Centre for Environmental Contaminants Research

Energy Technology

Gunnamatta Bay Contaminated Sediment Investigation and Remediation Plan

Stage 1 Report

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CSIRO Report No: ET/IR682

Prepared for

Sutherland Shire Council and the Department of Infrastructure, Planning & Natural Resources

May, 2004

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EXECUTIVE SUMMARY

As part of the 'Head of Gunnamatta Bay and Development of a Remediation Plan', Sutherland Shire Council (SSC) engaged the Centre for Environmental Contaminants Research, CSIRO Energy Technology, to undertake an investigation of sediment contamination and benthic invertebrate ecology in Gunnamatta Bay to provide a basis for considering the possible adverse impacts on the ecosystem, foreshore uses and recreation.

The main objectives of this consultancy were to (i) define the extent and level of sediment contamination through a detailed sampling regime, (ii) assess the risk of contaminated sediment to the ecosystem and waterway usage, (iii) develop a remediation plan based on the most cost effective strategy(s) and consultation with stakeholders, and (iv) secure all necessary approvals to action the remediation plan.

The consultancy project was undertaken in a staged approach. Stage 1 of the project was the focus of this report, and involved a comprehensive assessment of contaminant levels in the sediments and an examination of the benthic organisms (ecology) present throughout the study area. The results of assessment of sediment contaminants, contaminant bioavailability and benthic community health were used to assess the risk of the contaminated sediments to the ecosystem and waterway usage. It was proposed that the second stage of the project (Stage 2) should be undertaken if Stage 1 showed evidence of unacceptable risks to ecological and/or human health. This would include the development of a remediation plan and a review of environmental factors associated with sediment removal as part of a remediation plan.

The major water quality parameters at the Gunnamatta Bay study sites were similar to those at the reference sites in Burraneer Bay and Dolans Bay. All sites contained considerable amounts of fine sand (particles >180 µm). The sediment properties at the reference sites were generally very similar to those in Gunnamatta Bay. The Cronulla Marina and Public Wharf sites in Gunnamatta Bay were more silty than the other benthic sites. The Cronulla Marina site also had a higher amount of organic carbon.

Metal concentrations were generally below the interim sediment quality guideline trigger values (ISQG-Low) in Gunnamatta Bay, except at the inner sites of the Cronulla Marina and one site close to the boat ramp and a stormwater drain. Concentrations of Cu, Pb and Zn exceeded the guideline trigger values at these sites and exceeded the ISQG-High value for Pb and Zn at some sites. At the reference sites, no sediments had metal concentrations exceeding the trigger values. The sediment pore waters contained low concentrations of 'potentially toxic' metals. The tributyltin (TBT) concentrations were typical of estuarine bays that have significant boating activity. The TBT concentration was highest at the Cronulla Marina site and exceeded the ISQG-High value. The concentrations of all organics analysed were generally low at all sites. Detectable concentrations of polycyclic aromatic hydrocarbons (PAHs) were measured in most sediments, but were generally below or near the trigger value. TPHs, chlordane and phenol were detected at two sites. Polychlorinated biphenyls (PCBs) were detected at one site. Organochlorine (OC) pesticides were detected at one site.

Only at the marina sites with metal concentrations above ISQG-High values, were some effects to ecosystem health expected due to the combined effects of elevated Cu, Pb and Zn concentrations. Toxicity tests on sediments from the vicinity of the Cronulla Marina are recommended. In general, the concentrations of organic contaminants are not sufficiently elevated above the guideline trigger values to cause concerns for ecosystem health. For sediments where TBT concentrations exceeded the ISQG-High value, pore water analyses, elutriate testing and ultimately toxicity testing might be required.

During the survey of benthic fauna, a total of 1,680 individuals, comprising 42 taxa, were identified from the 36 grabs sampled from Gunnamatta Bay and the two control locations. Non-polychaete worms were the most abundant group (43% of all individuals), followed by polychaetes (41%), molluscs (10%), and crustaceans (6%). The top four numerically-dominant taxa were nematodes, oligochaetes, capitellids and nereidids, which together accounted for 70% of all individuals. No consistent patterns were observed in the results to suggest that

contamination has had a significant impact on the benthic assemblages at the head of Gunnamatta Bay.

The marine vegetation at the head of Gunnamatta Bay was dominated by the invasive alga, *Caulerpa taxifolia*. Three species of seagrass were also observed within the study site: *Posidonia australis*, *Zostera capricorni* and *Halophila ovalis*. Due to the extensive nature of *Caulerpa*, careful consideration is needed in determining the extent of dredging, if required, due to the effects that dredging may have on this alga. In particular, measures would need to be put in place to mitigate any effects that fragmentation of *Caulerpa* may have, not only within Gunnamatta Bay, but the Port Hacking estuary. Measures that should be considered include the use of a silt curtain to inhibit the spread of a turbid plume and fragments of *Caulerpa*, and initial skim-dredging of the dredge area to remove *Caulerpa*, followed by disposal on land.

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1 Introduction

As part of the 'Head of Gunnamatta Bay and Development of a Remediation Plan', a detailed investigation of sediment contamination and benthic invertebrate ecology in Gunnamatta Bay was undertaken to provide a basis for considering the possible adverse impacts on the ecosystem, foreshore uses and recreation.

Sutherland Shire Council (SSC) engaged the Centre for Environmental Contaminants Research, CSIRO Energy Technology, to undertake this investigation.

1.1 Background

Gunnamatta Bay is located on the northern side of Port Hacking in the southern Sydney metropolitan area. It is the easternmost of Port Hacking's northern bays and is surrounded by the Sutherland Shire suburbs of Cronulla, Woolooware and Burraneer. The study area generally encompassed the head of Gunnamatta Bay from Tonkin Park to the vicinity of the public boat ramp, Cronulla Marina and wharf (Figure 1).

A draft Gunnamatta Bay Estuary Management Plan had been prepared under the direction of the Gunnamatta and Gymea Bay Estuary Management Working Party and jointly funded by Sutherland Shire Council and the Department of Infrastructure, Planning and Natural Resources (DIPNR), under the NSW State Government Estuary Management Program. That study followed on from the Gunnamatta Bay Estuary Processes Study (January 2002), which summarised present knowledge and other background information relating to the status and trends for various physical, chemical and biological estuarine processes, and interactions between them and between other land and water uses. The Estuary Management Plan was based on the findings of the Estuary Processes Study, other background information, and the results of community and stakeholder consultation.

The Estuary Management Plan was prepared in accordance with NSW State Government Estuary Management Policy. The general goal of this policy is to achieve an integrated, balanced, responsible and ecologically sustainable use of the State's estuaries.

The goals of the Gunnamatta Bay Estuary Management Plan are to:

- enhance the quality of the Bay's waters, foreshores and aquatic habitats;
- enhance the biodiversity of Gunnamatta Bay;
- enhance the scenic amenity and natural values of Gunnamatta Bay and its foreshores and conserve cultural heritage features; and
- provide a safe and pleasant environment and access for a range of recreational pursuits, which reflect the maritime character and natural values of the Bay.

Figure 1. Gunnamatta Bay study area

2 Objectives

The main objectives of this consultancy were:

1. to define the extent and level of sediment contamination through a detailed sampling regime;
2. to assess the risk of contaminated sediment to the ecosystem and waterway usage;
3. to develop a remediation plan based on the most cost effective strategy(s) and consultation with stakeholders; and
4. to secure all necessary approvals to action the remediation plan.

1.2 Scope of Work

The Estuary Processes Study indicated that Gunnamatta Bay retains the majority of fluvial sediment that is transported into it from the catchment. Contaminants carried into the Bay are readily adsorbed by sediment particles, and so tend to accumulate. Limited sediment sampling had revealed that elevated concentrations of heavy metals and organic contaminants are present at some locations around the head of the Bay. Although there is evidence of elevated levels of contaminants in other locations within Gunnamatta Bay, this is unlikely to affect ecosystem health at current concentrations.

According to the Gunnamatta Bay Estuary Processes Study (2002), very few data are available regarding the contaminant concentrations in the sediments at the head of Gunnamatta Bay. That study reported contaminant concentrations for a single sediment sampling site within the study area (Figure 1). Sediments were collected from depths of 30 and 310 cm at the site. In the 30-cm depth sediment sample, concentrations of polycyclic aromatic hydrocarbons (PAHs), copper, lead, and mercury, were above the ANZECC/ARMCANZ (2000) interim sediment quality guideline 'trigger' values (ISQG-low). At 310-cm sediment depth, no contaminants were measured at concentrations above the guideline trigger values.

Further investigations of sediment quality are required to determine the extent of the sediment contamination at the head of Gunnamatta Bay, particularly in the vicinity of Cronulla Marina, westwards across the fluvial shoal fronting Tonkin Park.

2.1 Proposed Approach

The consultancy project was undertaken in a staged approach. Stage 1 of the project was the focus of this report, and involved a comprehensive assessment of contaminant levels in the sediments and an examination of the benthic organisms (ecology) present throughout the study area. The results of the assessment of sediment contaminants, contaminant bioavailability and benthic community health were used to assess the risk of the contaminated sediments to the ecosystem and waterway usage.

It was proposed that the second stage of the project (Stage 2) should be undertaken if Stage 1 showed evidence of unacceptable risks to ecological and/or human health. This would include the development of a remediation plan and a review of environmental factors associated with sediment removal as part of this plan.

2.1.1 Stage 1

This stage of the project involved the collection of new data on sediment contamination and benthic ecology. A combination of field and laboratory measurements was used to provide information regarding the levels of contamination three-dimensionally in the study area. Along with analyses of sediment contaminants, measurements of pH, redox potential, dissolved oxygen (DO), conductivity and temperature, and bulk sediment properties were obtained.

Physical factors such as sediment grain size, which may modify the bioavailability of different contaminants, were investigated. Analyses of organic matter (TOC) were made to allow better consideration of the bioavailability of hydrophobic organic substances (e.g. PAHs). Pore water analyses of metal contaminants were to be undertaken at selected sites (iron and manganese chemistry are important controls on pore water contaminants).

An investigation (survey) of biological communities (benthos) living in the sediments at the head of Gunnamatta Bay was also undertaken. A map of the distribution of seagrass and the invasive aquatic weeds *Caulerpa taxifolia* was prepared as part of this survey. Statistical analyses were used to investigate the populations and assemblages of benthos in relation to sediment contaminants and other sediment characteristics that may affect biological communities.

Reference sites for the benthic ecology data were selected at the heads of Burraneer Bay and Dolans Bay (within the Port Hacking Estuary). These sites were chosen to be in approximately 2 m water depths (at low tide) and have similar substrates and seagrass coverage as the Gunnamatta Bay sites. Limited sampling was undertaken at the reference sites and the data used in the assessment of the health of the biological communities in Gunnamatta Bay.

Limitations in funding available for this study restricted the amount of sampling and analyses that could be undertaken. Costly analyses of organic contaminants were made only at those sites that had 'likely' contaminant sources (e.g. stormwater drains, marinas). Similarly, the collection and analysis of sediments samples below the surface layer (depth samples) was also limited. In this regard, the analysis of sediment contamination, and benthic ecology health, may be considered 'less comprehensive'. However, sufficient information will be obtained to assess basic 'risks' to ecological and human health.

2.1.2 Stage 2

The development of a remediation plan, and review of environmental factors associated with sediment removal as part of a remediation plan will only proceed if warranted by the results of Stage 1 (i.e. evidence of unacceptable levels of sediment contamination).

If appropriate, a remediation plan will be developed based on the most cost effective strategy(s), and in consultation with stakeholders. Stakeholders will include the Sutherland Shire Council, the Department of Infrastructure, Planning & Natural Resources, the NSW Waterways, the NSW Department of Environment and Conservation, operators and users of the marina, sailing club and public wharf, community environmental groups and local residents. Provisions will be made to secure all necessary approvals to action the remediation plan. Consideration will be given to the presence of acid sulfate soils that may add to the difficulties in removing and dewatering of material.

2.2 This Document

This document (CSIRO Report No: ET/IR682) is the report for Stage 1 of the Gunnamatta Bay Contaminated Sediment Investigation and Remediation Plan investigation commenced by the CSIRO Centre for Environmental Contaminants Research on February 12, 2004. The document follows on from the following previous documents: proposal (File: ERA-120204-proposal), work plan (File: ERA-WP-240204), progress report 1 (File: ERA-PR-160304), and progress report 2 (File: ERA-PR-160404).

3 Experimental

3.1 Sampling Sites and Analyses

Sampling of sediments and benthos was conducted at on March 1 and 2, 2004, at close to low tide. A 30-min survey of the site area was undertaken by CSIRO and Ecology Labo staff. This survey involved dives to examine the extent of the weed *Caulerpa taxifolia*, and to finalise positions of the benthic ecology sites within Gunnamatta Bay (common water depth, seagrass coverage, substrate).

Four benthic ecology sites were selected with water depths of approximately 2 m. The benthic ecology sites were all selected in areas where the seagrass was absent (to aid between-site comparisons). These study sites, together with all of the sites where sediments were sampled for analyses of contaminants are shown in Figure 2.

Reference sites for the benthic ecology data were selected at the heads of Burraneer Bay and Dolans Bay, respectively (Figure 3). These sites were chosen to be in approximately 2 m water depths (at low tide) and have similar substrates and seagrass coverage to the Gunnamatta Bay sites.

General water quality parameters were measured at each site (water temperature, pH, redox potential, conductivity and DO). Measurements of sediment pH and redox potential were made in surface sediments from each site.

Surface sediment samples were collected at each site and deeper sediments only at selected sites. Analyses were made of general physico-chemical parameters (water content, density, particle size, organic carbon) and sediment metals on all samples. Analyses of organic contaminants were made at selected sites. Analyses of sediment pore waters were made at benthic ecology sampling sites.

3.2 Sediment Sample Collection and Handling

Surface sediment samples from sites in shallow water (<2 m) were obtained using an Ekman grab. For collection sites in deep water, samples were collected using a purpose-designed sediment coring device. Two personnel handled the collection equipment and containers respectively using a dirty-hands, clean-hands manner to ensure no contamination of samples occurred. This involves one person undertaking the initial handling of the sample (dirty hands) and a second person transferring the sample to a suitable container and bagging it in plastic zip-lock bags (clean hands). Cores were extruded at the site and depth and surface sediment transferred to respective containers. Powder-free vinyl gloves (Clean Room Garments) were worn at all time during sampling and new gloves were used at all sites. Core tubes were cleaned thoroughly between sites.

Sediment samples for physico-chemical parameter and metals analyses (~100 g) were transferred to 50 mL acid-washed centrifuge tubes. Sediment samples for organic analyses (~250 g) were transferred to solvent-rinsed glass jars, supplied by the Australian Governmenmt Analytical Laboratories (AGAL). Multiple sediment cores were collected to obtain sufficient sediment (composite sample) for the organic analyses. Sediment samples were stored on ice following collection. Upon return to CSIRO laboratories (Centre for Environmental Contaminants Research, Lucas Heights, Sydney) pore waters were extracted and preserved immediately (within 8 hours of collection) and the remaining sediment was frozen until analysed. Samples for organic analyses were stored on ice following collection and during transportation to the laboratory, where they were refrigerated (4ºC) until the time of analysis. Samples for organic analyses were couriered to AGAL in Esky's chilled to near 4ºC within two days of sample collection.

Figure 2. Location of sampling sites. Benthos sampling sites circled (6, 13, 21, 25).

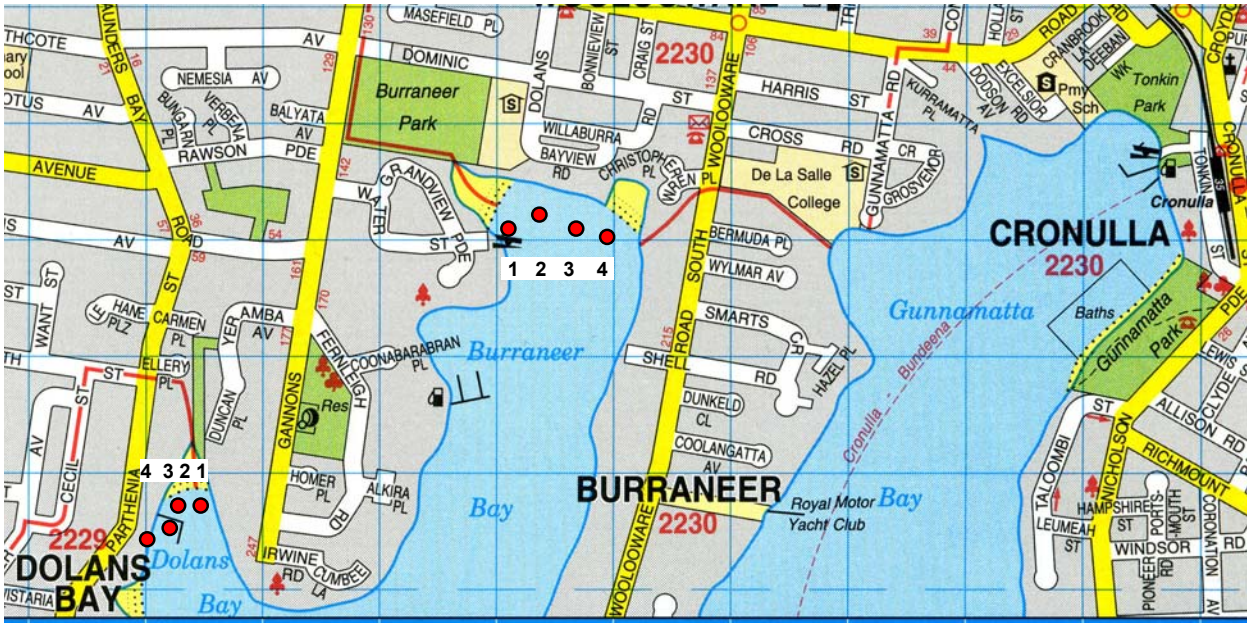

Figure 3. Location of Reference Sites in Burraneer Bay and Dolans Bay.

3.3 Chemical Analyses of Sediments

A summary of analytical detection limits for all the methods used is given in Table 1.

Table 1. Summary of limits of determination for each analysis method

Sediment Chemicals	Laboratory	LOD
Sediment Metals: Al, Cd, Co, Cr, Cu, Mn, Ni, Zn, Ag, As, Fe, Pb	CSIRO	0.2-1 mg/kg
Mercury in 1M HCl-extracted sediments	CSIRO	0.03 mg/kg
Tributyltin (TBT)	AGAL	0.005 mg/kg
Total organic carbon (TOC)	AGAL	200 mg/kg
Polycyclic aromatic hydrocarbons (PAHs)	AGAL	0.1 mg/kg
Total petroleum hydrocarbons (TPHs)	AGAL	25-100 mg/kg
Phenols	AGAL	0.1-0.2 mg/kg
Polychlorinated byphenyls (PCBs)	AGAL	0.01 mg/kg
Organochlorine (OC) pesticides	AGAL	0.001 mg/kg
Organophosphorus (OP) pesticides	AGAL	0.01 mg/kg

3.3.1 General analytical procedures

All glass- and plastic-ware for dissolved metal analyses was cleaned by soaking in 10% (v/v) HNO_3 (Trace Pur, Merck) for at least 24 hours and washed with copious quantities of deionised water prior to use. All glassware for organic analyses was solvent washed and air dried prior to use. Milli-Q deionised water was used to prepare all solutions. Trace metal grade acids (Trace Pur, Merck) were used for dissolved and particulate metal determinations. All other acids and chemicals were Analytical Reagent grade.

Sediment grain size fractionation was undertaken by sieving a known weight of wet sediment sequentially through stainless steel sieves of decreasing aperture (2 mm, 1 mm, 180 µm and 63 µm) using a minimal volume of Milli-Q water. The sediment remaining on each sieve was then dried in beakers (110ºC, >24 h). The dry weight and wet weight were then used to determine grain size fractionation of the sediments.

3.3.2 Water quality parameter measurements

All pH and redox potential measurements were made with a WTW pH meter, with an Orion sure-flow comb pH 9165BN pH probe or a Metrohn 6.0412.100 redox probe. The glass body pH probe (Orion sure-flow comb pH 9165BN) was used for all pH measurements. It was calibrated against standard NIST buffers pH 4.0 (160-180mV), and pH 7.0 (0 ± 20 mV) before use. Before and after each measurement the electrode was rinsed with deionised water. Whilst not in use the pH electrode was stored in a pH 4.0 buffer. Redox potentials were reported versus the standard hydrogen electrode triiodide solution (420 mV at 25ºC). This reference solution was measured before the sample and was used to correct the redox potential of the sample. Dissolved oxygen measurements were undertaken using a meter (Oxi 196, WTW) with an oxygen electrode (EO96, WTW) calibrated according to manufacturer's instructions. Conductivity and temperature measurements used a conductivity meter (LF 320, WTW) with a probe (TetraCon 325, WTW).

3.3.3 Extraction of sediment pore waters

Pore waters were extracted taking the precautions noted in ASTM (1994) and Batley et al. (2002) to reduce the likelihood of changes to chemical speciation, from in situ conditions. Centrifuge tubes (50 mL, Cellstar) were completely filled with sediment, so that there was no headspace (minimal oxygen) and capped tightly. Pore water was extracted by centrifugation at 3500 rpm for 5 minutes. After centrifugation, pore waters were filtered through acid-washed 0.45 µm membrane filters (25 mm, Sartorius Minisart). The first 3 mL was used to rinse the filter, and the remaining 5 mL was filtered into an acid-washed 20 mL polyethylene vial. Sample blanks were prepared by filtering Milli-Q water by the same procedure. The filtered samples were acidified (0.5% v/v) with concentrated HNO_3 (Merck, TracePure).

3.3.4 Determination of dissolved metals in sediment pore waters

Dissolved metals analyses used both inductively coupled plasma atomic emission spectrometry (ICP-AES, Spectroflame EOP). Matrix matched standards (generally 2% HNO_3) were run with all samples and spike-recoveries performed on selected samples for ICP-AES analyses. The detection limits for the metals of interest were: 3-10 µg/L (ICP-AES).

3.3.5 Determination of acid-extractable metals in sediments

A known wet weight of sediment was extracted with 1 M HCl for 30 minutes at room temperature (~10 g sediment/L). Acid-extracts were filtered through 0.45 µm membrane filters and analysed by ICP-AES against matrix-matched standards. This extraction is analogous to the acid-extraction used for AVS/SEM analyses (Allen et al., 1993). The detection limits for the metals of interest were: 0.4 mg/kg for Al, Cd, Co, Cr, Cu, Mn, Ni and Zn, and 1 mg/kg Ag, As, Fe and Pb. Analyses of mercury used hydride generation atomic fluorescence spectrometry (AFS) and standard analytical conditions recommended by the manufacturer (Merlin Analyser, PSA analytical).

3.3.6 Determination of butyltin species in sediments

Butyltin species (TBT, DBT, MBT) analyses in sediments were undertaken by AGAL in accordance with AGAL Method No: NWS 35 "TBT (Tributyl- or Organo-tin) in sediment." This in-house method is based on those of Attar (1996) and Abalos *et al*. (1997). The sediment is extracted with acidified ethanol then derivitised by sodium tetraethylborate. The ethylated derivitives are then extracted into hexane then analysed by GC-AED (Hewlett Packard Gas Chromatograph with atomic emission detection, HP 5921A) where two characteristic tin emission lines are used for quantitation and identification. Quantitation was against target standards. Tripropyltin was used as a surrogate to monitor extraction/method efficiencies. The method has a limit of determination of 0.5 µg/kg.

3.3.7 Determination of total organic carbon (TOC) in sediments

Total organic carbon (TOC) analyses in sediments were undertaken by the AGAL in accordance with AGAL Method No: NWS 15 "Determination of total organic carbon in soil and total (non-volatile) organic carbon in water." The sample was weighed into a small platinum boat and acid added to remove inorganic carbon (carbonates and bicarbonates). The residue was heated in an oven at 75^{o}C to dryness and the boat with the dried residue placed in the boat accessory of a Dohrmann DC-190 high temperature TOC analyser. The boat was heated in a furnace to convert all organic carbon to carbon dioxide, which was swept into the main body of the TOC analyser where its concentration was determined by a non-dispersive infrared detector. The instrument was fitted with software enabling it to give a read out of per cent organic carbon in the sample. The method had a limit of determination of 100 mg/kg. For QA, per batch or every 20 samples, two reagent blanks, one sample duplicate, one blank spike, one post-digestion matrix spike or sample spike and a reference material (where available) were analysed.

This method was used for all sediments were organic contaminants were analysed and organic contaminant concentrations were normalized to 1% TOC.

Estimation of the sediment organic carbon content using the 'loss-on-ignition' (LOI) method was made for all sediments where organic contaminants were not analysed. This was undertaken by heating a known mass of dried sediment at 400ºC for 24-h followed by gravimetric analysis. The method had a limit of determination of 0.1%.

3.3.8 Determination of PAHs and phenols in sediments

Analyses of PAHs in sediments were undertaken by AGAL in accordance with AGAL Method No: NGCMS 11.11 "Determination of Polynuclear Aromatic Hydrocarbons and Phenols in Environmental Samples using Electron Impact (EI) Selected Ion Monitoring (SIM)". The method was based on USEPA 3550 (for sample preparation) and detection was based on USEPA 8270. Sediments were extracted by sonication with a 50% dichloromethane/acetone solvent. The prepared extracts were analysed using the MSD/MS in SIM (Selected Ion Monitoring, Hewlett Packard HP5972 GCMS) mode. Quantitation of the analytes was carried using primary characteristic ions as specified in the USEPA 8270 method (PAH and phenols only). The volumetric internal standard compounds and the surrogate internal compounds were those specified in that method. The method has a limit of determination of 0.05-0.2 mg/kg.

3.3.9 Determination of total petroleum hydrocarbons (TPH) in sediments

Total petroleum hydrocarbons (TPH) in sediments were determined by AGAL in accordance with AGAL method NGCMS 11_12 "Determination of Petroleum Hydrocarbons in Soils and Water using GC-FID". The method was based on USEPA method 8015 respectively. Limits of recovery (LOR) were 25/50/100/100 mg/kg for TPH C6-9/C10-C14/C15-C28/C29-C36. For C6-9 TPHs, sediment samples were first dispersed in methanol and an aliquot of this solution was mixed with organic free water to be analysed by the purge and trap method. In the purge and trap method a sample (normally 98% water, 2% methanol extract) was purged with nitrogen and the volatile sample components were trapped in a tube containing suitable adsorbents. After purging was complete, the sorbent tube was rapidly heated and back-flushed with helium to desorb the trapped components. The analytes were transferred to the front of a narrow bore

capillary column operating in the split mode. The column was then temperature and pressure programmed to separate the analytes. The volatile compounds were introduced into the gas chromatograph by the purge and trap method and detected by the mass spectrometer (Tekmar Purge andTrap with Hewlett Packard HP5972 GCMS) operating in EI mode using full scan. The method can be used to quantitate the total petroleum hydrocarbons in the C6-C9 fraction with boiling points below 200ºC and that are insoluble or slightly soluble in water. Typical compounds present in this region include benzene, toluene, ethylbenzene, xylenes and the C6-C9 hydrocarbons [saturated and unsaturated]. For C10-C36 TPHs, sediment matrices were extracted with a 50% dichloromethane/ acetone solvent using sonication extraction. Prepared extracts were injected into a GC where separation of individual components was achieved with a non-polar capillary column and detection was by flame ionisation (HP 5890 Series 2 GC-FID). Concentrations were determined by comparison with alkane standards using electronic integration. All non-petroleum compounds that elute between C10 and C36 can potentially interfere with the quantitation. The method has a limit of determination of 0.05-0.2 mg/kg.

3.3.10 Determination of organochlorine (OC) and organophosphorus (OP) pesticides, and polychlorinated biphenyls (PCBs) in sediments.

Analyses of OC and OP pesticides, and PCBs in sediments were undertaken by AGAL in accordance with AGAL Method No: NR19 "Extraction, Cleanup and Analysis of Organochlorine and Organophosphorus Pesticides, PCBs and other Organic Residues in Soil, Sediment and other Environmental Matrices". The method was based on USEPA 3550 (for sample prep) and detection is based on USEPA 8081. Sediment matrices were mixed with anhydrous sodium sulfate and tumbled with hexane/acetone using rotating shaker. Extracts were then concentrated then cleaned up with florisil. If required, the extract was cleaned up by Gel Permeation Chromatography (GPC) and/or sulfur removal. The final extract was analysed by GC-ECD and confirmed by GCMS-NCI (HP5898 Engine GCMS set in CI mode (methane makeup) and HP6890 GC with ECD (twin column)). A laboratory blank was analysed with each batch of samples. The method has a limit of determination of 1-10 µg/kg. All results were reported on a dry weight basis.

3.4 Benthic Invertebrate Sampling Methods

Divers collected samples at the head of Gunnamatta Bay and two control locations in Port Hacking (Burraneer Bay and Dolans Bay) on the March 1,2004. Control locations were chosen at places with similar depths and sediment characteristics to Gunnamatta Bay (Figure 2). Five replicate benthic samples (approx. 5 m apart) were taken at four sites (50 - 100 m apart) within each of the three locations (approx. 1 km apart).

Benthic macroinvertebrates were collected by using a PVC cylinder (corer) with a diameter of 10 cm and a height of 25 cm. The corer was inserted into the substratum to a depth of approximately 9 cm and capped (to provide adequate suction and prevent sediment from escaping). This depth is appropriate to sample benthic macroinvertebrates which inhabit the top layer of sediment (Morrisey et al., 1992). The corer was carefully removed and the sediment placed into labeled plastic bags.

All samples were sieved through a 1-mm mesh sieve in the laboratory and material retained was preserved in 10% formalin solution stained with Rose Bengal. Benthic fauna were sorted into taxonomic groups at the lowest taxonomic level practicable (e.g. into family groups for polychaete worms and into orders for crustaceans), identified and counted. Although five replicate samples were collected per site, only three were sorted due to time constraints. After checks on identifications, numbers of each type of animal were entered into spreadsheet format and the data were proofread before analysis.

3.5 Mapping of Marine Vegetation

Mapping was done by taking GPS coordinates around the perimeter of different vegetation types (seagrasses and algae) and noting species present within each vegetation type. A hand held Garmin GPS 72 unit was used to obtain all GPS coordinates in the WGS84 datum. For all coordinates, depth was measured using a hand-held digital depth gauge and later corrected to

AHD to give an indication of the depth distribution of seagrasses and algae within the study area. GPS coordinates were plotted using the mapping software MapInfo Professional v7.

3.6 Statistical Methods

3.6.1 Assemblages

These analyses were used to test the general null hypothesis that: "there would be no difference among assemblages of benthos from each location". These analyses used the Bray-Curtis co-efficient of similarity to estimate differences between samples. Bray-Curtis values range between 0 and 1. Samples with the same species and same abundance will have a similarity value of 1. Those samples with no species in common will be totally dissimilar and, therefore, have a similarity value of 0. The ANOSIM randomisation test (Clarke, 1993) uses these similarities to test for differences among sampling locations and times. The analysis calculates the average rank similarities among pairs of replicates within each two groups minus the average rank similarity of replicates between groups and is scaled to give a value between -1 and 1 (Clarke, 1993). This value is termed the R test statistic and 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 and between groups are equally similar (i.e. no difference between groups). If R = -1 then pairs consisting of one replicate from each group are more similar to each other than are pairs of replicates from the same group (Clarke, 1993). Significance levels (P values) are provided for each R value and are calculated using random permutations of the data set to compare against the observed similarities. If these analyses were significant, pair-wise comparisons were made between groups within each of the significant factors. When differences were detected, SIMPER analysis was used to calculate the average dissimilarity between groups and determine the amount that each taxon contributed to this value.

Non-metric multi-dimensional scaling (nMDS) was used to graphically represent the relationship between assemblages of benthos among locations. The relative distance between samples is proportional to the relative similarity between the species composition and abundance of the samples (Clarke, 1993). The adequacy of the two-dimensional representation is indicated by the stress value. Stress values of <0.1 indicate a good representation which may be easily interpreted and plots with stress <0.2 provide a reasonable representation of the data. Plots where the stress value exceeds 0.2 indicate a poor representation of the samples. Note that the 'stress value' refers only to the relationship among data and is not indicative of any environmental conditions.

3.6.2 Populations

Asymmetrical analysis of variance (ANOVA) was used to test for differences in the total number of individuals, total number of taxa and the abundance of selected taxa at a number of spatial scales. The taxa analysed were identified in multivariate analyses as contributing most to the differences between assemblages. The variance associated with locations was partitioned into two components: Gunnamatta Bay versus control locations (i.e. Burraneer Bay and Dolans Bay) and that between the control locations. Sites within locations were also partitioned in a similar manner. In all ANOVA tests, the term that determined whether there was a difference between Gunnamatta Bay and the control locations was denoted GB vs C.

A significance level (α) of 0.05 was used for all tests. To determine the presence of heterogeneous variances within the data, Cochran's C test was used (Winer et al., 1991; Underwood, 1981, 1997). If needed, data were transformed to remove any heterogeneity of variances that may have occurred. If the transformation failed to do this, raw data were analysed at a reduced α level of 0.01 to decrease the probability of a Type I error (Underwood, 1981). To enable more powerful tests, factors that were not significant at $p \geq 0.10$ were pooled or eliminated where appropriate. All statistical analyses were done using the statistical software package GMAV v.5.

For each ANOVA test, “Location” was a random, orthogonal factor with three levels: Gunnamatta Bay, Burraneer Bay and Dolans Bay. “Site” was a random factor consisting of four levels nested within location (Figure 2). Three replicate benthic cores were analysed per site.

4 Results

4.1 Site Description and Field Measurements

The water quality measurements indicated that the physico-chemical properties of the waters at all sites were typical of high-salinity estuary bays (Table 2). The water properties at the Gunnamatta Bay study sites were similar to the reference sites in Burraneer Bay and Dolans Bay, respectively. Quality assurance reports for analyses are shown in Appendix A.

Table 2. Physico-chemical properties of site waters

Site	Temperature	Dissolved oxygen	Salinity	pH	Redox potential
	ºC	mg/L	‰		mV
Gunnamatta Bay	20.9-22.2	7.1-7.9	30.8-32.9	7.85-8.16	155-460
Burraneer Bay	22.4-23.4	8.5-9.2	32.6-32.8	8.06-8.26	50-150
Dolans Bay	22.5-23.3	7.9-9.2	32.5-32.8	7.98-8.10	100-170

4.2 Physico-chemical Properties of the Sediments

The sediment sample site details and the physico-chemical properties of the sediments samples collected are shown in Tables 3 (benthos sites) and 4 (non-benthos sites), respectively.

The sediment properties at the reference sites were generally very similar to those in Gunnamatta Bay (Table 3). The Cronulla Marina and Public Wharf sites in Gunnamatta Bay were more silty than the other benthic sites, i.e. contained a greater portion of fine particles, than the other sites. The Cronulla Marina site sediment also had a higher amount or organic carbon, reflecting the sheltering of this site from waves that would otherwise resuspend and disperse fine sediment particles and organic matter.

4.3 Chemical Analyses

4.3.1 Sediment metal concentrations

The concentrations of metals in the tested sediments are shown in Tables 5 (benthos sites) and 6 (non-benthos sites), together with the interim sediment quality guideline (ISQG) trigger values for these metals (ANZECC/ARMCANZ, 2000). Quality assurance data are shown in Appendix A. Metal concentrations in the sediments from which benthos were collected were in the range 3-266 mg Cu/kg, 7-225 mg Pb/kg and 15-433 mg Zn/kg. Sediments from the non-benthos fell within these ranges at 7-87, 13-176, 18-337 mg/kg for Cu, Pb and Zn, respectively.

Metal concentrations were generally below the ISQG trigger values at all sites in Gunnamatta Bay except at the inner sites of the Cronulla Marina (sites 10, 11, 13 and 14) and at site 8 that was close to the boat ramp and a storm water drain. Copper concentrations were above the trigger value at sites 8, 12 and 13. At site 13, the copper concentration was 266 mg/kg, which is close to the ISQG-High value of 270 mg/kg. Lead concentrations were above the ISQG trigger value of 50 mg/kg at many sites and was above the ISQG-High value of 220 mg/kg at site 13. Zinc concentrations were above the ISQG trigger value of 200 mg/kg only at some Cronulla Marina sites and one Public Wharf site. It was above the ISQG-High value of 410 mg/kg at site 13. At the reference sites, elevated concentrations of copper (11-39 mg/kg), lead (20-32 mg/kg) and zinc (37-111 mg/kg) were present in the sediments at sites close to the public boat ramp in

Burraneer Bay (site B-1) and in the vicinity many private boat ramps in Dolans Bay (sites D-3 and D-4)).

For sites where sediment samples were collected at depths (e.g. 30 cm depth, Table 6), metal concentrations were generally within a factor of 2-3 lower or higher than the concentrations measured in the surface sediments. The coarse nature of the sediments at most sites meant that deeper sediments could not be collected unless a vibro-corer, or similar coring device, was used.

Mercury concentrations were <0.03 mg/kg in all sediments tested (benthic sites), and were less than the guideline trigger value of 1.0 mg/kg.

The concentrations of butyltin species are shown in Table 7, along with the interim sediment quality guideline trigger values for these metals (ANZECC/ARMCANZ, 2000). The tributyltin (TBT) concentrations were typical of estuarine bays the have significant boating activity. The TBT concentration was highest at the Cronulla Marina site. At site 16, TBT was 69 µg Sn/kg in the 0-2 cm surface sediment layer and 35 µg Sn/kg in the sediment at 25-30 cm depth. This may indicate that TBT concentrations are lower in the deeper sediments, however this would need further investigation at other sites, e.g. site 13 where TBT was 270 µg Sn/kg.

4.3.2 Pore water metal concentrations

Concentrations of metals were analysed in sediment pore waters from the sites where benthic organisms were collected. In all pore waters analysed, concentrations were below the analytical detection limit, Ag, Cd, Co, Cr, Cu, Ni (3 µg/L), Pb (10 µg/L) and Zn (5 µg/L). This is consistent were the low concentrations of these metals in the sediments and indicates pore water metals would not be expected to cause any toxicological or ecological effects to benthic organisms.

Pore water concentrations of iron (predominantly iron(II)) provide useful information on the redox conditions in the sediments and whether iron hydroxides/oxides (sub-oxic conditions) or iron sulfides (anoxic/sulfidic conditions) will be controlling metal solubility. At the Gunnamatta Bay benthic sites, pore water iron concentrations were 0.2-1.1, 1.7-6.7, 0.13-0.66, and 0.07-0.5 mg/L, at sites 6, 11, 21 and 25 respectively. At the reference sites, pore water iron concentrations were 0.16-0.38 (Burraneer Bay) and 0.01-0.35 (Dolans Bay). Pore water sulfide concentrations were negligible (<10 µg/L) at all sites.

Table 3. Sampling site details and physico-chemical properties of sediments at the benthos sampling sites

Site	Location	GPS location		Date	Time	Depth, cm	Sediment		Particle Size, %					Water	Density	Organic carbon	
		Easting	Northing				pH	Eh, mV	<63 µm	63-180 µm	0.18-1 mm	1-2 mm	>2 mm	%	g/cm^3	TOC, %	LOI,%
6-A	Tonkin Park Shoal	329187	6230140	01/03/04	10:00	0-2	7.55	44	0.7	20.4	78.9	0.0	0.0	26.6	1.81	0.4	1.59
6-B	Tonkin Park Shoal	329198	6230146	01/03/04	10:00	0-2	7.53	5	3.7	12.4	83.9	0.0	0.0	27.4	1.77	NM	1.50
6-C	Tonkin Park Shoal	329204	6230152	01/03/04	10:00	0-2	7.60	15	4.3	14.2	81.5	0.0	0.0	26.2	1.79	NM	1.70
13-A	Cronulla Marina	329232	6230114	01/03/04	9:30	0-2	7.50	204	42.2	33.3	24.5	0.0	0.0	46.0	1.37	3.5	13.80
13-B	Cronulla Marina	329234	6230109	01/03/04	9:30	0-2	7.62	108	37.3	29.9	32.7	0.0	0.0	44.1	1.44	NM	11.10
13-C	Cronulla Marina	329236	6230105	01/03/04	9:30	0-2	7.58	156	49.1	34.2	16.7	0.0	0.0	56.8	1.30	NM	12.50
21-A	Public Wharf	329264	6230054	01/03/04	11:30	0-2	7.66	54	7.7	7.2	79.9	1.0	4.1	29.9	1.80	0.7	2.27
21-B	Public Wharf	329273	6230065	01/03/04	11:30	0-2	7.54	101	9.9	10.5	78.3	0.2	1.1	30.4	1.73	NM	2.10
21-C	Public Wharf	329279	6230074	01/03/04	11:30	0-2	7.62	86	25.5	18.1	55.8	0.0	0.6	31.4	1.68	NM	2.20
25-A	Sailing Club	329244	6230021	01/03/04	11:00	0-2	7.58	254	4.6	10.1	84.6	0.6	0.0	25.7	1.82	0.4	2.52
25-B	Sailing Club	329249	6230023	01/03/04	11:00	0-2	7.54	152	1.0	7.1	91.8	0.0	0.0	24.9	1.80	NM	2.10
25-C	Sailing Club	329253	6230029	01/03/04	11:00	0-2	7.61	168	1.2	8.3	90.5	0.0	0.0	25.0	1.83	NM	2.40
B1-A	Burraneer Bay	327878	6229959	01/03/04	13:30	0-2	7.55	-76	13.1	18.3	56.8	2.8	8.9	31.0	1.67	1.2	1.50
B1-B	Burraneer Bay	327900	6230011	01/03/04	13:40	0-2	7.65	-16	0.9	5.6	92.1	1.4	0.0	22.0	1.89	NM	1.45
B1-C	Burraneer Bay	328011	6230012	01/03/04	13:50	0-2	7.53	-106	1.9	5.0	90.7	2.4	0.0	24.1	1.85	NM	1.70
B1-D	Burraneer Bay	328116	6229983	01/03/04	14:00	0-2	7.00	-106	5.3	8.5	81.2	2.3	2.7	23.6	1.90	NM	1.62
D2-A	Dolans Bay	327257	6229373	01/03/04	14:30	0-2	7.77	-6	0.5	7.5	92.0	0.0	0.0	24.3	1.84	0.4	2.77
D2-B	Dolans Bay	327232	9229371	01/03/04	14:40	0-2	7.59	84	0.5	7.5	92.0	0.0	0.0	24.9	1.89	NM	2.80
D2-C	Dolans Bay	327191	6229360	01/03/04	14:50	0-2	7.20	-56	2.2	15.8	81.5	0.0	0.5	27.4	1.80	NM	2.60
D2-D	Dolans Bay	327144	6229295	01/03/04	15:00	0-2	7.66	44	1.0	8.9	89.0	1.0	0.1	25.3	1.85	NM	3.10

[a] All samples are surface sediments (0-2 cm) [b] NM = not measured

Table 4. Sampling site details and physico-chemical properties of sediments at the non-benthos sampling sites

Site	Location	GPS location		Date	Time	Depth, cm	Sediment		Particle Size, %					Water	Density	Organic carbon	
		Easting	Northing				pH	Eh, mV	<63 µm	63-180 µm	0.18-1 mm	1-2 mm	>2 mm	%	g/cm^3	TOC, %	LOI,%
1S	Tonkin Park Shoal	329162	6230225	02/03/04	9:45	0-2	7.80	240	0.4	0.1	22.8	13.8	62.8	22.6	2.06	NM	2.53
2S	Tonkin Park Shoal	329159	6230193	02/03/04	9:35	0-2	7.47	101	2.1	10.5	87.1	0.0	0.3	24.2	1.91	NM	0.98
2D	Tonkin Park Shoal	329159	6230193	02/03/04	9:35	20-25	NM	NM	2.3	8.4	84.4	5.0	0.0	30.7	1.90	NM	3.61
3S	Tonkin Park Shoal	329129	6230180	02/03/04	10:00	0-2	7.50	44	4.3	28.0	67.7	0.0	0.0	27.0	1.88	NM	2.35
3D	Tonkin Park Shoal	329129	6230180	02/03/04	10:00	20-25	NM	NM	8.4	35.8	55.8	0.0	0.0	33.4	1.81	NM	1.86
4S	Tonkin Park Shoal	329113	6230149	02/03/04	9:15	0-2	7.53	-54	16.2	15.1	55.7	3.0	10.0	37.5	1.68	NM	3.17
5S	Tonkin Park Shoal	329195	6230175	01/03/04	10:15	0-2	7.66	4	7.8	14.9	72.4	2.1	2.7	27.0	1.76	NM	3.08
7S	Tonkin Park Shoal	329165	6230139	02/03/04	9:00	0-2	7.50	-43	13.1	31.3	55.6	0.0	0.0	45.2	1.50	NM	3.64
7D	Tonkin Park Shoal	329165	6230139	02/03/04	9:00	25-30	NM	NM	24.4	19.0	56.6	0.0	0.0	31.1	1.75	NM	2.93
8S	Tonkin Park Shoal	329250	6230165	02/03/04	8:30	0-2	7.30	-56	0.8	28.9	67.5	0.8	2.0	32.9	2.13	NM	2.49
9S	Tonkin Park Shoal	329231	6230153	02/03/04	10:15	0-2	7.65	-14	3.2	22.9	73.8	0.0	0.0	34.4	1.88	NM	3.52
10S	Cronulla Marina	329223	6230126	02/03/04	8:45	0-2	7.72	-111	22.9	28.5	43.1	0.0	5.5	58.2	1.34	4.1	9.44
10D	Cronulla Marina	329223	6230126	02/03/04	8:45	20-25	NM	NM	23.4	22.1	54.5	0.0	0.0	36.8	1.62	2.1	5.59
11S	Cronulla Marina	329212	6230114	02/03/04	14:00	0-2	7.72	-63	25.7	26.3	47.4	0.0	0.7	44.9	1.50	NM	6.30
12S	Cronulla Marina	329181	6230102	02/03/04	14:30	0-2	7.64	41	12.7	12.3	74.0	1.0	0.0	34.7	1.63	NM	3.02
14S	Cronulla Marina	329221	6230096	02/03/04	14:15	0-2	7.57	-6	27.5	18.0	50.9	0.6	3.0	52.8	1.43	NM	7.57
15S	Cronulla Marina	329199	6230081	02/03/04	14:45	0-2	7.81	44	18.0	8.0	74.0	0.0	0.0	36.8	1.58	NM	4.43
16S	Cronulla Marina	329188	6230073	02/03/04	13:30	0-2	7.81	24	6.7	5.9	87.4	0.0	0.0	30.8	1.90	0.4	2.07
16D	Cronulla Marina	329188	6230073	02/03/04	13:30	25-30	NM	NM	7.2	4.6	88.2	0.0	0.0	26.4	1.76	0.4	1.15
17S	Cronulla Marina	329235	6230089	02/03/04	15:15	0-2	7.38	-11	28.6	11.4	55.7	1.4	2.9	55.3	1.38	3.2	7.46
17D	Cronulla Marina	329235	6230089	02/03/04	15:15	25-30	NM	NM	17.9	0.7	69.4	3.0	9.0	30.1	1.68	2.4	2.59
18S	Cronulla Marina	329212	6230062	02/03/04	15:30	0-2	7.50	144	10.9	4.9	66.4	0.1	17.7	32.5	1.65	0.9	2.52
18D	Cronulla Marina	329212	6230062	02/03/04	15:30	0-2	NM	NM	16.2	3.7	79.0	1.2	0.0	26.6	1.63	0.7	1.97
19S	Cronulla Marina	329205	6230053	02/03/04	13:45	0-2	7.62	-14	13.8	4.4	81.9	0.0	0.0	37.9	1.68	NM	2.41
20S	Public Wharf	329231	6230064	02/03/04	15:00	0-2	7.72	20	5.7	1.6	46.8	2.3	43.6	35.9	1.78	NM	2.38
22S	Sailing Club	329242	6230019	02/03/04	12:00	0-2	7.50	22	16.1	9.5	74.3	0.0	0.0	40.8	1.54	1.2	3.74
22D	Sailing Club	329242	6230019	02/03/04	12:00	25-30	NM	NM	7.6	6.3	78.0	1.0	7.0	34.6	1.63	0.9	0.88
23S	Sailing Club	329238	6230008	02/03/04	11:45	0-2	7.52	22	8.8	15.9	75.3	0.0	0.0	31.8	1.67	NM	1.00
24S	Sailing Club	329216	6229998	02/03/04	11:30	0-2	7.57	-9	2.9	19.7	77.4	0.0	0.0	51.5	1.75	0.8	1.56
24D	Sailing Club	329216	6229998	02/03/04	11:30	25-30	NM	NM	5.8	4.7	89.5	0.0	0.0	24.9	1.84	0.7	1.33
26S	Gunnamatta Park Shoal	329263	6229988	02/03/04	11:15	0-2	7.49	52	0.2	10.1	89.2	0.5	0.0	26.3	1.64	NM	1.36
27S	Gunnamatta Park Shoal	329277	6229955	02/03/04	10:45	0-2	7.61	94	0.7	4.0	87.2	5.0	3.1	23.9	1.83	NM	2.10
28S	Gunnamatta Park Shoal	329231	6229949	02/03/04	11:00	0-2	7.45	126	0.0	3.2	96.6	0.2	0.0	22.7	1.93	NM	0.68

[a] All samples are surface sediments (0-2 cm) [b] NM = not measured

Table 5. Concentrations of acid-extractable metals in sediments, mg/kg – benthos sampling sites

Location	Site	Al	Fe	Mn	Ag	As	Cd	Co	Cr	Cu	Ni	Pb	Zn
Tonkin Park Shoal	6-A	1100	3190	17.0	<0.6	<0.8	<0.3	1.1	2.6	11.5	1.7	43.5	55.0
Tonkin Park Shoal	6-B	1130	3340	16.4	<0.6	<0.8	<0.3	1.1	2.7	12.7	1.9	52.9	58.4
Tonkin Park Shoal	6-C	1100	3150	13.9	<0.6	<0.8	<0.3	1.1	2.4	12.9	1.9	40.3	51.4
Cronulla Marina	13-A	1400	8970	27.9	<0.6	2.3	0.3	3.1	10.4	181	4.8	222	394
Cronulla Marina	13-B	1290	7090	22.7	<0.6	2.0	0.4	2.4	8.4	103	3.9	181	313
Cronulla Marina	13-C	1730	9680	27.2	<0.6	3.0	0.4	3.1	10.9	266	5.0	225	433
Public Wharf	21-A	590	1480	6.1	<0.6	1.1	<0.3	0.6	2.7	34.0	0.9	37.8	59.0
Public Wharf	21-B	670	1800	6.6	<0.6	1.3	<0.3	0.6	2.8	52.0	1.0	41.6	68.1
Public Wharf	21-C	1350	4840	12.7	<0.6	1.8	<0.3	1.4	6.2	55.3	2.1	101	158
Sailing Club	25-A	320	950	6.6	<0.6	<0.8	<0.3	0.3	1.3	8.8	0.4	13.0	18.6
Sailing Club	25-B	250	750	3.9	<0.6	<0.8	<0.3	<0.3	0.97	6.3	0.3	9.69	15.1
Sailing Club	25-C	400	860	5.7	<0.6	<0.8	<0.3	0.3	0.98	7.2	0.4	10.8	15.3
Burraneer Bay	B-1	1230	3510	20.6	<0.6	1.4	<0.3	1.3	3.7	20.5	2.5	32.8	111
Burraneer Bay	B-2	640	1540	11.9	<0.6	<0.8	<0.3	0.6	1.5	4.2	1.0	11.2	24.7
Burraneer Bay	B-3	810	1580	9.8	<0.6	<0.8	<0.3	0.6	1.2	3.9	1.0	11.2	19.7
Burraneer Bay	B-4	550	1610	6.6	<0.6	<0.8	<0.3	0.4	1.4	3.3	0.6	15.3	19.6
Dolans Bay	D-1	510	1020	5.8	<0.6	<0.8	<0.3	0.4	0.73	3.2	0.6	7.3	17.7
Dolans Bay	D-2	590	1280	6.1	<0.6	<0.8	<0.3	0.5	1.1	5.5	0.9	12.3	23.3
Dolans Bay	D-3	630	1510	4.6	<0.6	0.9	<0.3	0.5	1.4	11.4	0.8	20.9	36.5
Dolans Bay	D-4	630	2990	7.7	<0.6	2.5	<0.3	0.8	2.3	38.7	1.2	53.5	64.2
ISQG-Low [c]		NA	NA	NA	1.0	20	1.5	NA	80	65	21	50	200
ISQG-High [c]		NA	NA	NA	3.7	70	10	NA	370	270	52	220	410

[a] All samples are surface sediments (0-2 cm)

[b] NM = not measured

[c] ANZECC/ARMCANZ (2000) guideline values.

[d] NA = not available

Table 6. Concentrations of acid-extractable metals in sediments (mg/kg) at non-benthos sampling sites

Site	Location	Al		Fe		Mn		Ag		As		Cd		Cu		Co		Cr		Ni		Pb		Zn	
		S[a]	D[a]	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D
1	Tonkin Park Shoal	1100	NM	9180	NM	72.4	NM	<0.6	NM	1.1	NM	<0.3	NM	23.4	NM	4.7	NM	5.0	NM	7.73	NM	60.6	NM	106	NM
2	Tonkin Park Shoal	670	1250	2060	4260	11.3	16.4	<0.6	<0.6	0.8	0.9	<0.3	<0.3	10.0	17.6	0.7	1.3	1.6	4.0	1.13	1.91	27.5	45.9	34.1	54.2
3	Tonkin Park Shoal	1180	1200	2900	3210	15.0	21.8	<0.6	<0.6	0.9	0.7	<0.3	<0.3	14.1	12.5	1.1	1.3	2.9	4.3	1.93	2.28	39.7	74.4	57.5	147
4	Tonkin Park Shoal	1060	NM	2330	NM	10.2	NM	<0.6	NM	1.3	NM	<0.3	NM	18.6	NM	0.8	NM	3.4	NM	1.27	NM	55.9	NM	78.0	NM
5	Tonkin Park Shoal	1170	NM	3850	NM	16.5	NM	<0.6	NM	1.3	NM	<0.3	NM	38.5	NM	1.4	NM	3.5	NM	2.16	NM	61.2	NM	88.6	NM
7	Tonkin Park Shoal	1500	1040	3780	2490	13.4	9.6	<0.6	<0.6	1.3	1.3	<0.3	<0.3	22.6	16.9	1.2	1.0	4.5	4.0	1.82	1.28	60.6	63.9	85.5	79.7
8	Tonkin Park Shoal	1120	NM	2980	NM	16.2	NM	<0.6	NM	1.4	NM	<0.3	NM	86.7	NM	1.5	NM	3.9	NM	2.37	NM	60.5	NM	140	NM
9	Tonkin Park Shoal	730	NM	2460	NM	12.8	NM	<0.6	NM	<0.8	NM	<0.3	NM	13.3	NM	1.1	NM	2.7	NM	1.63	NM	28.7	NM	54.8	NM
10	Cronulla Marina	1710	1150	9040	5010	25.0	22.6	<0.6	<0.6	1.1	1.3	<0.3	0.4	23.2	71.1	2.8	2.1	8.8	7.0	4.35	3.62	176	203	337	269
11	Cronulla Marina	1370	NM	5560	NM	19.0	NM	<0.6	NM	1.4	NM	<0.3	NM	57.7	NM	2.0	NM	6.6	NM	3.04	NM	133	NM	203	NM
12	Cronulla Marina	960	NM	2500	NM	8.4	NM	<0.6	NM	1.1	NM	<0.3	NM	67.7	NM	0.9	NM	3.8	NM	1.26	NM	53.2	NM	76.1	NM
14	Cronulla Marina	1510	NM	6970	NM	19.8	NM	<0.6	NM	1.5	NM	<0.3	NM	33.4	NM	2.3	NM	8.9	NM	3.20	NM	142	NM	228	NM
15	Cronulla Marina	1210	NM	3670	NM	12.7	NM	<0.6	NM	1.3	NM	0.3	NM	46.1	NM	1.3	NM	5.5	NM	2.10	NM	78.6	NM	114	NM
16	Cronulla Marina	640	520	2110	1240	6.0	3.8	<0.6	<0.6	1.3	<0.8	<0.3	<0.3	19.8	11.4	0.7	0.5	3.7	2.6	0.85	0.59	32.6	21.8	41.0	27.7
17	Cronulla Marina	1160	NM	3290	NM	11.1	NM	<0.6	NM	1.3	NM	<0.3	NM	21.8	NM	1.0	NM	4.4	NM	1.49	NM	70.9	NM	109	NM
18	Cronulla Marina	750	690	2490	1920	7.2	6.4	<0.6	<0.6	<0.8	0.8	<0.3	<0.3	24.2	23.8	0.8	0.7	3.7	3.3	1.25	1.04	45.1	49.7	70.2	61.0
19	Cronulla Marina	1100	NM	2830	NM	7.4	NM	<0.6	NM	1.1	NM	<0.3	NM	24.7	NM	0.8	NM	4.2	NM	1.36	NM	38.9	NM	60.5	NM
20	Public Wharf	560	NM	1820	NM	6.4	NM	<0.6	NM	1.0	NM	<0.3	NM	24.6	NM	0.5	NM	2.5	NM	0.78	NM	36.8	NM	74.0	NM
22	Sailing Club	920	400	3280	660	9.8	4.9	<0.6	<0.6	1.4	3.4	0.9	<0.3	20.1	1.0	0.9	0.3	5.0	1.8	1.53	1.22	57.6	1.4	89.3	6.7
23	Sailing Club	640	NM	2110	NM	6.6	NM	<0.6	NM	0.9	NM	<0.3	NM	14.3	NM	0.7	NM	3.2	NM	1.12	NM	31.0	NM	50.9	NM
24	Sailing Club	610	450	2510	1620	7.1	5.5	<0.6	<0.6	1.7	1.2	<0.3	<0.3	33.1	14.0	0.7	0.5	3.3	2.4	0.92	0.65	28.9	26.3	46.6	30.4
26	Gunnamatta Park Shoal	330	NM	980	NM	7.1	NM	<0.6	NM	0.9	NM	<0.3	NM	9.5	NM	0.3	NM	2.1	NM	0.46	NM	15.6	NM	20.3	NM
27	Gunnamatta Park Shoal	610	NM	1010	NM	9.3	NM	<0.6	NM	0.9	NM	<0.3	NM	6.9	NM	0.5	NM	1.3	NM	0.55	NM	13.0	NM	24.3	NM
28	Gunnamatta Park Shoal	530	NM	1120	NM	7.1	NM	<0.6	NM	<0.8	NM	<0.3	NM	8	NM	0.6	NM	1.1	NM	0.84	NM	13.5	NM	18.8	NM
ISQG-Low [c]		NA		NA		NA		1.0		20		1.5		65		NA		80		21		50		200	
ISQG-High [c]		NA		NA		NA		3.7		70		10		270		NA		370		52		220		410	

[a] S = surface sediment (0-2 cm), D = depth sample (generally 25-30 cm) [b] NM = not measured [c] ANZECC/ARMCANZ (2000) guideline values. [d] NA = not available

Table 7. Concentrations of butyltin species in sediments

Site	Monobutyltin µg Sn/kg		Dibutyltin µg Sn/kg		Tributyltin µg Sn/kg	
	S [a]	D [a]	S	D	S	D
6-A	4.9	NM [b]	7.6	NM	20	NM
13-A	6.0	NM	88	NM	270	NM
16	2.0	2.4	29	22	69	35
21-A	3.7	NM	23	NM	49	NM
25-A	0.7	NM	4.3	NM	2.4	NM
B1-A	1.4	NM	10	NM	52	NM
D2-A	<0.2	NM	<0.2	NM	<0.2	NM
ISQG-Low [c]	NA [d]		NA		5	
ISQG-High	NA		NA		70	

[a] S = surface sediment (0-2 cm), D = depth sample (generally 25-30 cm)
[b] NM = not measured [c] ANZECC/ARMCANZ (2000) guideline values.
[d] NA = not available

4.4 Sediment Organics

Concentrations of PAHs, TPH, phenols, OC and OP pesticides, and PCBs measured at selected sites are shown in Table 8. Detailed summaries of all chemical analyses are provided in Appendix B. Quality assurance reports for analyses are shown in Appendix C along with the concentration data before normalization to 1% organic carbon.

Organic contaminants are generally hydrophobic and adsorb strongly to organic carbon (e.g. plant degradation products) in sediments. The absorption to organic carbon results in low pore water concentrations and low bioavailability of organic contaminants. Because organic contaminants are expected to be less bioavailable in sediments that have greater amounts of organic carbon, the sediment quality guidelines are expressed as concentrations normalised to organic carbon (1%) (ANZECC/ARMCANZ, 2000). Where concentrations were below detection limits, the values were not normalised (Appendix B). For the normalisation of organic concentrations to 1% total organic carbon (TOC) concentrations, lower and upper limits of 0.2% and 10% TOC were used respectively. At high TOC concentrations (>10%), the additional protective nature of organic carbon is not well understood, so the use of an upper limit of 10% for the TOC normalisation has been adopted as part of the precautionary principle due to these concerns (ANZECC/ARMCANZ, 2000). Organic carbon concentrations were low, generally below or near 1% TOC, in most of the sediments (i.e. they contained a lot of sand).

The concentrations of most organics were below analytical detection limits at the majority of sites and were below guideline values at all sites, except site 6 (Table 8). Detectable concentrations of PAHs were measured in most sediments, but were generally below or near the ISQGtrigger value (Appendix A). TPHs and chlordane were detected at site 6 and site 13. Phenol was detected in the site 13 and site 21 sediments. PCBs were detected in the site 6 sediments. Other OC pesticides (DDT, DDD, DDE, dieldrin, endrin) were only detected at site 13.

Table 8. Concentrations of organic contaminants in sediments (normalized to 1% organic carbon)

Organic Concentrations in Sediments, mg/kg

Site	Total PAHs [a]		low-MW PAHs		high-MW PAHs		ΣTPH	Phenol	PCBs	Chlordane (trans & cis)	DDT	DDE	Dieldrin	Endrin
	mg/kg		mg/kg		mg/kg		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
	S [b]	D [b]	S	D	S	D	S	S	S	S	S	S	S	S
6-A	<46	NM [c]	<11.6	NM	<34	NM	<710	<0.023	0.15	0.0044	<0.0023	<0.0023	<0.0023	<0.0023
10	<3.3	6.8	<0.60	<1.2	<2.7	<5.6	NM	NM	NM	NM	NM	NM	NM	NM
13-A	<4.3	NM	<0.74	NM	<3.6	NM	<250	0.80	<0.003	0.0011	0.0018	0.0005	0.0031	0.0006
17	<2.1	2.6	<0.41	<0.50	<1.7	<2.2	NM	NM	NM	NM	NM	NM	NM	NM
16	<5.5	5.5	<1.7	<1.7	<3.8	<3.8	NM	NM	NM	NM	NM	NM	NM	NM
21-A	<4.9	NM	<1.3	NM	<3.6	NM	<400	1.88	<0.014	<0.0014	<0.0014	<0.0014	<0.0014	<0.0014
22	<2.8	3.8	<0.68	<0.90	<2.1	<3.0	NM	NM	NM	NM	NM	NM	NM	NM
25-A	<4.8	NM	<1.5	NM	<3.3	NM	<640	<0.023	<0.023	<0.0023	<0.0023	<0.0023	<0.0023	<0.0023
23	<4.5	5.6	<1.2	<1.2	<3.3	<4.4	NM	NM	NM	NM	NM	NM	NM	NM
18	<5.1	3.8	<1.1	<1.1	<4.0	<2.7	NM	NM	NM	NM	NM	NM	NM	NM
B1-A	<1.3	NM	<0.50	NM	<0.80	NM	<230	<0.0083	<0.008	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008
D2-A	<4.4	NM	<1.7	NM	<2.8	NM	<760	<0.0278	<0.028	<0.0028	<0.0028	<0.0028	<0.0028	<0.0028
ISQG-Low [d]	4		0.55		1.7		NA [e]	NA	<0.023	0.0005	0.0016	0.0022	0.0020	0.0020
ISQG-High	45		3.16		9.6		NA	NA	NA	0.006	0.046	0.027	0.008	0.008

[a] For the total, low- and high- molecular weight PAHs, individual PAHs below the limit of determination concentration have been included in sum.

[b] S = surface sediment (0-2 cm), D = depth sample (generally 25-30 cm) [c] NM = not measured

[d] ANZECC/ARMCANZ (2000) guideline values. [e] NA = not available

4.5 Results of Benthic Invertebrate Sampling

Full results for the benthic ecology studies and a more detailed discussion is given in Appendix D (The Ecology Lab: Benthos Report). A summary of these results is presented below.

4.5.1 General findings

A total of 1,680 individuals, comprising 42 taxa, were identified from the 36 grabs sampled from Gunnamatta Bay and the two control locations (Appendix D, Appendix 3 of the Ecology Lab Report). Non-polychaete worms were the most abundant group (43% of all individuals), followed by polychaetes (41%), molluscs (10%), and crustaceans (6%). The largest numbers of taxa were among the polychaetes, followed by the crustaceans, molluscs and non-polychaete worms. Specifically, the top four dominant taxa were nematodes, oligochaetes, capitellids and nereidids, which together accounted for 70% of all individuals. (Appendix D, Ecology Lab Report Appendix 3).

4.5.2 Analyses of assemblages

The assemblages of benthos differed significantly among locations (Global R = 0.269 and p = 0.002), and even more so among sites within locations (Global R = 0.408 and p = 0.001). However, pair-wise comparisons of the locations could not detect consistent patterns when Gunnamatta Bay was compared with both control locations individually. For example, pair-wise comparisons showed that Gunnamatta Bay and Burraneer Bay were the only locations significantly different from one another (R = 0.474, p = 0.029), whereas Gunnamatta Bay and Dolans Bay showed no significant difference (R = 0.125, p = 14.3). Burraneer Bay and Dolans Bay (both controls) also showed no significant difference from one another (R = 0.188, p = 14.3). There were also no distinct patterns of differences with respect to sites, although Sites 2 and 3 within Gunnamatta Bay (Cronulla Marina and Public Wharf, respectively) did show some degree of separation from the other sites within this location. These results are illustrated in the MDS plot of Appendix D (Figure 3 of the Ecology Lab Report). As can be seen from the nMDS plot, assemblages at Dolans Bay were quite variable compared with those at Gunnamatta Bay and Burraneer Bay.

Table 1 in Appendix D (Ecology Lab Report) ranks the taxa in terms of their contribution towards differentiating the locations. The taxa that attributed most towards differentiating the locations are listed at the top. Gunnamatta Bay was most differentiated from the controls by oligochaetes, nematodes, nereidids, spionids and capitellids. The average abundance of nematodes and nereidids in Gunnamatta Bay was in between the averages found in the two controls. Therefore, Gunnamatta Bay and the controls were not significantly different with respect to these two taxa. The other three taxa, however, were more abundant in Gunnamatta Bay; hence, univariate analyses were performed on these three taxa to determine whether these differences were significant.

4.5.3 Analyses of derived variables and selected taxa

Of the nine variables examined, only two showed significant differences between Gunnamatta Bay and the controls: the mean abundance of both crustaceans and spionids (Appendix D, Table 2 and Figure 4 of Ecology Lab Report). Crustaceans were significantly more abundant at the controls, whilst spionids were more abundant in Gunnamatta Bay. However, both the abundance of crustaceans and spionids did not differ among sites within Gunnamatta Bay. This was also consistent with other variables analysed.

On average, there were 0.83 (SE = 0.41) crustaceans per sample in Gunnamatta Bay compared to 3.71 (SE = 0.48) at the controls; and 4.08 (SE = 1.28) spionids per sample in Gunnamatta Bay compared to 0.46 (SE = 0.15) at the controls.

4.6 Mapping of Marine Vegetation

The marine vegetation at the head of Gunnamatta Bay was dominated the invasive alga, *Caulerpa taxifolia* (Appendix D, Figure 5, Appendix 4 of Ecology Lab Report). Three species of seagrass were also observed within the study site: *Posidonia australis, Zostera capricorni* and *Halophila ovalis*.

Caulerpa was prominent throughout much of the study area, covering an area of 17,863 m2. It extended from the western shoreline, across the shoal fronting Tonkin Park, to the southern side of the sailing club. In the deeper areas adjacent to the western half of the shoal, *Caulerpa* was extremely dense, covering large areas of the seabed.

Along the western shoreline closer to shore, beds of *Posidonia* and *Zostera* were also prominent. Both *Posidonia* and *Zostera* appeared to be in good health and covered areas of 1,104 m^2 and 974 m^2, respectively. In addition, a small area of *Halophila* (254 m^2) was observed to the south-west of the boat ramp, near the marina, although was quite sparse.

5 Discussion

5.1 Sediment properties and contaminants

The water properties at the Gunnamatta Bay study sites were similar to the reference sites in Burraneer Bay and Dolans Bay, respectively. All sites were contained considerable amounts to fine sand (particles >180 µm). The sediment properties at the reference sites were generally very similar to those in Gunnamatta Bay. The Cronulla Marina and Public Wharf sites in Gunnamatta Bay were more silty than the other benthic sites. The Cronulla Marina site also had a higher amount or organic carbon.

Metal concentrations were generally below the ISQG trigger values in Gunnamatta Bay except at the inner sites of the Cronulla Marina and one site close to the boat ramp and a stormwater drain. Concentrations of Cu, Pb and Zn exceeded the guideline trigger values at these sites and exceeded the ISQG-High value for Pb and Zn at some sites. At the reference sites, no sediments had metal concentrations exceeding the trigger value. The sediment pore waters contain low concentrations of 'potentially toxic' metals. The TBT concentrations were typical of estuarine bays that have significant boating activity. The TBT concentration was highest at the Cronulla Marina site and exceeded the ISQG-High value.

The concentrations of all organics analysed generally were low at all sites. Detectable concentrations of PAHs were measured in most sediments, but were generally below or near the trigger value. TPHs, chlordane and phenol were detected at two sites. PCBs were detected at one site. OC pesticides were detected at one site.

The dredging of sediments and their disposal at sea, where contaminant concentrations exceed the ISQG trigger values, is regulated by the National Ocean Disposal Guidelines for Dredged Material (2002). An assessment hierarchy is provided in this document that evaluates the potential risk on ecosystems if such material is to be disposed of at sea. For sediments where TBT concentrations exceeded the ISQG-High value, pore water analyses, elutriate testing and ultimately toxicity testing might be required.

5.1.1 Sediment quality guidelines and their use

The Australian Interim Sediment Quality Guidelines (ISQGs) are intended as trigger values that, when exceeded, indicate a likelihood of toxic effects (ANZECC/ARMCANZ, 2000). Unlike the Australian Water Quality Guidelines, they are not based on cause-effect relationships, but instead, by comparing biological effects with contaminant concentrations in a large database of field-collected sediments. This has sometimes caused some confusion and misinterpretation of the toxicological significance of the sediment chemistry data.

The guidelines contain two values, the ISQG-Low value (or trigger value) and the ISQG-High value. The trigger value is a threshold value, and below this value the frequency of adverse biological effects is expected to be very low. The ISQG-High value is intended to represent a value, above which adverse biological effects are expected to occur more frequently. The ISQGs are not independent of sediment properties, but are based largely on data for clay/silt sediments. The occurrence of effects will be altered by the properties of the sediments (i.e. the amount of fine particles and organic matter, pH) and overlying water conditions. This is the reason for the site-specific approach of the ANZECC/ARMCANZ (2000) guideline decision tree for assessing sediment contamination. Exceeding either the ISQG-High value does not necessarily mean that adverse biological effects will occur in the sediments, but further investigations should be undertaken to confirm this.

5.1.2 Likelihood of toxicity to benthic organisms

The ANZECC/ARMCANZ (2000) guideline trigger values for metals are quite conservative, particularly for marine systems where the pH of sediments is well buffered by the overlying

seawater and pore water metal concentrations seldom exceed low µg/L concentrations. Recent studies by CSIRO CECR and other groups globally (e.g. Borgmann, 2003) have indicated that most 'interim' SQGs for metals are overly conservative, sufficiently so that regulatory processes require excessive site investigation to proof the absence of possible effects to ecosystems.

Research by CECR and NSW EPA on the sensitivity of the juvenile amphipod *Melita plumulosa* (10-day whole sediment toxicity tests) to metals indicates that effects to amphipod survival (e.g. no observable effect concentrations, NOECs, and lethal concentrations, LC50s) will not be observed until concentrations at least four times greater than the current ISQG-High values for Cd, Cu, Ni, Pb and Zn. This bioassay is currently regarded as the most sensitive whole-sediment bioassay available in Australia. With regard to the Gunnamatta Bay study, only at the marina sites with metal concentrations above ISQG-High value, will some effects on ecosystem health be possible due to the combined effects of elevated Cu, Pb and Zn concentrations. Toxicity tests on sediments from the vicinity of the Cronulla Marina are recommended.

In general, the concentrations of organic contaminants are not sufficiently elevated above the guideline trigger value to cause concerns for ecosystem health. Extensive toxicity testing of marine sediments contaminated with PAHs has indicated that the ISQG-High value is sufficiently protective against acute toxicity effect to benthic organisms (Simpson et al., 2004), while a value of 15 mg/kg total-PAHs (normalized to 1% TOC) should be protective against chronic effects (Kravitz et al., 1999; Di Toro et al., 2000.

5.1.3 Effects of contamination to benthos

Results from both multivariate and univariate analyses showed no distinct patterns in terms of the benthic assemblages at Gunnamatta Bay and the control locations of Burraneer Bay and Dolans Bay. Although some differences were highlighted by the analyses, these were not consistent enough to suggest that contamination has had an unambiguous effect on the benthic organisms within Gunnamatta Bay. Results from contaminant testing by CSIRO showed that some sites within Gunnamatta Bay were contaminated. However, this contamination does not appear to have had a large impact on the benthic communities at the sites sampled.

5.1.4 Effects of dredging on the spread of the weed

The effects of dredging on the spread of the weed *Caulerpa taxifolia* is a major concern NSW Fisheries (2004) have recently issued a control plan for *Caulerpa* in NSW waters. This control plan highlights the need to minimise any disturbance to *Caulerpa,* as the main method by which this alga spreads and establishes itself into new areas is by fragmentation (NSW Fisheries, 2004). Although not specifically mentioned in the control plan, dredging procedures could have a dramatic effect on *Caulerpa*, not only at the head of Gunnamatta Bay, but within the Port Hacking estuary. Therefore, if dredging is to be done in areas that contain *Caulerpa*, extreme care should be taken to minimise any fragments from entering other parts of the bay, and to limit the size of the area to be dredged. One approach that should be considered is to skim-dredge the upper layer (say 20 - 30 cm depth) of the sediment to remove *Caulerpa* without a large amount of sediment. This surface veneer could then be disposed of on land. The remaining dredge material removed from the area could then be disposed of by more conventional means, subject to issues of contamination.

6 Conclusions

Metal concentrations were generally below the interim sediment quality guideline trigger values in Gunnamatta Bay except at the inner sites of the Cronulla Marina and one site close to the boat ramp and a stormwater drain. Concentrations of Cu, Pb and Zn exceeded the guideline trigger values at these sites and exceeded the ISQG-High value for Pb and Zn at some sites. At the reference sites, no sediments had metal concentrations exceeding the trigger values. The sediment pore waters contain low concentrations of 'potentially toxic' metals. The TBT concentrations were typical of estuarine bays the have significant boating activity. The TBT concentration was highest at the Cronulla Marina site and exceeded the ISQG-High value. The concentrations of all organics analysed generally were low at all sites. Detectable concentrations of PAHs were measured in most sediments, but were generally below or near the trigger value. TPHs, chlordane and phenol were detected at two sites. PCBs were detected at one site. OC pesticides were detected at one site.

Contamination at the head of Gunnamatta Bay appeared to have had little effect on the benthic macroinvertebrate assemblages associated with soft sediment habitat within this area. Although some variables were found to be significantly different between Gunnamatta Bay and the controls, no consistent pattern was observed to suggest that contamination has had an impact on these organisms. It is important to recognise, however, that this conclusion is based on a one-off survey and different effects may occur at different times. Not withstanding this limitation, the results suggest no major effects are likely to be occurring to benthos in the area due to contaminated sediments.

The dredging of sediments and their disposal at sea, where contaminant concentrations exceed the ISQG trigger values, is regulated by the National Ocean Disposal Guidelines for Dredged Material (2002). An assessment hierarchy is provided in this document that evaluates the potential risk on ecosystems if such material is to be disposed of at sea. For sediments where TBT concentrations exceeded the ISQG-High value, pore water analyses, elutriate testing and ultimately toxicity testing might be required.

If dredging was undertaken, benthic communities would be affected, however these communities could be expected to recover over time frames of months. The effect of dredging on the spread of the weed, *Caulerpa taxifolia,* is a major concern and dredging approaches that remove this weed (e.g. skim-dredging) should be considered.

7 Acknowledgments

The authors are grateful to David Bishop and Brett Warden (CSIRO) for the help with field work and chemical analyses. The authors thank Dr. Dianne Jolley (University of Wollongong) for assisting in field work. We thank the staff at The Ecology Lab for conducting the benthic ecology survey and assisting with sediment sampling. We thank the Australian Government Analytical Laboratories (AGAL) for the fast and quality analyses of sediment organics. The authors thank Anthony Chariton for discussions on the interpretation of benthic ecology data.

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9 Appendices

Appendix A Quality Assurance Reports for Analyses.

Physical Properties Quality Assurance / Quality Control (QA/QC)

Gunnamatta Bay Sediments 04042003

Site	Location	Particle Size, %					Water	Density
		<63 µm	63-180 µm	0.18-1 mm	1-2 mm	>2 mm	%	g/cm^3
5S	Tonkin Park Shoal	8.2	14.7	72.3	2.2	2.6	28.4	1.71
5S replicate	Tonkin Park Shoal	7.4	15.1	72.6	2.0	2.9	25.6	1.80
10S	Cronulla Marina	10.2	37.5	52.3	0.0	0.0	55.0	1.35
10S replicate	Cronulla Marina	35.6	19.5	33.9	0.0	11.0	61.5	1.32
19S	Cronulla Marina	16.2	4.9	78.9	0.0	0.0	43.3	1.56
19S replicate	Cronulla Marina	11.3	3.8	84.9	0.0	0.0	32.5	1.79

[a] All samples are surface sediments (0-2 cm)

Weak-Acid Extactable Metals Quality Assurance / Quality Control (QA/QC)

Gunnamatta Bay Sediments 04042003

Spike recoveries were 85-110% for all metals. Dilutions of 1/50 were required for some analyses by ICP-AES.

Blanks — **Weak-Acid Extactable Metals, mg/kg)**

Sample	Al	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Ag	Cd	Pb
Blank 1	<0.4	<0.4	<0.4	<1	<0.4	<0.4	<0.4	<0.4	<1	<1	<0.4	<1
Blank 2	<0.4	<0.4	<0.4	<1	<0.4	<0.4	<0.4	<0.4	<1	<1	<0.4	<1
Blank 3	<0.4	<0.4	<0.4	<1	<0.4	<0.4	<0.4	<0.4	<1	<1	<0.4	<1

Analysis Duplicates — **Weak-Acid Extactable Metals, mg/kg)**

Sample	Al	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Ag	Cd	Pb
3D A	1233	3.1	26.8	2926	1.2	1.9	12.3	76.0	0.7	<1	<0.4	62.3
3D A r	1048	4.3	27.2	3670	1.5	2.7	14.2	106	0.9	<1	<0.4	70.5
5S F	1178	2.2	13.4	3317	1.1	2.0	10.7	45.6	0.8	<1	<0.4	35.9
5S F r	960	1.9	14.9	2649	1.0	1.6	10.5	39.2	0.6	<1	<0.4	36.2
7S B	1188	3.6	16.1	3249	1.5	2.6	97.3	123	1.6	0.2	<0.4	61.6
7S B r	1051	3.2	16.8	3248	1.4	2.1	108	147	1.5	<1	<0.4	85.0
10S B	1328	6.6	19.2	5733	2.0	3.0	46.0	207	1.3	<1	<0.4	134
10S B r	1310	6.5	19.1	5473	1.9	3.2	54.6	202	1.2	<1	<0.4	134
12S D	1410	6.9	19.2	6329	2.1	3.1	53.2	295	1.6	<1	0.5	151
12S D r	1263	11.1	28.9	8598	2.9	5.5	191.5	373	2.4	<1	0.4	198
15S A	1279	5.2	9.9	3784	1.1	1.6	32.4	81.0	1.3	<1	<0.4	52.2
15S A r	948	5.9	9.1	3349	1.0	2.1	35.9	70.2	1.2	<1	<0.4	45.0
19S B	620	2.9	6.0	1576	0.6	0.9	36.8	60.8	1.4	<1	<0.4	43.0
19S B r	516	2.7	4.9	1379	0.5	0.9	31.4	59.1	0.9	<1	<0.4	38.7
20b S A	689	3.5	7.3	2276	0.7	1.4	15.1	53.6	0.7	<1	<0.4	31.3
20b S A r	652	3.4	7.2	2114	0.7	1.3	22.6	53.3	1.3	<1	<0.4	32.3
22S A	415	1.4	7.6	1129	0.4	0.7	10.4	20.2	0.7	<1	<0.4	20.3
22S A r	291	1.3	6.1	857	0.3	0.3	7.4	17.1	0.8	<1	<0.4	12.3
25D A	681	3.0	6.7	1927	0.7	1.0	20.1	59.1	0.7	<1	<0.4	49.3
25D A r	755	4.2	6.8	2150	0.7	1.3	25.5	71.4	0.9	<1	<0.4	55.1
12S <63 A	4095	20.3	46.0	15559	6.1	9.8	725	797	10.6	<1	1.0	469
12S <63 A r	3672	20.4	43.4	14874	5.8	9.5	702	751	10.0	<1	1.2	441

Weak-Acid Extactable Metals Quality Assurance / Quality Control (QA/QC)

SOPA Sediments 04042003

Spike recoveries were 85-110% for all metals. Dilutions of 1/50 were required for some analyses by ICP-AES.

Field Duplicates	Weak-Acid Extactable Metals, mg/kg)											
Sample	Al	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Ag	Cd	Pb
1S A	1151	5.9	85	9577	5.3	10.4	27.1	121	1.0	<1	<0.4	75.1
1S B	1053	4.1	59	8782	4.1	5.0	19.8	91	1.1	<1	<0.4	46.2
2S A	727	1.6	11.3	2143	0.7	1.1	11.0	37	0.8	<1	<0.4	28.1
2S B	613	1.6	11.2	1984	0.7	1.2	9.0	31	0.8	<1	<0.4	27.0
3S A	1196	3.3	15.7	3115	1.2	2.2	15.0	62	0.8	<1	<0.4	45.1
3S B	1161	2.4	14.4	2681	1.0	1.7	13.2	53	0.9	<1	<0.4	34.2
3D A	1140	3.7	27.0	3298	1.4	2.3	13.2	91	0.8	<1	<0.4	66.4
3D B	1260	4.8	16.6	3126	1.2	2.3	11.8	204	0.6	<1	<0.4	82.5
3.5S A	844	3.2	9.7	2070	0.7	1.1	17.2	89	1.3	<1	<0.4	56.6
3.5S B	1274	3.7	10.8	2582	0.9	1.4	20.1	67	1.2	<1	<0.4	55.2
4S A	1198	3.4	16.7	4091	1.6	2.4	42.4	89	1.6	<1	<0.4	60.4
4S B	1134	3.5	16.3	3617	1.2	1.9	34.7	88	1.1	<1	<0.4	62.0
5S A	1079	2.6	13.1	3297	1.0	1.7	10.3	62	0.4	<1	<0.4	51.3
5S B	1129	2.6	21.0	3086	1.1	1.7	12.6	48	0.7	<1	<0.4	35.6
5S C	1186	3.0	18.7	3630	1.3	2.2	16.3	63	0.8	<1	<0.4	72.0
5S D	1084	2.5	14.0	3048	1.0	1.6	9.1	53	0.6	<1	<0.4	33.7
5S E	1121	2.7	13.6	3313	1.1	2.0	15.2	60	0.7	<1	<0.4	44.5
5S F	1069	2.1	14.2	2983	1.1	1.8	10.6	42	0.7	<1	<0.4	36.0
6S A	1573	4.6	13.3	3917	1.2	1.8	25.6	89	1.6	<1	<0.4	62.6
6S B	1428	4.5	13.4	3634	1.2	1.8	19.7	82	1.0	<1	<0.4	58.6
6D A	1077	4.0	9.9	2553	1.0	1.3	17.5	84	1.3	<1	<0.4	62.5
6D B	1003	4.0	9.2	2426	0.9	1.3	16.3	76	1.2	<1	<0.4	65.4
7S A	1117	4.4	16.0	2714	1.5	2.4	70.6	144	1.2	<1	<0.4	47.7
7S B	1119	3.4	16.5	3248	1.5	2.3	102.8	135	1.6	<1	<0.4	73.3
8S A	394	1.8	6.8	1304	0.6	0.8	9.6	30	0.2	<1	<0.4	18.8
8S B	1066	3.6	18.8	3620	1.7	2.4	16.9	79	0.8	<1	<0.4	38.6
9S A	1567	8.6	24.5	8714	2.7	4.1	16.2	313	0.7	<1	<0.4	165.3
9S B	1850	9.1	25.4	9358	3.0	4.6	30.2	360	1.5	<1	<0.4	185.9
9D A	1094	5.8	22.1	4667	2.0	3.3	72.1	279	1.3	<1	<0.4	188.0
9D B	1207	8.3	23.1	5354	2.2	3.9	70.0	258	1.3	<1	<0.4	217.0
10S A	1412	6.6	18.7	5510	2.0	3.0	65.2	202	1.5	<1	<0.4	131.6
10S B	1319	6.6	19.2	5603	2.0	3.1	50.3	205	1.3	<1	<0.4	134.0

Weak-Acid Extactable Metals Quality Assurance / Quality Control (QA/QC)

SOPA Sediments 04042003

Spike recoveries were 85-110% for all metals. Dilutions of 1/50 were required for some analyses by ICP-AES.

Field Duplicates	Weak-Acid Extactable Metals, mg/kg)											
Sample	Al	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Ag	Cd	Pb
11S A	1101	4.0	9.6	2688	0.9	1.4	38.8	84	1.0	<1	<0.4	59.6
11S B	823	3.5	7.2	2306	0.8	1.1	96.6	68	1.1	<1	<0.4	46.8
12S A	1444	11.1	30.2	9853	3.3	5.2	188	425	2.5	<1	<0.4	234.3
12S B	1365	9.7	25.6	8097	2.8	4.3	175	363	2.1	<1	<0.4	208.8
12S C	1249	7.8	21.4	6711	2.3	3.6	83.4	291	1.9	<1	<0.4	187.5
12S D	1336	9.0	24.1	7463	2.5	4.3	122	334	2.0	<1	<0.4	174.7
12S E	1566	11.0	27.2	9655	3.0	4.9	241.3	437	3.0	<1	<0.4	225.9
12S F	1903	10.9	27.1	9709	3.2	5.1	290.7	430	3.1	<1	<0.4	223.6
13S A	1634	9.6	21.0	6970	2.3	3.2	35	222	1.6	<1	<0.4	133.1
13S B	1380	8.2	18.6	6976	2.2	3.2	31	234	1.4	<1	<0.4	150.1
14S A	1164	5.4	12.9	3707	1.3	2.2	41.3	114	1.3	<1	<0.4	80.6
14S B	1263	5.6	12.6	3624	1.4	2.0	51	113	1.3	<1	<0.4	76.6
15S A	1113	5.6	9.5	3567	1.0	1.9	34.1	76	1.3	<1	<0.4	48.6
15S B	1083	2.9	5.3	2102	0.6	0.9	15.3	45	1.0	<1	<0.4	29.2
16S	1677	6.7	18.9	5599	1.7	2.4	30.4	170	1.4	<1	<0.4	109.0
16D	646	2.1	3.3	972	0.4	0.5	13.1	48	1.2	<1	<0.4	32.8
18S A	555	3.2	5.3	2020	0.6	0.8	15.9	35	1.1	<1	<0.4	28.5
18S B	722	4.3	6.6	2203	0.7	0.9	23.7	47	1.4	<1	<0.4	36.7
18D A	482	2.4	3.6	1153	0.4	0.5	9.8	25	0.7	<1	<0.4	19.4
18D B	564	2.8	4.1	1319	0.5	0.7	13.0	30	0.8	<1	<0.4	24.1
19S A	614	2.5	6.8	1474	0.6	0.9	33.8	58	1.1	<1	<0.4	34.9
19S B	568	2.8	5.4	1477	0.6	0.9	34.1	60	1.2	<1	<0.4	40.8
19S C	606	2.5	5.3	1668	0.5	0.9	51.6	60	1.3	<1	<0.4	37.2
19S D	744	3.1	8.0	1941	0.7	1.1	52.3	76	1.4	<1	<0.4	46.0
19S E	1509	7.2	14.0	5741	1.7	2.5	84.0	192	2.6	<1	<0.4	124.4
19S F	1193	5.2	11.5	3941	1.1	1.8	26.7	125	1.0	<1	<0.4	77.6
19.5S A	924	5.0	10.0	3557	1.0	1.6	21.5	100	1.4	<1	<0.4	71.7
19.5S B	907	5.0	9.5	2994	0.9	1.5	18.7	78	1.3	<1	<0.4	43.4
19.5D A	426	1.8	4.3	709	0.4	1.5	1.2	11	4.3	<1	<0.4	1.5
19.5D B	381	1.8	5.6	606	0.3	1.0	0.9	3	2.4	<1	<0.4	1.3
20S A	356	1.4	8.6	957	0.4	0.4	8.3	19	0.8	<1	<0.4	13.7
20S B	286	1.2	4.7	953	0.3	0.4	9.3	18	0.8	<1	<0.4	12.3
20S C	265	1.2	4.3	838	0.3	0.4	7.7	17	0.7	<1	<0.4	11.4
20S D	228	0.8	3.4	664	0.3	0.3	4.9	13	0.4	<1	<0.4	8.0
20S E	280	1.2	6.0	863	0.3	0.4	10.0	17	0.8	<1	<0.4	13.8
20S F	530	0.8	5.4	851	0.4	0.4	4.4	13	0.4	<1	<0.4	7.8
20b S A	671	3.4	7.2	2195	0.7	1.3	18.9	53	1.0	<1	<0.4	31.8
20b S B	616	2.9	6.0	2027	0.6	0.9	9.7	48	0.8	<1	<0.4	30.3

Weak-Acid Extactable Metals Quality Assurance / Quality Control (QA/QC)

SOPA Sediments 04042003

Spike recoveries were 85-110% for all metals. Dilutions of 1/50 were required for some analyses by ICP-AES.

Field Duplicates	Weak-Acid Extactable Metals, mg/kg)											
Sample	Al	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Ag	Cd	Pb
21D A	420	2.2	5.2	1477	0.4	0.6	12.7	30	1.1	<1	<0.4	27.1
21D B	489	2.6	5.8	1763	0.5	0.7	15.4	31	1.3	<1	<0.4	25.6
22S A	353	1.4	6.8	993	0.4	0.5	8.9	19	0.8	<1	<0.4	16.3
22S B	309	2.9	7.3	968	0.3	0.4	10.2	22	1.0	<1	<0.4	15.0
23S A	977	1.5	10.4	1341	0.7	0.8	8.0	34	1.0	<1	<0.4	15.2
23S B	241	1.0	8.1	670	0.2	0.3	5.8	15	0.8	<1	<0.4	10.9
24S A	475	1.3	7.5	1108	0.5	0.7	7.5	17	0.7	<1	<0.4	14.5
24S B	590	0.9	6.8	1123	0.6	1.0	8.4	21	0.7	<1	<0.4	12.5
25S A	822	3.9	7.5	2700	0.8	1.3	23.7	75	0.8	<1	<0.4	47.5
25S B	686	3.5	6.9	2288	0.7	1.2	24.7	66	0.8	<1	<0.4	42.6
25D A	718	3.6	6.7	2038	0.7	1.1	22.8	65	0.8	<1	<0.4	52.2
25D B	655	2.9	6.0	1800	0.6	1.0	24.8	57	0.9	<1	<0.4	47.1
C1 A	1209	2.8	17.1	3360	1.3	2.3	18.6	100	1.4	<1	<0.4	33.3
C1 B	1245	4.7	24.1	3669	1.4	2.6	22.3	122	1.4	<1	<0.4	32.2
C1 C	538	1.5	5.9	1363	0.5	1.0	3.1	16	0.3	<1	<0.4	7.0
C1 D	743	1.4	18.0	1717	0.8	1.1	5.3	34	0.5	<1	<0.4	15.5
C1 E	860	1.3	11.6	1803	0.7	1.3	4.9	24	0.5	<1	<0.4	15.4
C1 F	757	1.1	7.9	1352	0.5	0.7	2.9	15	0.3	<1	<0.4	6.9
C1 G	610	1.7	8.3	1978	0.5	0.6	3.1	21	0.5	<1	<0.4	17.2
C1 H	483	1.1	4.8	1243	0.4	0.6	3.4	18	0.3	<1	<0.4	13.5
C2 1	538	0.7	5.5	1044	0.4	0.7	3.4	18	0.3	<1	<0.4	7.7
C2 B	475	0.7	6.2	991	0.4	0.5	3.0	17	0.5	<1	<0.4	7.0
C2 C	510	1.0	5.5	1132	0.4	0.7	5.8	23	0.7	<1	<0.4	12.0
C2 D	676	1.2	6.7	1424	0.6	1.0	5.3	23	0.5	<1	<0.4	12.5
C2 E	689	1.5	5.4	1676	0.5	0.9	11.1	41	0.7	<1	<0.4	22.9
C2 F	566	1.3	3.8	1340	0.4	0.7	11.7	32	1.0	<1	<0.4	18.8
C2 G	600	1.6	6.6	2736	0.7	1.1	35.4	69	2.5	<1	<0.4	46.8
C2 H	670	3.1	8.8	3253	0.9	1.4	42.0	59	2.5	<1	<0.4	60.3

Appendix B Analyses of Organic Contaminants

Centre for Advanced Analytical Chemistry
March 24, 2004

Polycyclic Aromatic Hydrocarbon (PAH) Concentrations in Sediments

Site	PAHs, mg/kg [a, b]						Total Organic Carbon, %	
	Total		Low molecular weight		High molecular weight			
	surface	depth	surface	depth	surface	depth	surface	depth
6-A	<46	NM [c]	<11.6	NM	<34	NM	0.43	NM
10	<3.3	6.8	<0.60	<1.2	<2.7	<5.6	4.10	2.10
13-A	<4.3	NM	<0.74	NM	<3.6	NM	3.50	NM
17	<2.1	2.6	<0.41	<0.50	<1.7	<2.2	3.20	2.40
16	<5.5	5.5	<1.7	<1.7	<3.8	<3.8	0.39	0.37
21-A	<4.9	NM	<1.3	NM	<3.6	NM	0.69	NM
22	<2.8	3.8	<0.68	<0.90	<2.1	<3.0	1.20	0.89
25-A	<4.8	NM	<1.5	NM	<3.3	NM	0.43	NM
23	<4.5	5.6	<1.2	<1.2	<3.3	<4.4	0.82	0.74
18	<5.1	3.8	<1.1	<1.1	<4.0	<2.7	0.87	0.69
B1-A	<1.3	NM	<0.50	NM	<0.80	NM	1.20	NM
D2-A	<4.4	NM	<1.7	NM	<2.8	NM	0.36	NM
ISQG-Low [c]	4		0.55		1.7		-	
ISQG-High	45		3.16		9.6		-	

Notes: [a] Where concentrations of any individual PAH was below the detection limit, the sum of the total, low- and high-molecular weight PAHs includes the detection limit values.
[b] NM = Not measured
[c] ANZECC/ARMCANZ (2000) guideline values.

Individual PAH Concentrations in Sediments

Individual PAH Concentrations in Sediments, mg/kg [a]

Site	Naphthalene		Acenaphthylene		Acenaphthene		Fluorene		Phenanthrene		Anthracene		Fluoranthene		Pyrene		Benz(a)anthracene	
	surface	depth	surface	depth	surface	depth	surface	depth	surface	depth	surface	depth	surface	depth	surface	depth	surface	depth
6-A	0.47	NM b	0.47	NM	<0.23	NM	0.84	NM	8.14	NM	1.49	NM	10.00	NM	9.07	NM	2.33	NM
10	0.03	0.05	0.04	0.08	<0.02	<0.05	0.03	0.06	0.39	0.81	0.09	0.19	0.63	1.33	0.61	1.24	0.20	0.43
13-A	0.03	NM	0.05	NM	<0.03	NM	0.04	NM	0.49	NM	0.11	NM	0.83	NM	0.80	NM	0.27	NM
17	<0.03	<0.04	<0.03	<0.04	<0.03	<0.04	<0.03	<0.04	0.23	0.24	0.05	0.05	0.38	0.46	0.38	0.46	0.15	0.18
16	<0.26	<0.27	<0.26	<0.27	<0.26	<0.27	<0.26	<0.27	0.41	0.38	<0.26	<0.27	0.69	0.70	0.74	0.73	0.36	0.32
21-A	<0.15	NM	<0.15	NM	<0.14	NM	<0.15	NM	0.57	NM	<0.15	NM	0.87	NM	0.80	NM	0.35	NM
22	<0.08	<0.11	<0.08	<0.11	<0.08	<0.11	<0.08	<0.11	0.26	0.31	<0.08	<0.11	0.48	0.60	0.48	0.62	0.22	0.29
25-A	<0.23	NM	<0.23	NM	<0.23	NM	<0.23	NM	0.37	NM	<0.23	NM	0.60	NM	0.58	NM	0.35	NM
23	<0.12	<0.14	<0.12	<0.14	<0.12	<0.14	<0.12	<0.14	0.56	0.54	0.13	<0.14	0.91	0.96	0.85	0.95	0.37	0.38
18	<0.11	<0.14	<0.11	<0.14	<0.11	<0.14	<0.11	<0.14	0.49	0.33	0.13	<0.14	0.90	0.59	0.86	0.59	0.36	0.28
B1-A	<0.08	NM	<0.08	NM	<0.08	NM	<0.08	NM	<0.08	NM	<0.08	NM	<0.08	NM	<0.08	NM	<0.08	NM
D2-A	<0.28	NM	<0.28	NM	<0.28	NM	<0.28	NM	<0.28	NM	<0.28	NM	<0.28	NM	<0.28	NM	<0.28	NM
ISQG-Low [c]	0.16		0.044		0.016		0.019		0.24		0.085		0.6		0.665		0.261	
ISQG-High	2.1		0.64		0.5		0.54		1.5		1.1		5.1		2.6		1.6	

[a] "less than" value denotes less than the detection limit normalised to 1% TOC.

[b] NM = Not measured [c] ANZECC/ARMCANZ (2000) guideline values.

Individual PAH Concentrations in Sediments

Individual PAH Concentrations in Sediments, mg/kg [a]

Site	Chrysene		Benzo(b)&(k)fluoranthene		Benzo(a)pyrene		Indeno(1,2,3cd)fluoranthene		Dibenz(ah)anthracene		Benzo(ghi)perylene	
	surface	depth	surface	depth	surface	depth	surface	depth	surface	depth	surface	depth
6-A	2.56	NM	4.19	NM	2.79	NM	1.47	NM	<0.23	NM	1.81	NM
10	0.22	0.46	0.44	0.90	0.27	0.57	0.13	0.29	<0.02	<0.05	0.16	0.31
13-A	0.31	NM	0.60	NM	0.34	NM	0.17	NM	<0.03	NM	0.20	NM
17	0.15	0.19	0.29	0.38	0.17	0.22	0.08	0.11	<0.03	<0.04	0.10	0.12
16	0.33	0.30	0.59	0.57	0.33	0.32	<0.26	<0.27	<0.26	<0.27	<0.26	<0.27
21-A	0.36	NM	0.55	NM	<0.14	NM	0.16	NM	<0.14	NM	0.19	NM
22	0.22	0.28	<0.17	0.52	0.22	0.29	0.12	0.13	<0.08	<0.11	0.13	<0.11
25-A	0.30	NM	<0.47	NM	0.26	NM	<0.23	NM	<0.23	NM	<0.23	NM
23	0.40	0.41	<0.24	0.70	<0.12	0.41	<0.12	0.20	<0.12	<0.14	0.20	0.23
18	0.36	0.25	0.64	0.29	0.36	0.26	0.17	0.14	<0.11	<0.14	0.23	<0.14
B1-A	<0.08	NM	<0.17	NM	<0.08	NM	<0.08	NM	<0.08	NM	<0.08	NM
D2-A	<0.28	NM	<0.56	NM	<0.28	NM	<0.28	NM	<0.28	NM	<0.28	NM
ISQG-Low [c]	0.384		NA [d]		0.43		NA		0.063		NA	
ISQG-High	2.8		NA		1.6		NA		0.26		NA	

[a] "less than" value denotes less than the detection limit normalised to 1% TOC.

[b] NM = Not measured [c] ANZECC/ARMCANZ (2000) guideline values. [d] NA = not available

Total Petroleum Hydrocarbons (TPH) Concentrations in Sediments

TPH Concentrations in Sediments, mg/kg

Site	Total petroleum hydrocarbons [a, c]				sum [b]
	C6-C9	C10-C14	C15-C28	C29-C36	C6-C36
6-A	<58	<116	302	<232	<710
13-A	<7	<14	131	94	<250
21-A	<36	<72	<145	<145	<400
25-A	<58	<116	<232	<232	<640
B1-A	<20	<41	<83	<83	<230
D2-A	<69	<138	<277	<277	<760
ISQG-Low [c]	NA [d]	NA	NA	NA	NA
ISQG-High	NA	NA	NA	NA	NA

Notes: [a] "less than" value denotes less than the detection limit normalised to 1% TOC.
[b] Where concentrations were below the detection limit, the sum (C6-C36) includes the detection limit value.
[c] ANZECC/ARMCANZ (2000) guideline values.
[d] NA = not available

Phenol and PCB Concentrations in Sediments

Phenol Concentrations in Sediments, mg/kg

Site	Phenol	o-Cresol	m+p-Cresols	2,4-Dichloro-phenol	2,6-Dichloro-phenol	2,4,6-Trichloro-phenol	2,4,5-Trichloro-phenol	2,3,4,6-Tetrachloro-phenol	Pentachloro-phenol
6-A	<0.023 [a]	<0.023	<0.47	<0.023	<0.023	<0.47	<0.47	<0.47	<0.47
13-A	0.80	<0.0029	<0.057	<0.0029	<0.0029	<0.057	<0.057	<0.057	<0.057
21-A	1.88	<0.015	<0.29	<0.015	<0.015	<0.29	<0.29	<0.29	<0.29
25-A	<0.023	<0.023	<0.47	<0.023	<0.023	<0.47	<0.47	<0.47	<0.47
B1-A	<0.0083	<0.0083	<0.17	<0.0083	<0.0083	<0.17	<0.17	<0.17	<0.17
D2-A	<0.0278	<0.0278	<0.56	<0.0278	<0.0278	<0.56	<0.56	<0.56	<0.56
ISQG-Low [b]	NA [c]	NA	NA	NA	NA	NA	NA	NA	NA
ISQG-High	NA	NA	NA	NA	NA	NA	NA	NA	NA

Polychloinated byphenyls (PCB) Concentrations in Sediments, mg/kg

Site	PCBs
6-A	0.151
13-A	<0.003
21-A	<0.014
25-A	<0.023
B1-A	<0.008
D2-A	<0.028
ISQG-Low	<0.023
ISQG-High	NA

[a] "less than" value denotes less than the detection limit normalised to 1% TOC.

[b] ANZECC/ARMCANZ (2000) guideline values.

[c] NA = not available

OC and OP Pesticide Concentrations in Sediments

Analyses: In case of replicate analyses, results given are average of two.

OC Pesticide Concentrations in Sediments, mg/kg

Site	HCB	gamma BHC (Lindane)	Heptachlor	Aldrin	BHC (other than g-BHC)	Heptachlor epoxide	Chlordane (trans & cis)	DDT	DDE	DDD	Dieldrin	Endrin	Methoxy-chlor	Total Endosulfan
6-A	[a]<0.0023	<0.0023	<0.0023	<0.0023	<0.0023	<0.0023	0.0044	<0.0023	<0.0023	<0.0023	<0.0023	<0.0023	<0.0023	<0.0023
13-A	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	0.0011	0.0018	0.0005	<0.0003	0.0031	0.0006	<0.0003	<0.0003
21-A	<0.0014	<0.0014	<0.0014	<0.0014	<0.0014	<0.0014	<0.0014	<0.0014	<0.0014	<0.0014	<0.0014	<0.0014	<0.0014	<0.0014
25-A	<0.0023	<0.0023	<0.0023	<0.0023	<0.0023	<0.0023	<0.0023	<0.0023	<0.0023	<0.0023	<0.0023	<0.0023	<0.0023	<0.0023
B1-A	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008	<0.0008
D2-A	<0.0028	<0.0028	<0.0028	<0.0028	<0.0028	<0.0028	<0.0028	<0.0028	<0.0028	<0.0028	<0.0028	<0.0028	<0.0028	<0.0028
ISQG-Low [b]	NA [c]	0.0003	NA	NA	NA	NA	0.0005	0.0016	0.0022	0.0020	0.0020	0.0020	NA	NA
ISQG-High	NA	0.001	NA	NA	NA	NA	0.006	0.046	0.027	0.020	0.008	0.008	NA	NA

OP Pesticide Concentrations in Sediments, mg/kg

Site	Demeton-S-Methyl	Diazinon	Dimethoate	Pirimiphos-Methyl	Chlor-pyriphos	Parathion	Malathion-(Maldison)	Fenthion	Ethion	Azinphos-Methyl
6-A	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023
13-A	<0.0029	<0.0029	<0.0029	<0.0029	<0.0029	<0.0029	<0.0029	<0.0029	<0.0029	<0.0029
21-A	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
25-A	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023	<0.023
B1-A	<0.0083	<0.0083	<0.0083	<0.0083	<0.0083	<0.0083	<0.0083	<0.0083	<0.0083	<0.0083
D2-A	<0.0278	<0.0278	<0.0278	<0.0278	<0.0278	<0.0278	<0.0278	<0.0278	<0.0278	<0.0278
ISQG-Low	NA	0.0003	NA	NA	NA	NA	0.0005	0.0016	0.0022	0.0020
ISQG-High	NA	0.001	NA	NA	NA	NA	0.006	0.046	0.027	0.020

[a] "less than" value denotes less than the detection limit normalised to 1% TOC.

[b] ANZECC/ARMCANZ (2000) guideline values.

[c] NA = not available

Appendix C AGAL Quality Assurance Reports for Analyses and Analysis Data.

Sites names were changed from 'Field Site Name' to 'Report Site Name' according to the lists below.

Field Site Name	Report Site Name	Location	Field Site Name	Report Site Name	Location
1	1S	Tonkin Park Shoal	17	20S	Public Wharf
2S	2S	Tonkin Park Shoal	19A	21-A	Public Wharf
2D	2D	Tonkin Park Shoal	19C	21-B	Public Wharf
3S	3S	Tonkin Park Shoal	19.5S	22S	Sailing Club
3D	3D	Tonkin Park Shoal	19.5D	22D	Sailing Club
3.5	4S	Tonkin Park Shoal	20-B	23S	Sailing Club
4	5S	Tonkin Park Shoal	21S	24S	Sailing Club
5A	6-A	Tonkin Park Shoal	21D	24D	Sailing Club
5C	6-B	Tonkin Park Shoal	20A	25-A	Sailing Club
5E	6-C	Tonkin Park Shoal	20C	25-B	Sailing Club
6S	7S	Tonkin Park Shoal	20E	25-C	Sailing Club
6D	7D	Tonkin Park Shoal	22	26S	Gunnamatta Park Shoal
7	8S	Tonkin Park Shoal	23	27S	Gunnamatta Park Shoal
8	9S	Tonkin Park Shoal	24	28S	Gunnamatta Park Shoal
9S	10S	Cronulla Marina	Control site 1, A/B	B1-A	Burraneer Bay
9D	10D	Cronulla Marina	Control site 1, C/F	B1-B	Burraneer Bay
10	11S	Cronulla Marina	Control site 1, D/E	B1-C	Burraneer Bay
11	12S	Cronulla Marina	Control site 1, G/H	B1-D	Burraneer Bay
12A	13-A	Cronulla Marina	Control site 2, A/B	D2-A	Dolans Bay
12C	13-B	Cronulla Marina	Control site 2, C/D	D2-B	Dolans Bay
12E	13-C	Cronulla Marina	Control site 2, E/F	D2-C	Dolans Bay
13	14S	Cronulla Marina	Control site 2, G/H	D2-D	Dolans Bay
14	15S	Cronulla Marina			
18S	16S	Cronulla Marina			
18D	16D	Cronulla Marina			
16S	17S	Cronulla Marina			
16D	17D	Cronulla Marina			
25S	18S	Cronulla Marina			
25D	18D	Cronulla Marina			
15	19S	Cronulla Marina			

Appendix D The Ecology Lab : Benthos Report