.99
Nereididae	3.42	25.92	5.50	0.90	7.12	83.11
Salinator solida	9.96	10.38	2.89	0.77	3.74	86.86
Ophicardelus ornatus	2.79	8.25	2.51	0.69	3.24	90.10

Average Dissimilarity = 77.31

c) SAR and NAR

Taxon	Av. Abundance SAR	Av. Abundance NAR	Av. Diss	Diss/SD	Contrib%	Cum%
Tatea spp	70.08	213.17	33.00	1.59	49.06	49.06
Oligochaeta	18.96	35.71	8.05	0.90	11.97	61.03
Insect larvae	2.08	34.54	7.00	1.01	10.40	71.43
Hyalidae (hyalid sp 1)	7.13	28.83	5.35	1.07	7.96	79.39
Nereididae	16.00	25.92	4.96	0.97	7.38	86.76
Salinator solida	11.00	10.38	2.48	0.86	3.68	90.45

Average Dissimilarity = 67.26

Table 11: ANOVA results for the number of taxa and abundance of benthic taxa per quadrat in mangrove forests from two transects at three sites and at three locations. N = 4. Significant terms are in bold print. A indicates that the term was pooled (P > 0.25).

a) Total number of Taxa — Cochran's Test: C = 0.1831 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Location	24.25	2	12.13	1.46	0.239	Pooled
Site (location)^A	49.50	6	8.250	0.99	0.437	Pooled
Transect^A	81.25	9	9.028	1.09	0.384	Pooled
Residual^A	442.50	54	8.194			

Transform: none

b) Total abundance — Cochran's Test:C = 0.1639 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Location	1004.1	2	502.0	15.46	**0.000**	Pooled
Site (location)^A	221.1	6	36.85	1.13	0.352	Pooled
Transect^A	251.2	9	27.91	0.86	0.565	Pooled
Residual^A	1768.3	54	32.75			

SNK: Tourle Street = Ref 1< Ref 2 — Transform:Sqrt(X+1)

c) Polychaete taxa — Cochran's Test: C = 0.2743(Not Significant)

Source	SS	DF	MS	F	P	F versus
Location	22.33	2	11.17	7.31	**0.025**	Si(Lo)
Site (location)	9.167	6	1.528	1.84	0.106	Pooled
Transect^A	8.625	9	0.958	1.15	0.341	Pooled
Residual^A	43.75	54	0.810			

SNK: Tourle Street = Ref 1< Ref 2 — Transform: none

d) Polychaete abundance — Cochran's Test: C = 0.2030 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Location	50.19	2	25.09	4.63	**0.013**	Pooled
Site (location)^A	24.66	6	4.110	0.76	0.605	Pooled
Transect^A	39.78	9	4.420	0.82	0.604	Pooled
Residual^A	309.5	54	5.731			

SNK: Tourle Street < Ref 1 = Ref 2 — Transform:Sqrt(X+1)

e) Mollusc taxa — Cochran's Test: C = 0.1630 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Location	65.86	2	32.93	14.28	**0.005**	Si(Lo)
Site (location)	13.83	6	2.306	1.4	0.228	Pooled
Transect^A	13.38	9	1.486	0.9	0.528	Pooled
Residual^A	90.25	54	1.671			

SNK: Tourle Street = Ref 1 < Ref 2 — Transform:Sqrt(X+1)

Table 11: Continued

f) Mollusc abundance — Cochran's Test: C =0.1630 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Location	692.7	2	346.4	10.53	**0.000**	Pooled
Site (location)[A]	196.9	6	32.81	1	0.434	Pooled
Transect[A]	233.2	9	25.91	0.79	0.629	Pooled
Residual[A]	1840.2	54	34.08			

SNK: Tourle Street = Ref 1 < Ref 2 — Transform: Sqrt(X+1)

g) Crustacean taxa — Cochran's Test:C = 0.1310 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Location	21.86	2	10.93	4.38	**0.032**	Pooled
Site (location)	16.92	6	2.819	1.13	0.392	Pooled
Transect[A]	20.50	9	2.278	1.46	0.185	Residual
Residual[A]	84.00	54	1.556			

SNK: Tourle Street > Ref 1 = Ref 2 — Transform: none

h) Crustacean abundance — Cochran's Test: C = 0.1581 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Location	66.15	2	33.08	2.37	0.174	Si(Lo)
Site (location)	83.70	6	13.95	4.19	**0.001**	Pooled
Transect[A]	28.16	9	3.129	0.94	0.497	Pooled
Residual[A]	181.4	54	3.359			

SNK: Tourle: S1 < S2 = S3; Ref 2: S7 = S8 < S9 — Transform: Sqrt(X+1)

i) Nereididae abundance — Cochran's Test: C =0.1802 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Location	6103.4	2	3051.7	12.53	**0.007**	Si(Lo)
Site (location)	1460.9	6	243.5	0.84	0.542	Pooled
Transect[A]	1713.8	9	190.4	0.66	0.743	Pooled
Residual[A]	16499.0	54	305.5			

SNK: Tourle Street < Ref 1 = Ref 2 — Transform: none

j) Hyalidae species 1 abundance — Cochran's Test: C = 0.2656 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Location	111.6	2	55.78	4.93	0.054	Si(Lo)
Site (location)	67.87	6	11.31	3.81	**0.003**	Pooled
Transect[A]	12.09	9	1.344	0.45	0.900	Pooled
Residual[A]	174.7	54	3.236			

SNK: Ref 2: S7 = S8 > S9 — Transform:Sqrt(X+1)

Table 12: ANOSIM results comparing assemblages of demersal fish and invertebrates between categories and sites within categories in the Hunter River estuary in October 2002. Significant terms are in **bold** print. Alpha (α) = 0.05. Pairwise comparisons are not displayed since there were insufficient permutations to obtain a significant *p* -value.

Source of Variation	Permutations	*R*	p
Category	15	0.444	0.067
Site (Ca)	999	0.483	**0.001**

Table 13: SIMPER results comparing the relative contribution of various demersal fish and invertebrate species to the dissimilarity of the assemblages among categories. Cut-off for low contributions 90.00%. PDA = proposed dredge area, NASW = North Arm shallow water, DW = Deep water.

a) PDA and NASW

Taxon	Av. Abundance SA	Av. Abundance NAR	Av. Diss	Diss/SD	Contrib%	Cum%
Yellowfin bream	1.29	12.88	26.73	1.35	30.40	30.40
Sandy sprat	0.00	0.88	8.40	0.74	9.56	39.95
Tarwhine	2.14	0.38	8.09	0.85	9.19	49.15
Silver biddy	1.14	0.38	7.22	0.96	8.20	57.35
Luminous bay squid	0.86	0.13	6.17	0.81	7.01	64.36
School prawn	0.29	0.13	4.18	0.59	4.76	69.12
Smooth toadfish	0.14	0.63	4.12	0.61	4.69	73.81
Eastern fortescue	0.29	0.00	3.86	0.54	4.39	78.20
Dusky flathead	0.14	0.63	3.70	0.50	4.20	82.40
Sand whiting	0.00	0.13	2.50	0.34	2.85	85.25
Flattail mullet	0.00	0.13	1.83	0.35	2.08	87.33
Large tooth flounder	0.00	0.25	1.74	0.56	1.98	89.31
Yellowtail	0.00	0.13	1.70	0.35	1.93	91.25

Average Dissimilarity = 87.95

b) PDA and DW

Taxon	Av. Abundance SA	Av. Abundance DR	Av. Diss	Diss/SD	Contrib%	Cum%
Luminous bay squid	0.86	6.38	15.83	1.33	18.37	18.37
School prawn	0.29	5.38	11.16	1.10	12.95	31.32
Mulloway	0.14	2.25	10.51	1.53	12.19	43.51
Yellowfin bream	1.29	1.13	8.19	1.32	9.51	53.02
Tarwhine	2.14	0.00	5.24	0.79	6.09	59.11
Yellowtail	0.00	1.00	5.02	0.92	5.83	64.93
Silver Biddy	1.14	0.00	4.52	0.83	5.25	70.18
Red gurnard	0.00	0.75	3.68	0.62	4.27	74.45
Sandy sprat	0.00	0.75	3.54	0.55	4.11	78.56
Woods siphonfish	0.00	0.50	3.31	0.68	3.84	82.40
Eastern fortescue	0.29	0.13	2.86	0.67	3.32	85.73
Mosaic leatherjacket	0.00	0.25	1.55	0.55	1.80	87.53
Southern herring	0.00	0.13	1.22	0.36	1.41	88.94
Unidentified flatfish	0.00	0.13	1.21	0.36	1.40	90.34

Average Dissimilarity = 86.16

(Continued)

Table 13: Continued.

c) NASW and DW

Taxon	Av. Abundance NA	Av. Abundance DR	Av. Diss	Diss/SD	Contrib%	Cum%
Luminous bay squid	0.13	6.38	14.89	1.59	17.92	17.92
Yellowfin bream	12.88	1.13	12.63	1.20	15.20	33.12
School prawn	0.13	5.38	9.41	0.96	11.33	44.45
Mulloway	0.00	2.25	9.29	1.81	11.18	55.63
Sandy sprat	0.88	0.75	5.39	0.98	6.48	62.11
Yellowtail	0.13	1.00	4.34	0.98	5.22	67.33
Red gurnard	0.00	0.75	3.14	0.63	3.78	71.12
Woods siphonfish	0.13	0.50	2.97	0.75	3.58	74.70
Silver biddy	0.38	0.00	2.22	0.74	2.67	77.36
Smooth toadfish	0.63	0.00	2.16	0.52	2.60	79.97
Large tooth flounder	0.25	0.13	1.78	0.65	2.14	82.11
Dusky flathead	0.63	0.00	1.69	0.37	2.03	84.14
Glassfish	0.25	0.13	1.53	0.53	1.84	85.98
Tarwhine	0.38	0.00	1.51	0.37	1.82	87.79
Mosaic leatherjacket	0.00	0.25	1.36	0.55	1.64	89.43
Sand whiting	0.13	0.00	1.11	0.37	1.34	90.77

Average Dissimilarity = 83.1

Table 14: ANOVA results for the total abundance, number of taxa and the abundance of selected taxa of demersal fish and invertebrates from the Hunter River estuary in October 2002. N=4. Significant terms are in bold print. ^A indicates that the term was pooled (P > 0.25). PDA = Proposed dredge area, NASW = North Arm shallow water, DW = Deep water.

a) Total abundance — Transform: Sqrt(x+1), Cochran's Test: C = 0.5118 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Category	18.62	2	9.31	2.19	0.259	Si(Ca)
Site(Ca)	12.73	3	4.24	2.40	0.101	Residual
Residual	31.81	18	1.77			

b) Number of taxa — Transform: None, Cochran's Test: C = 0.2565 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Category	40.75	2	20.38	6.56	**0.006**	Pooled
Site(Ca)^A	7.75	3	2.58	0.83	0.492	Pooled
Residual^A	57.50	18	3.19			
SNK	Ca:	PDA = NASW < DW				

c) Yellowfin bream — Transform: Ln (x+1), Cochran's Test: C = 0.4161 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Category	9.25	2	4.62	1.37	0.377	Si(Ca)
Site(Ca)	10.10	3	3.37	6.63	**0.003**	Residual
Residual	9.14	18	0.51			
SNK	Si (Ca):	PDA:	Tourle St Bridge = Windmill			
		NASW:	Downstream Stockton Bridge < Upstream Stockton Bridge			
		DW:	South Arm Deep = North Arm Deep			

d) Tarwhine — Transform: None, Cochran's Test: C = 0.9172 (P < 0.01)

Source	SS	DF	MS	F	P	F versus
Category	15.75	2	7.88	0.81	0.524	Si(Ca)
Site(Ca)	29.25	3	9.75	2.15	0.129	Residual
Residual	81.50	18	4.53			

e) Mulloway — Transform: None, Cochran's Test: C = 0.8082 (P < 0.01)

Source	SS	DF	MS	F	P	F versus
Category	25.58	2	12.79	13.18	**0.000**	Pooled
Site(Ca)^A	2.13	3	0.71	0.73	0.546	Pooled
Residual^A	18.25	18	1.01			
SNK	Ca:	PDA = NASW < DW				

(Continued)

Continued.

f) Silver biddy — Transform: Ln (x+0.1), Cochran's Test: C = 0.4522 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Category	6.44	2	3.22	0.76	0.541	Si(Ca)
Site(Ca)	12.73	3	4.24	4.16	**0.021**	Residual
Residual	18.37	18	1.02			
SNK	Si (Ca):	PDA:	Tourle St Bridge < Windmill			
		NASW:	Downstream Stockton Bridge = Upstream Stockton Bridge			
		DW:	South Arm Deep = North Arm Deep			

g) Sandy sprat — Transform: None, Cochran's Test: C = 0.4835 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Category	3.58	2	1.79	1.33	0.287	Pooled
Site(Ca)[A]	5.63	3	1.88	1.39	0.274	Pooled
Residual[A]	22.75	18	1.26			

h) School prawn — Transform: Ln (x+0.1), Cochran's Test: C = 0.2956 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Category	17.30	2	8.65	0.64	0.587	Si(Ca)
Site(Ca)	40.57	3	13.52	16.69	**0.000**	Residual
Residual	14.59	18	0.81			
SNK	Si (Ca):	PDA:	Tourle St Bridge = Windmill			
		NASW:	Downstream Stockton Bridge = Upstream Stockton Bridge			
		DW:	South Arm Deep > North Arm Deep			

i) Luminous bay squid — Transform: None, Cochran's Test: C = 0.5067 (Not Significant)

Source	SS	DF	MS	F	P	F versus
Category	189.58	2	94.79	2.65	0.217	Si(Ca)
Site(Ca)	107.25	3	35.75	8.58	**0.001**	Residual
Residual	75.00	18	4.17			
SNK	Si (Ca):	PDA:	Tourle St Bridge = Windmill			
		NASW:	Downstream Stockton Bridge = Upstream Stockton Bridge			
		DW:	South Arm Deep < North Arm Deep			

Table 15: Mean fork length (+SE) in mm of economically important fishes caught from six sites in the Hunter River estuary in October 2002. SJ = small juveniles, LJ = large juveniles, A = adults, NA = non applicable.

	MFL (SE)	Min	Max	SJ	LJ	A
Proposed dredge area						
Tourle St Bridge						
Dusky Flathead	200.00 (NA)	200	200		1	
Windmill						
Mulloway	238.00 (NA)	238	238	1		
Silver Biddy	126.12 (3.28)	109	134		2	6
Snapper	143.00 (NA)	143	143	1		
Tarwhine	120.20 (2.48)	103	132	15		
Yellowfin Bream	94.67 (7.96)	72	150	8	1	
North Arm shallow water						
Downstream Stockton Bridge						
Dusky Flathead	312.00 (20.01)	256	375		3	2
Flattail Mullet	301.00 (NA)	301	301	1		
Sand Whiting	154.00 (NA)	154	154		1	
Silver Biddy	134.50 (5.50)	129	140			2
Tarwhine	141.33 (9.84)	131	161	3		
Yellowfin Bream	21.17 (16.82)	145	247		2	4
Upstream Stockton Bridge						
Large Tooth Flounder	152.00 (5.00)	147	157	2		
Silver Biddy	94.00 (NA)	94	94		1	
Yellowfin Bream	131.92 (2.90)	80	246	19	77	1
Yellowtail	41.00 (NA)	41	41	1		
Deeper water reference area						
South Arm Deep						
Mosaic Leatherjacket	43.00 (0)	43	43	2		
Mulloway	201.36 (9.75)	144	261	11		
Red Gurnard	60.83 (3.13)	54	72	6		
Stout Whiting	109.00 (NA)	109	109	1		
Yellowfin Bream	199.00 (17.00)	182	216		1	1
Yellowtail	143.00 (33.60)	36	207	2	4	
North Arm Deep						
Large Tooth Flounder	163.00 (NA)	163	163		1	
Mulloway	232.16 (3.70)	226	250	6		
Southern Herring	159.00 (NA)	159	159		1	
Tailor	175.00 (NA)	175	175		1	
Yellowfin Bream	135.50 (8.37)	108	161		6	
Yellowtail	51.00 (4.00)	47	55	2		

FIGURES

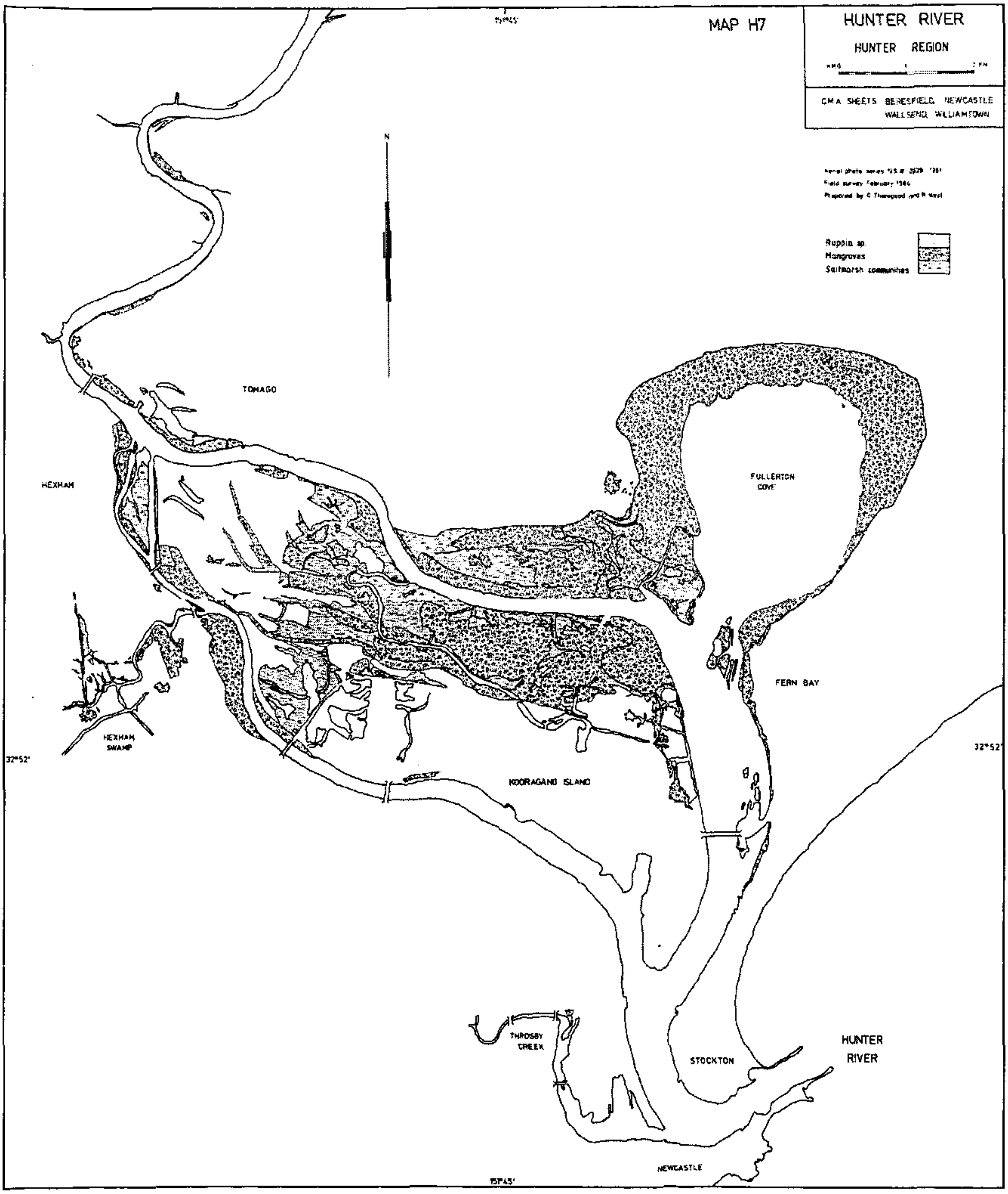

Figure 1: Map of the Hunter estuary showing habitats mapped by West *et al.* (1985).

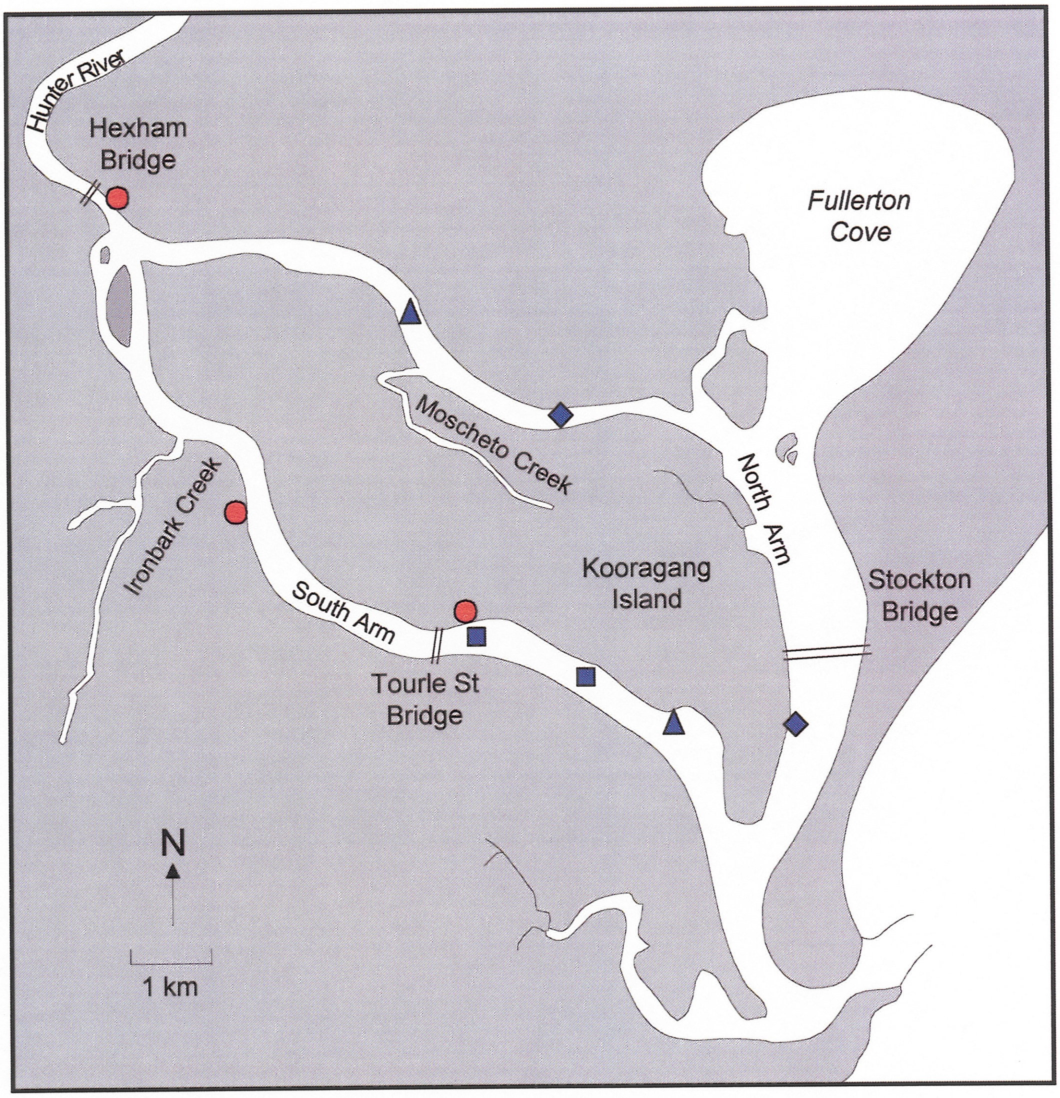

Figure 2: Location of mangrove forests (red circles) and trawl sites sampled in the Hunter River estuary in September and October 2002, proposed dredge area – blue squares, North Arm shallow water – blue diamonds, deep water – blue triangles.

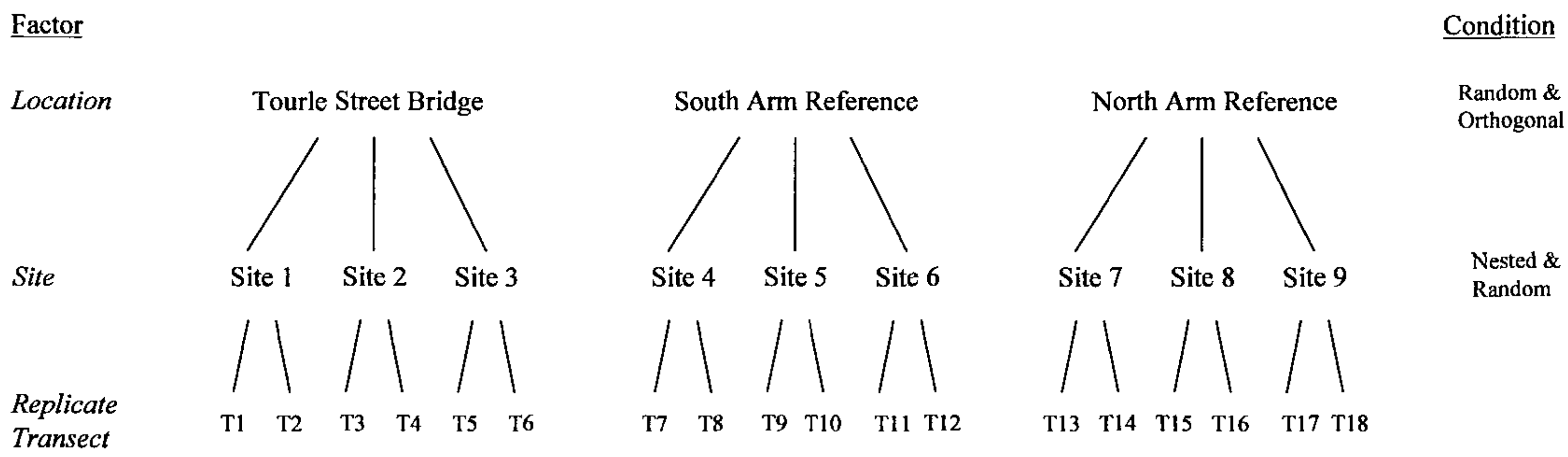

Figure 3: Sampling design for the study of damage in mangrove forest at locations in the Hunter River estuary.

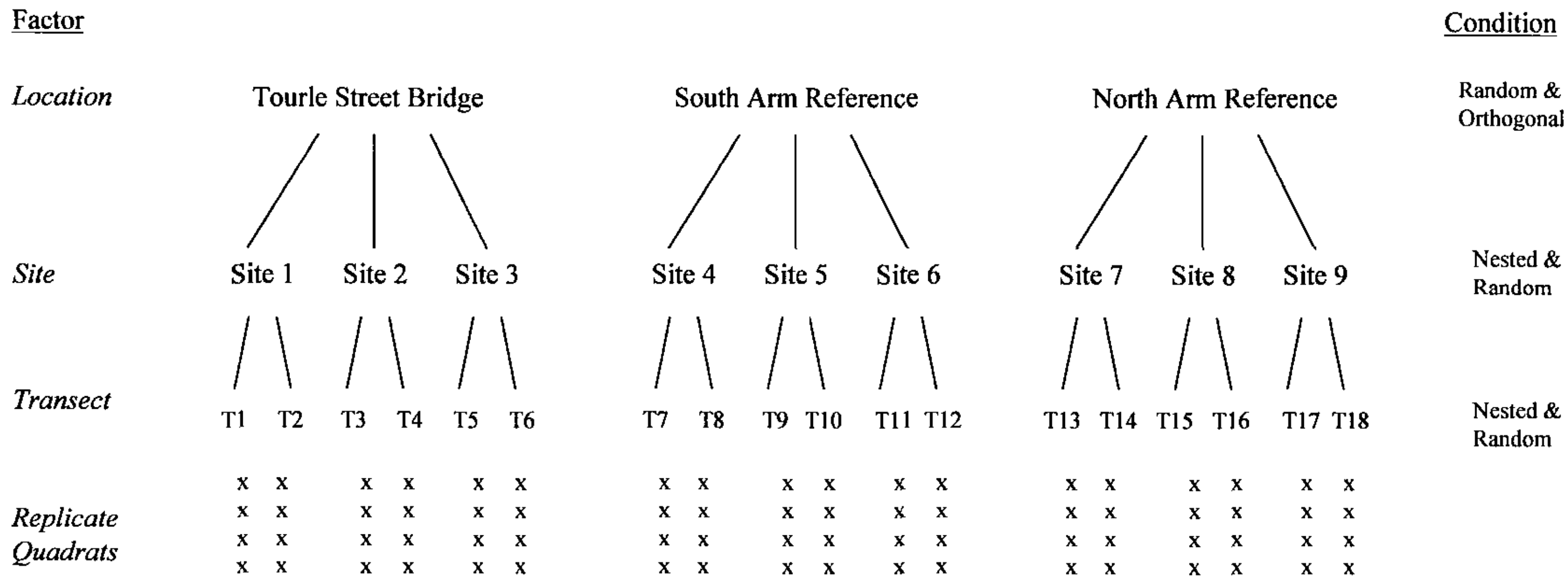

Figure 4: Sampling design for the study of habitat components and fauna per quadrat in mangrove forest at locations in the Hunter River estuary.

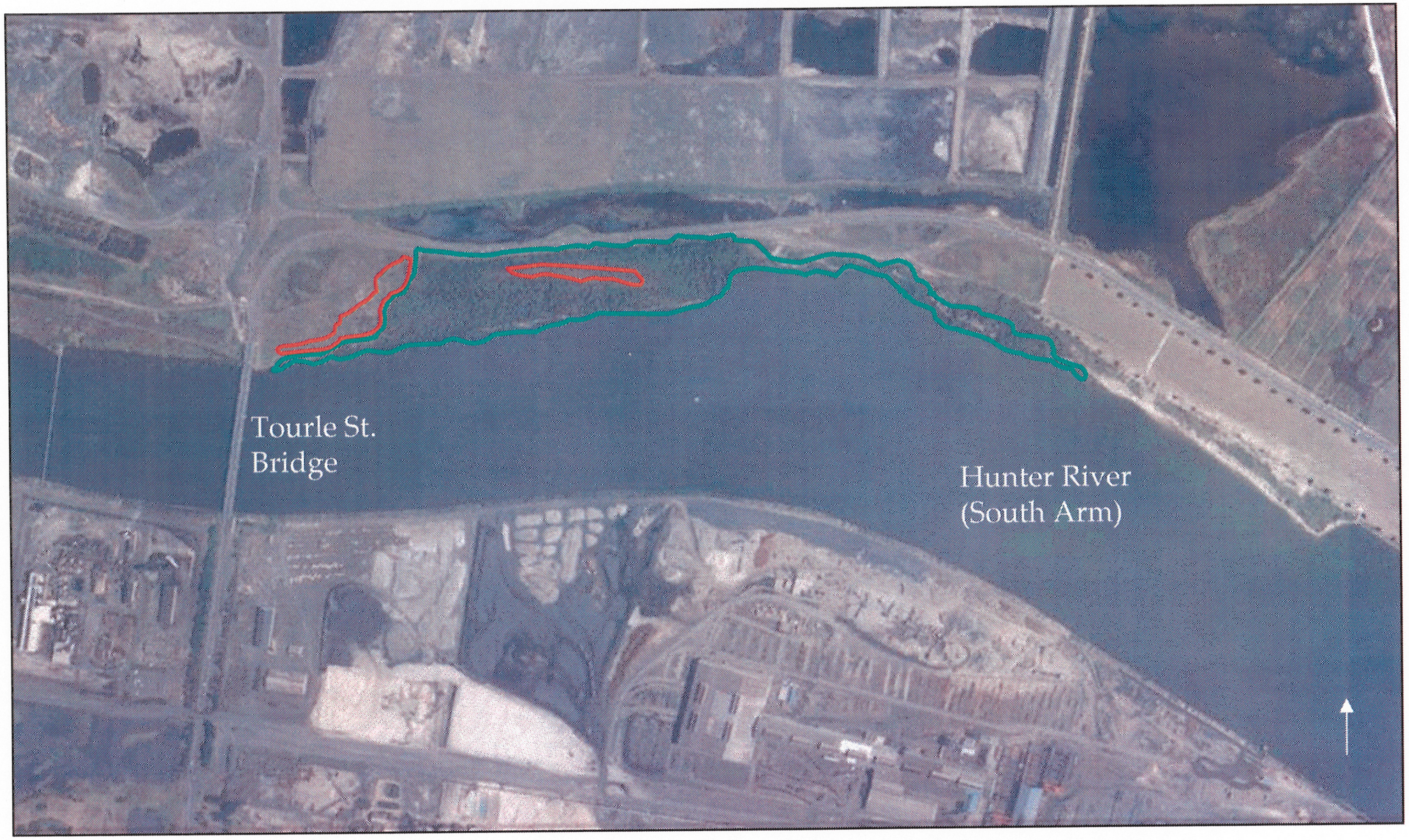

Figure 5: Aerial photograph of proposed dredging site in the Hunter River South Arm showing the existing area of mangrove (green) and saltmarsh (red) habitat.

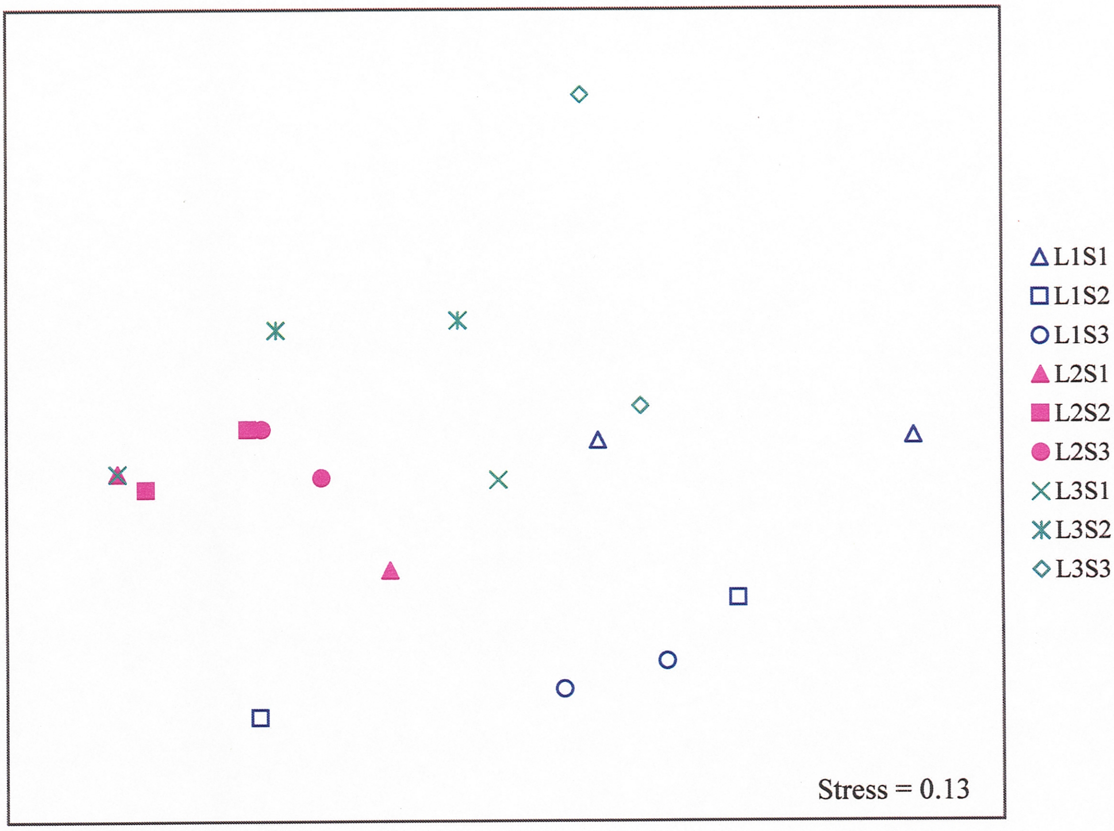

Figure 6: Two-dimensional MDS plot of mangrove habitat components at Tourle Street bridge (L1), South Arm Reference (L2) and North Arm Reference Location (L3) at three sites (colours). N=2 replicate transects.

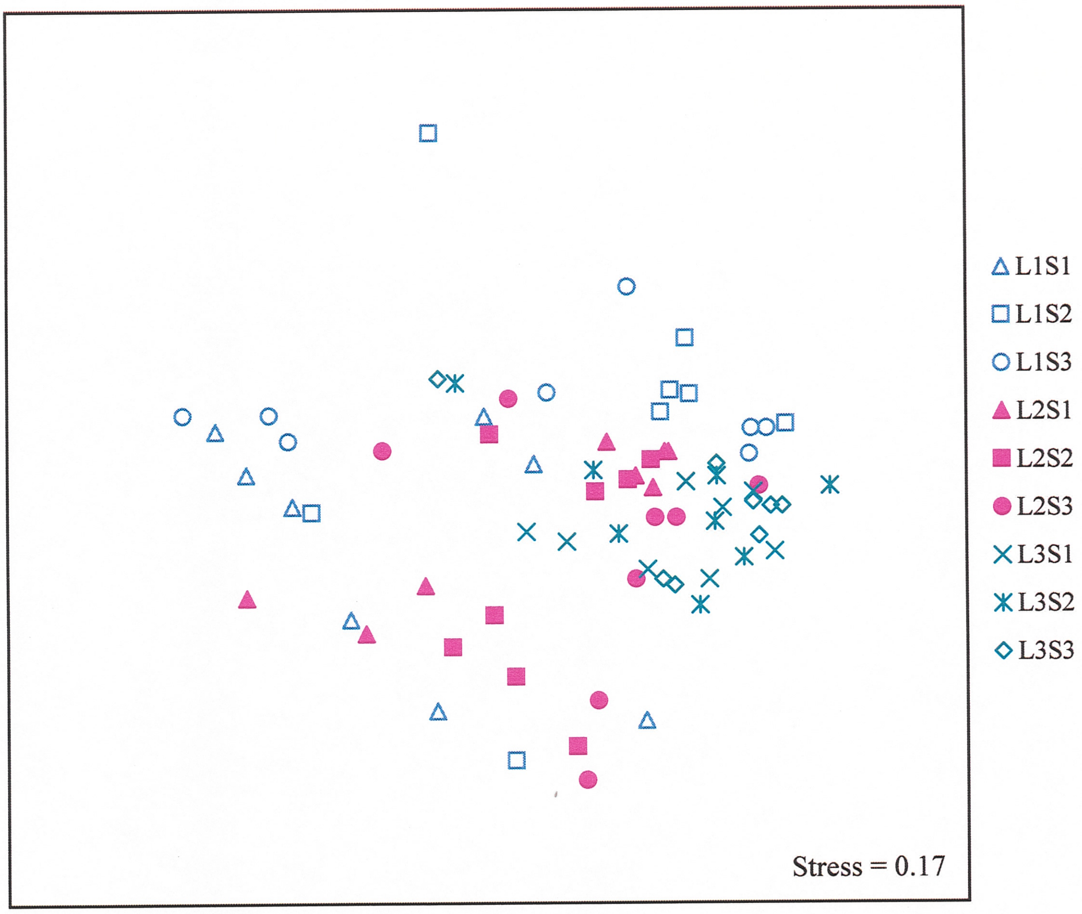

Figure 7: Two-dimensional MDS plot of benthic assemblage at Tourle Street bridge (L1), South Arm Reference (L2) and North Arm Reference location (L3) at three sites (colours). N=8 replicate quadrats.

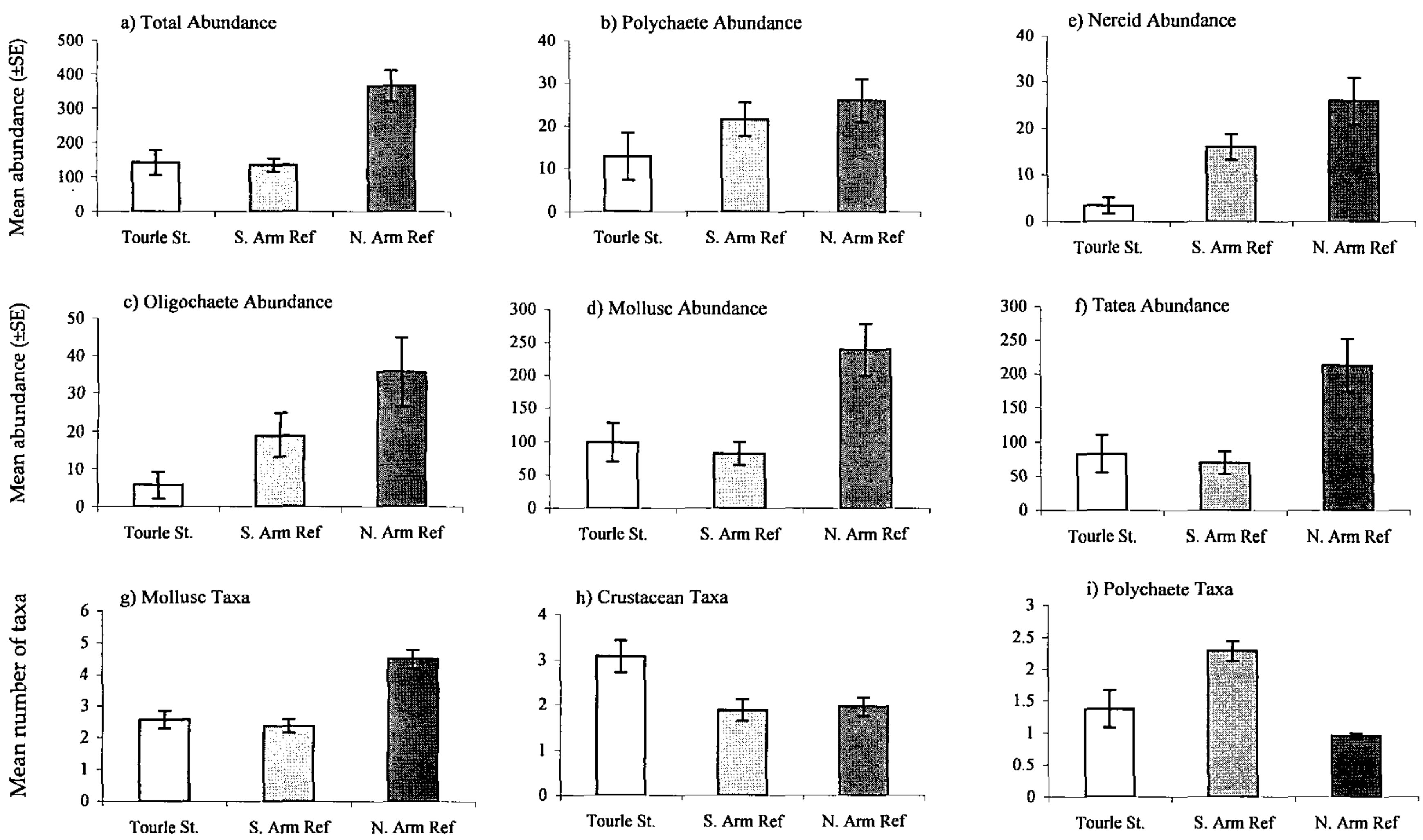

Figure 8: Mean number or mean abundance of benthic invertebrate taxa per 0.1 m^2 in mangrove forests at Tourle Street Bridge location, South Arm and North Arm reference locations.

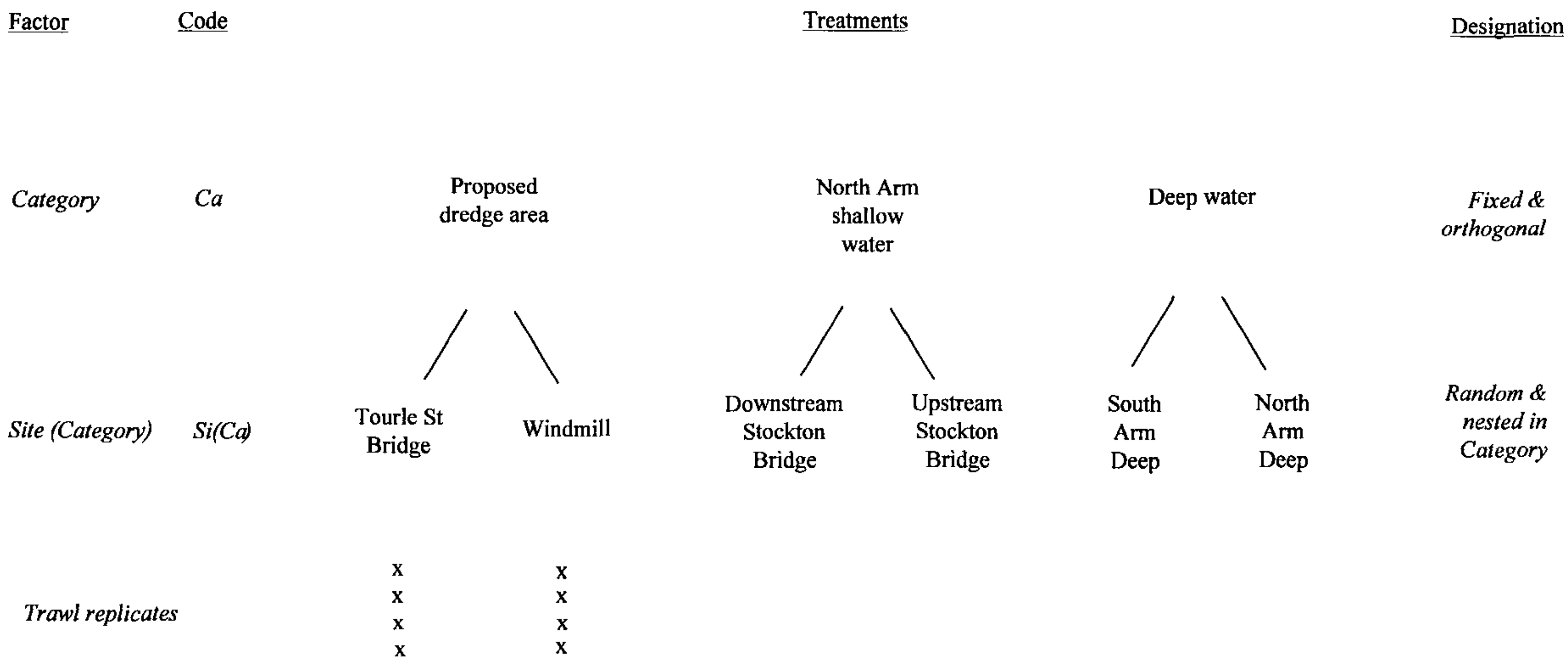

Figure 9: Sampling design for the survey of demersal fish and invertebrates in the Hunter River estuary in October 2002. ($N = 4$).

Figure 10. Two-dimensional nMDS plot of demersal fish and invertebrate assemblages from six sites in the Hunter River estuary in October 2002. TSB = Tourle St Bridge, WM = Windmill, DSB = Downstream Stockton Bridge, USB = Upstream Stockton Bridge, SAD = South Arm Deep, NAD = North Arm Deep. N=4 replicate trawls.

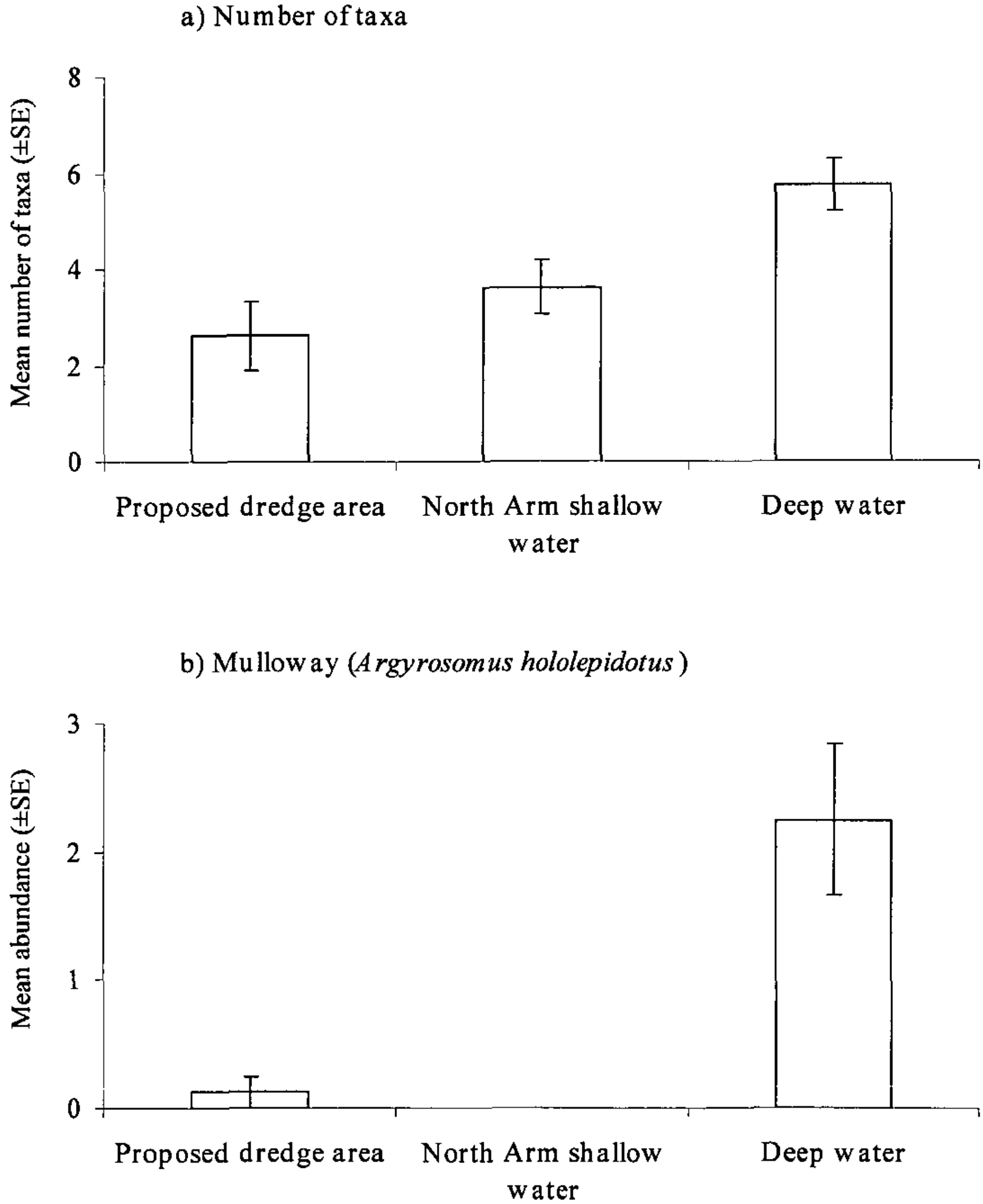

Figure 11: Mean (±SE) number of taxa and mulloway abundance in three categories in the Hunter River estuary in October 2002. N = 8.

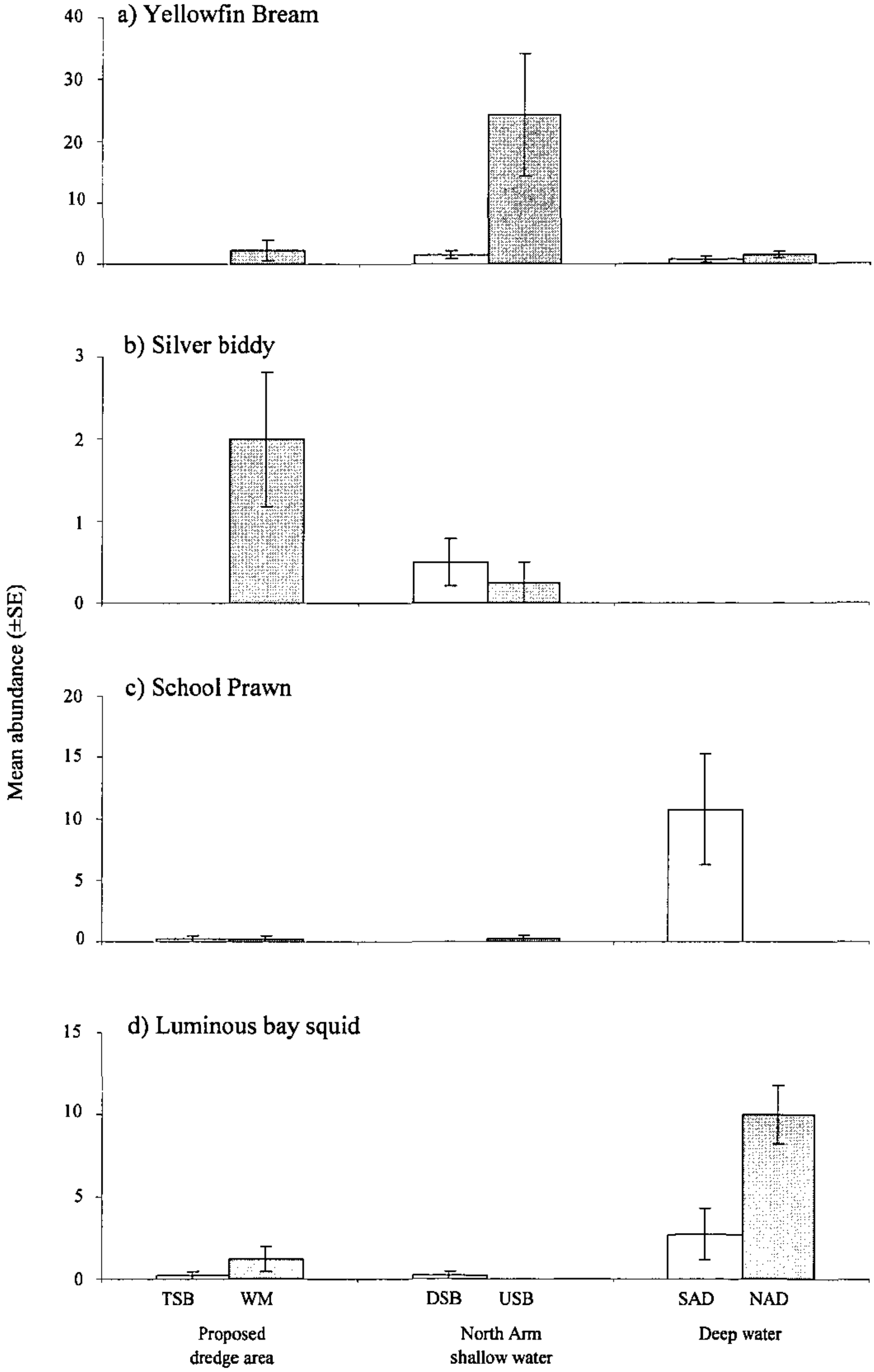

Figure 12. Mean (±SE) abundance of yellowfin bream, silver biddy, school prawns and luminous bay squid at six sites in the Hunter River estuary in October 2002. N = 4.TSB = Tourle St Bridge, WM = Windmill, DSB = Downstream Stockton Bridge, USB = Upstream Stockton Bridge, SAD = South Arm Deep, NAD =North Arm Deep.

APPENDICES

Appendix 1: Statistical procedures.

Appendix 2: GPS coordinates of mangrove forest at the proposed dredging site east of Tourle Street Bridge.

Appendix 3: GPS coordinates of transects sampled at each mangrove location.

Appendix 4: Mean (± SE) abundance of benthic taxa from each location.

Appendix 5: Taxonomic classification of benthic fauna identified in mangrove forests.

Appendix 6: GPS coordinates of replicate trawls taken at sites in the lower Hunter River.

Appendix 7: Water quality measures taken at trawl sites in the lower Hunter River.

Appendix 8: Mean abundance of demersal fish and invertebrates collected from trawling in the lower Hunter River.

Appendix 1: Summary of Statistical Procedures

Data were analysed statistically using two broad procedures, multivariate and univariate analysis. Multivariate analysis allows us to examine differences among sites, locations, times and depth for all species or taxa present (commonly called "the assemblage"). Univariate analysis allows us to examine differences for a single species or factor among sites, locations, times and depth.

Multivariate analyses were done using PRIMER (Version 5.2). Bray-Curtis similarities were calculated between every pair of samples. The ANOSIM test statistic, *R*, was calculated using the average rank similarity among pairs of replicates within each of the groups minus the average rank similarity of replicates between groups and was scaled to give a value between -1 and 1 (Clark 1993). Thus *R* approaches 1 when all pairs of replicates within a group are more similar to each other than they are to pairs of replicates from another group (i.e. groups are different) and *R* approaches 0 when, on average, pairs of replicates within a group and between groups are equally similar (i.e. no difference between groups). If R approaches -1, then pairs consisting of one replicate from each group are more similar to each other than pairs of replicates from the same group (Clarke 1993). Pairwise comparisons were used to determine which sites or locations differed. Groups are considered to be well separated if the R values are greater then 0.75, overlapping but clearly different if the R values are greater than 0.5 and barely separable if the R values are less than 0.25 (Clarke & Gorley, 2001).

Variation in the assemblage of species between sites and among locations was assessed using multivariate procedures such as Bray-Curtis similarity matrix with the statistical program PRIMER (Clarke, 1993). Spatial variation in assemblages was examined using analysis of similarities (ANOSIM). The null hypothesis tested was one of no difference between sites and among locations. The significance levels in pairwise tests were adjusted to allow for multiple comparisons using the Bonferroni correction (Winer *et al.*, 1991). Variation in assemblages was presented graphically using multi-dimensional scaling (MDS) plots, based on Bray-Curtis similarity measures. The adequacy of the three dimensional representations of the similarities among samples is assessed by examining the stress value. This value is in no way connected to any measure of "environmental stress". Stress values of < 0.1 indicate a good representation which may be easily interpreted and plots with < 0.2

indicate reasonable representation of the data. Plots where stress values exceed 0.2 indicate a poor representation of the relationship among samples in three dimensions and are of little value (Clarke, 1993). If variation in assemblages was detected, the species that contributed most to the dissimilarity among places or times was identified using similarity of percentage (SIMPER) analyses.

Species richness, total abundance and individual taxa that were identified as contributing substantially to the dissimilarity in assemblages among locations was analysed using asymmetrical analyses of variance (ANOVA). Variances was tested for homogeneity using Cochran's C-Test ($\alpha = 0.05$). Data was transformed where necessary to stabilise variances if the Cochran's C-Test was significant. If transformations fail, untransformed data was used but the level of significance, α, was reduced from 0.05 to 0.01 to reduce the chance of making a Type 1 error (Underwood, 1981). When the ANOVAs are significant, means was compared using planned comparisons among locations. To enable a test of the factor location, non-significant interactions at $P>0.25$ were pooled (Underwood 1981).

Appendix 2: GPS coordinates of mangrove forest area at the proposed dredging site east of Tourle Street Bridge. Datum: WGS 84.

Position	Northing	Eastings
1	382879	6361508
2	382777	6361555
3	382682	6361588
4	382633	6361607
5	382560	6361664
6	382500	6361671
7	382400	6361681
8	382329	6361697
9	382290	6361664
10	382260	6361636
11	382178	6361637
12	382099	6361626
13	382031	6361627
14	381955	6361600
15	381892	6361607
16	381816	6361590
17	381779	6361575

Position	Northing	Eastings
18	381641	6361569
19	381585	6361563
20	381548	6361560
21	381570	6361569
22	381642	6361586
23	381730	6361612
24	381747	6361627
25	381765	6361677
26	381818	6361747
27	381897	6361735
28	382023	6361754
29	382294	6361762
30	382394	6361740
31	382573	6361714
32	382797	6361641
33	382841	6361581

Appendix 3: GPS coordinates of mangrove forest transects at the Tourle Street Bridge location (Location 1), the South Arm Reference location (Location 2) and the North Arm Reference Location (Location 3). Datum: WGS 84.

			Start		End	
Location	Site	Transect	Northings	Eastings	Northings	Eastings
1	1	1	381827	6361593	381825	6361726
1	1	2	381836	6361599	381851	6361731
1	2	3	381944	6361609	382939	6361729
1	2	4	381961	6361609	381975	6361741
1	3	5	382041	6361634	382039	6261748
1	3	6	382057	6361633	382057	6361743
2	4	7	379353	6372999	379201	6362985
2	4	8	379347	6362988	379210	6362967
2	5	9	379354	6362898	379253	6362885
2	5	10	379353	6362884	379203	6362875
2	6	11	379361	6362794	379225	6362810
2	6	12	379362	6362789	379240	6362805
3	7	13	377285	6367441	377370	6367558
3	7	14	377296	6367436	377383	6367539
3	8	15	377406	6367377	377466	6367463
3	8	16	377412	6367371	377440	6367455
3	9	17	377515	6367563	377571	6367378
3	9	18	377522	6367303	377571	6367357

Appendix 4: Mean abundance of benthos in mangrove forests in the lower Hunter River.

	Tourle Street Bridge												South Arm Reference					
	Site 1				Site 2				Site 3				Site 4				Site 5	
	Tr 1		Tr2		Tr3		Tr4		Tr5		Tr6		Tr7		Tr8		Tr9	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
1. POLYCHAETES																		
Capitellidae	1.00	1.00	0.00	0.00	14.00	13.34	0.50	0.50	15.75	15.42	0.50	0.29	1.00	0.58	1.75	1.18	5.50	4.84
Cirratulidae	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	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	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nereididae	4.25	4.25	2.50	2.50	10.00	9.34	0.50	0.50	2.50	1.89	0.75	0.75	6.50	1.85	13.00	3.76	16.25	4.71
Orbiniidae	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sabellidae	0.50	0.50	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spionidae	0.25	0.25	0.00	0.00	4.75	3.09	1.50	1.50	12.00	11.02	4.75	2.81	1.25	0.63	1.25	0.63	1.25	1.25
2. CRUSTACEANS																		
Order: Amphipoda																		
Aoridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hyalidae (hyalid sp 1)	1.00	0.71	2.00	1.68	22.75	21.42	3.00	1.29	14.25	10.99	7.50	7.50	3.00	1.78	2.25	1.03	8.50	5.68
Hyalidae (hyalid sp 2)	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
Lysianassidae	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
Order: Isopoda																		
Sphaeromatidae sp1	0.00	0.00	0.00	0.00	0.50	0.50	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25
Sphaeromatidae sp2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.75	1.75	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00
Order: Tanaidacea																		
Leptocheliidae	0.00	0.00	0.00	0.00	6.25	6.25	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Caridea (shrimps)																		
Macrobrachium intermedium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00
Brachyura (crabs)																		
Helographsus haswellianus	0.00	0.00	0.75	0.75	0.50	0.50	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Paragrapsus laevis	0.00	0.00	0.00	0.00	0.50	0.50	0.50	0.50	0.00	0.00	0.50	0.50	0.25	0.25	0.00	0.00	0.25	0.25
Sesarma erythrodactyla	0.25	0.25	3.25	2.29	5.00	2.80	2.00	2.00	5.50	2.63	1.25	1.25	0.25	0.25	0.00	0.00	0.25	0.25
Diogenidae	0.00	0.00	0.25	0.25	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
Australoplax tridentata	0.00	0.00	0.50	0.29	0.75	0.48	1.50	1.19	1.75	0.75	0.00	0.00	1.00	1.00	0.00	0.00	1.25	1.25
Juvenile crabs	2.50	1.50	2.50	1.32	8.75	1.70	3.25	1.49	10.75	5.94	7.00	4.73	0.00	0.00	1.50	1.19	1.00	0.71
Megalopa larvae	0.25	0.25	0.00	0.00	0.25	0.25	0.25	0.25	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 4 continued: Mean abundance of benthos in mangrove forests in the lower Hunter River.

	Tourle Street Bridge												South Arm Reference					
	Site 1				Site 2				Site 3				Site 4				Site 5	
	Tr 1		Tr2		Tr3		Tr4		Tr5		Tr6		Tr7		Tr8		Tr9	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Balanidae																		
Cirripedia (barnacle sp.1)	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3. MOLLUSCS																		
Class Gastropoda																		
Salinator solida	17.00	13.69	7.50	1.71	14.00	8.18	1.25	0.75	13.50	6.59	6.50	2.96	11.50	7.26	20.75	4.15	8.50	5.55
Assiminea buccinoides	3.50	3.50	0.75	0.75	3.75	2.39	0.00	0.00	0.25	0.25	0.75	0.75	1.00	1.00	0.75	0.75	0.00	0.00
Ophicardelus ornatus	9.75	9.75	4.00	3.67	2.75	2.75	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	1.25	0.75	0.00	0.00
Ophicardelus quoyi	1.00	1.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	1.00	0.41	0.00	0.00
Ophicardelus sulcatus	0.75	0.75	0.50	0.50	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00
Class Bivalva																		
Tatea spp	1.25	0.63	14.50	8.07	166.50	98.29	55.75	31.95	160.00	88.67	100.75	89.46	69.25	40.93	89.50	33.17	57.75	32.54
Arthritica helmsi	0.00	0.00	0.00	0.00	0.75	0.75	1.00	0.71	4.75	4.75	1.50	1.50	0.00	0.00	0.00	0.00	0.00	0.00
Glauconome plankta	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hiatella australis	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Class Littorinoidea																		
Bembicium auratum	0.00	0.00	0.25	0.25	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5. OTHER PHYLA																		
Oligochaeta	21.00	21.00	4.50	4.17	0.25	0.25	0.75	0.48	4.75	4.75	3.75	2.59	7.75	4.59	3.50	1.55	15.50	9.56
Nematoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.75	2.75	0.25	0.25	0.00	0.00	0.00	0.00	0.50	0.50
Mugilogobius paludis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.75	0.75	0.00	0.00	0.00	0.00	0.00	0.00
Arachnida	0.00	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Insect larvae	7.25	5.36	3.00	0.71	4.50	1.66	1.25	1.25	2.00	1.22	1.25	0.75	0.50	0.50	2.50	1.26	1.25	0.75
Adult insects	0.25	0.25	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 4 continued: Mean abundance of benthos in mangrove forests in the lower Hunter River.

	South Arm Reference										North Arm Reference							
	Site 5		Site 6				Site 7				Site 8				Site 9			
	Tr10		Tr11		Tr12		Tr13		Tr14		Tr15		Tr16		Tr17		Tr18	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
1. POLYCHAETES																		
Capitellidae	1.00	0.41	14.00	11.49	1.75	0.63	0.00	0.00	0.00	0.00	0.00	0.00	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	0.00	0.00	0.00	0.00	0.00	0.00	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	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nereididae	14.00	4.67	21.50	9.85	24.75	11.18	13.00	4.98	24.25	8.34	19.25	13.38	43.25	15.32	28.00	14.82	27.75	15.74
Orbiniidae	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
Sabellidae	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
Spionidae	1.25	0.25	1.50	0.65	1.50	1.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2. CRUSTACEANS																		
Order: Amphipoda																		
Aoridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hyalidae (hyalid sp 1)	13.50	5.52	8.50	3.01	7.00	4.34	15.50	6.74	6.75	1.03	24.00	9.29	26.25	4.96	56.00	18.13	44.50	11.53
Hyalidae (hyalid sp 2)	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.48	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Lysianassidae	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	0.25	0.25
Order: Isopoda																		
Sphaeromatidae sp1	0.50	0.50	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	0.25	0.25
Sphaeromatidae sp2	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
Order: Tanaidacea																		
Leptocheliidae	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
Caridea (shrimps)																		
Macrobrachium intermedium	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
Brachyura (crabs)																		
Helographsus haswellianus	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
Paragrapsus laevis	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00
Sesarma erythrodactyla	0.75	0.48	0.75	0.48	0.50	0.50	0.25	0.25	0.50	0.29	0.00	0.00	0.25	0.25	2.25	0.48	1.75	0.63
Diogenidae	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
Australoplax tridentata	0.25	0.25	0.25	0.25	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
Juvenile crabs	0.25	0.25	1.25	0.48	2.25	1.31	0.00	0.00	1.50	0.96	0.50	0.50	1.00	1.00	0.00	0.00	0.00	0.00
Megalopa larvae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 4 continued: Mean abundance of benthos in mangrove forests in the lower Hunter River.

	South Arm Reference										North Arm Reference							
	Site 5		Site 6				Site 7				Site 8				Site 9			
	Tr10		Tr11		Tr12		Tr13		Tr14		Tr15		Tr16		Tr17		Tr18	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Balanidae																		
Cirripedia (barnacle sp.1)	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
3. MOLLUSCS																		
Class Gastropoda																		
Salinator solida	9.50	3.30	6.00	2.86	9.75	4.77	9.25	3.94	7.50	1.26	4.75	1.93	17.25	1.80	6.75	2.43	16.75	4.99
Assiminea buccinoides	1.25	0.95	0.00	0.00	0.00	0.00	1.00	1.00	2.50	2.50	1.50	1.50	2.00	1.68	1.00	0.71	2.25	0.75
Ophicardelus ornatus	0.00	0.00	0.25	0.25	0.50	0.50	3.00	1.91	3.25	1.80	6.50	3.18	3.75	1.25	22.25	15.45	10.75	2.32
Ophicardelus quoyi	0.00	0.00	0.00	0.00	0.00	0.00	1.50	0.87	2.50	1.19	2.00	1.35	2.50	1.32	2.25	0.85	4.75	1.80
Ophicardelus sulcatus	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	3.50	2.87	3.00	1.58	5.75	5.42	5.00	3.72
Class Bivalva																		
Tatea spp	24.75	15.69	47.75	29.92	131.50	79.56	99.25	39.13	247.50	70.92	150.75	45.76	288.25	186.20	181.50	62.12	311.75	106.02
Arthritica helmsi	3.25	2.63	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
Glauconome plankta	0.00	0.00	0.25	0.25	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
Hiatella australis	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
Class Littorinoidea																		
Bembicium auratum	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
5. OTHER PHYLA																		
Oligochaeta	12.00	3.81	36.25	14.78	38.75	27.43	28.50	15.06	44.00	32.03	63.50	38.41	13.00	6.15	39.00	21.24	26.25	11.96
Nematoda	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	0.25	0.25	0.25	0.25
Mugilogobius paludis	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
Arachnida	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
Insect larvae	0.75	0.75	2.50	0.87	5.00	3.44	47.25	18.82	45.75	22.24	28.50	9.92	21.00	13.25	17.50	4.41	47.25	25.17
Adult insects	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	0.25	0.25

Appendix 5: Taxonomic classification of benthos in mangrove forests in the lower Hunter River.

Phyla: ANNELIDA
Class: Polychaeta
Family: Capitellidae
Family: Cirratulidae
Family: Nephtyidae
Family: Nereididae
Family: Orbiniidae
Family: Sabellidae
Family: Spionidae
Class: Oligochaeta

Phyla: ARTHROPODA
Super Class: CRUSTACEA
Order: Amphipoda
Family: Aoridae
Family: Hyalidae (hyalid sp 1)
Family: Hyalidae (hyalid sp 2)
Family: Lysianassidae
Order: Cyclopoida

Order: Isopoda
Family: Sphaeromatidae
Sphaeromatid sp1
Sphaeromatid sp2

Order: Tanaidacea
Leptocheliidae

Order: Decapoda
Infra Order: Caridea (shrimps)
Family: Palaemonidae
Macrobrachium intermedium

Infra Order: Brachyura (crabs)
Family: Grapsiidae
Helographsus haswellianus
Paragrapsus laevis
Sesarma erythrodactyla
Family: Ocypodidae
Australoplax tridentata
Juvenile crabs
Megalopa larvae

Order: Decapoda continued
Infra Order: anomura (hermit crab)
Family: Diogenidae
Infra Order: Balanidae
Family: Cirripedia (barnacle sp.1)

Class: Insecta
Insect larvae
Adult insects

Class: Chelicerata
Subclass: Arachnida
Arachnida (spiders)

Phyla: MOLLUSCA
Class Gastropoda
Family: Amphibolidae
Salinator solida
Family: Assiminiidae
Assiminea buccinoides
Family: Ellobiidae
Ophicardelus ornatus
Ophicardelus quoyi
Ophicardelus sulcatus
Family: Hydrobiidae
Tatea spp

Class Bivalva
Family: Galeommatiidae
Arthritica helmsi
Family: Glauconomidae
Glauconome plankta
Family: Hiatellidae
Hiatella australis

Class Littorinoidea
Family: Lacuninae
Bembicium auratum

OTHER WORM GROUPS
Phyla: Nematoda

OTHER GROUPS
Mugilogobius paludis (fish)

Appendix 6: GPS coordinates of replicate trawls taken within the South Arm proposed dredge area (Location 1), North Arm shallow water reference area (Location 2) and the deeper water reference area (Location 3). Datum: WGS 84.

			Start		End	
Location	Site	Replicate	Northings	Eastings	Northings	Eastings
1	1	1	0381677	6361395	0382001	6361403
1	1	2	0381644	6361418	0381967	6361445
1	1	3	0381664	6361471	0381938	6361465
1	1	4	0382235	6361437	0382373	6361458
1	2	1	0383251	6361175	0382832	6361450
1	2	2	0384022	6360732	0383618	6361020
1	2	3	0383499	6361078	0383077	6361291
1	2	4	0383119	6361200	0383415	6361100
2	3	1	0386196	6359722	0386002	6359330
2	3	2	0385992	6359248	0386139	6359534
2	3	3	0386190	6359553	0386279	6359834
2	3	4	0386005	6359286	0385705	6358810
2	4	1	0384596	6364362	0384277	6364356
2	4	2	0384147	6364346	0383802	6364320
2	4	3	0383692	6364325	0383332	6364339
2	4	4	0383355	6364325	0382985	6364377
3	5	1	0384938	6360212	0384444	6360430
3	5	2	0384929	6360098	0384501	6360426
3	5	3	0384752	6360375	0384228	6360344
3	5	4	0384462	6360330	0384862	6359968
3	6	1	0381441	6365561	0381265	6365938
3	6	2	0381320	6365854	0381480	6365398
3	6	3	0381501	6365449	0381353	6365822
3	6	4	0381354	6365779	0381486	6365324

Appendix 7: Water quality measurements taken at trawl sites in the Hunter River estuary in October 2002.

	South Arm Proposed Dredge Area		South Arm Proposed Dredge Area		North Arm Shallow Water Reference		North Arm Shallow Water Reference		Deep Water Reference		Deep Water Reference	
	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
	Time: 9:15 Depth: 2.0m		Time: 12.55 Depth: 3.0m		Time: 7:25 Depth: 2.8m		Time: 9:00 Depth: 1.8m		Time:12:35 Depth:16.0m		Time: 10:08 Depth: 10.5m	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
Temperature (°C)	18.87	18.50	19.66	19.27	19.09	19.11	19.70	19.69	19.31	18.56	20.29	19.69
Turbidity (NTU)	18.30	7.20	18.80	18.10	23.20	22.20	24.90	22.70	27.50	12.70	18.20	13.30
Dissolved Oxygen (mg/L)	6.50	6.60	6.60	6.80	6.10	6.00	6.00	5.70	6.50	6.30	6.20	5.60
Dissolved Oxygen (% Sat.)	85.00	85.50	88.90	90.00	81.30	80.40	78.80	75.30	NDA[A]	NDA[A]	79.40	74.00
pH	8.36	8.40	8.70	8.74	8.41	8.34	8.24	8.22	8.50	8.50	8.17	8.24
Salinity (ppt)	33.01	33.44	34.88	34.93	34.80	34.81	31.24	31.51	34.91	34.93	25.38	31.55

[A] No data available

Appendix 8: Mean abundance of demersal fish and invertebrates collected from the Hunter River estuary by trawling in October 2002. N = 4.

			South Arm Proposed Dredge Area				North Arm Shallow Water Reference				Deep Water Reference			
			Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
Family name	Common name	Scientific name	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
FISH														
Chandidae	Glassfish	*Ambassis* spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.25	0.25
Engraulidae	Anchovy	*Engraulis australis*	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00
Gerreidae	Common Silver Biddy	*Gerres subfasciatus*	0.00	0.00	2.00	0.82	0.50	0.29	0.25	0.25	0.00	0.00	0.00	0.00
Platycephalidae	Dusky Flathead	*Platycephalus fuscus*	0.25	0.25	0.00	0.00	1.25	1.25	0.00	0.00	0.00	0.00	0.00	0.00
Scorpaenidae	Eastern Fortesque	*Centropogon australis*	0.50	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00
Mugildae	Flattail Mullet	*Liza argentea*	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00
Paralichthyidae	Large Tooth Flounder	*Pseudorhombus arsius*	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.29	0.00	0.00	0.25	0.25
Monacanthidae	Mosaic Leatherjacket	*Eubalichthys mosaicus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.29	0.00	0.00
Sciaenidae	Mulloway	*Argyrosomus hololepidotus*	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	2.75	0.48	1.75	1.11
Triglidae	Red Gurnard	*Chelidonichthys kumu*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50	0.87	0.00	0.00
Sillaginidae	Sand Whiting	*Sillago ciliata*	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00
	Stout Whiting	*Sillago robusta*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00
Clupeidae	Sandy Sprat	*Hyperlophus vittatus*	0.00	0.00	0.00	0.00	1.25	0.95	0.50	0.29	0.00	0.00	1.50	0.96
	Southern Herring	*Herklotsichthys castelnaui*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25
Tetraodontidae	Smooth Toadfish	*Tetractenos glaber*	0.25	0.25	0.00	0.00	1.00	1.00	0.25	0.25	0.00	0.00	0.00	0.00
Pomatomidae	Tailor	*Pomatomus saltatrix*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25
Sparidae	Tarwhine	*Rhabdosargus sarba*	0.00	0.00	3.75	2.50	0.75	0.75	0.00	0.00	0.00	0.00	0.00	0.00
	Snapper	*Chrysophrys aurata*	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Yellowfin Bream	*Acanthopagrus australis*	0.00	0.00	2.25	1.65	1.50	0.65	24.25	9.98	0.75	0.48	1.50	0.50
Tetraodontidae	Weeping Toadfish	*Torquigener pleurogramma*	0.00	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00
Apogonidae	Woods Siphonfish	*Siphaemia cephalotes*	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	1.00	0.41	0.00	0.00
Carangidae	Yellowtail	*Trachurus novaezelandiae*	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	1.50	0.87	0.50	0.29
Soleidae	Unidentified Flatfish		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25
Dasyatididae	Stingray		0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INVERTEBRATES														
Loliginidae	Luminous Bay Squid	*Loliolus noctiluca*	0.25	0.25	1.25	0.75	0.25	0.25	0.00	0.00	2.75	1.55	10.00	1.78
Penaeidae	School Prawn	*Metapenaeus macleayi*	0.25	0.25	0.25	0.25	0.00	0.00	0.25	0.25	10.75	4.50	0.00	0.00
Aplysiidae	Sea Hare	*Aplysia* spp.	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alpheidae	Snapping Shrimp		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00