GUNNS LTD PULP MILL

MARINE BIOLOGICAL AND SEDIMENT SURVEY
AT THE PROPOSED WHARF SITE

LONG REACH, TAMAR ESTUARY

Prepared by

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For

GHD PTY LTD
&
GUNNS LTD

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1 INTRODUCTION AND PROJECT BRIEF

The proposed Gunns Ltd pulp mill development includes a wharf facility in the Tamar Estuary, located in Long Reach (Figure 1).

The current survey was aimed at characterising the marine communities, seabed habitats and sediment conditions that occur at the proposed wharf site. The study also included investigations of major habitat and biological community types in neighbouring bays that may be affected by construction activities associated with the wharf.

The study brief incorporated the following tasks:

- Investigate seabed habitats and epi-benthic flora and fauna using video techniques
- Sample benthic infauna communities
- Assess intertidal habitats and communities
- Assess sediment condition through analyses of particle size, settling rates, redox potential and heavy metal concentrations
- On the basis of the survey and a brief literature review describe the following:
    - Habitat types and major epi-benthic communities at the wharf site and in adjacent bays
    - The composition and diversity of benthic infauna populations at the wharf site
    - The condition and characteristics of sediments at the wharf site relevant to assessments of heavy metal mobilisation during construction disturbance
    - Any threatened or protected marine species and other species or communities of conservation significance at the wharf site and in adjacent parts of the estuary
    - Fish populations and commercial fisheries in the vicinity of the wharf site
    - Introduced marine species that occur in the estuary and may colonise new wharf structures or spread as a result of disturbance at the site

2 METHODS

2.1 Overview and study sites

A field survey of the marine environment at the proposed Gunns Ltd pulp mill wharf site in Long Reach, Tamar Estuary, was conducted from the 4th to 12nd April 2005. A range of sampling techniques was used to survey marine habitats and communities, including towed video surveys, rocky intertidal transect surveys and collection of sediments for pollutant, particle size, redox, sediment settling rate and benthic infauna analysis. Specific field methodologies are described in sections below.

The sites surveyed are indicated in the maps in Figure 2 (benthic infauna, sediment and intertidal sampling sites) and Figure 3 (remote video tow sites for habitat assessment), while a key to the sites sampled, including geographical coordinates, depths and survey types performed at each site, is provided in Appendix 1. Note that the diagram of the proposed wharf structure, provided as an overlay in all maps, is approximate only and is based on a diagram provided by GHD. Sediment and benthic infauna samples were collected from a total of six sites distributed through the subtidal section of the proposed development zone, whilst rocky intertidal transect surveys were performed at two sites (Figure 2). Habitat assessments were performed along three towed video transects through the proposed development zone and in neighbouring bays, Big Bay and Dirty Bay (Figure 3), that may be affected by wharf construction works. Geographical coordinates, in projection WGS84, were recorded for all sites using a Garmin/Omnistar DGPS system accurate to ~2 m.

The field survey was supplemented by a literature review to further characterise the marine environment of the area and to describe any significant communities and species that have been recorded in previous studies.

2.2 Bathymetry

Bathymetry readings were collected at regular intervals across the proposed development area using a Garmin 185 GPS/sounder, coupled with an Omnistar differential unit. The readings were adjusted to the Port of Launceston chart datum level and provided as depth contours on a map of the coastline produced using Mapinfo Professional® software. The bathymetric survey was performed to collect 5 m depth contour data for the purpose of interpreting major habitat and biological community types. It was not performed to the detail required for many engineering assessments and therefore should not be used for assessments of that nature.

2.3 Seabed habitats and epi-benthic communities

Seabed habitats were assessed using a towed video system. This comprised a video camera mounted on a diving foil which was connected to an onboard TV monitor and Sony video recorder. Transect routes for the towed video were determined on the basis of bathymetry readings and echo sounder bottom profiles to assess the various habitats in the vicinity of the proposed wharf. No transect lines were set for these surveys; instead the tow boat was navigated along them and the route marked by DGPS. At the start of each transect, the video camera was lowered to approximately 0.5 m above the seabed, enabling a broad view of seabed habitat types. It was then towed slowly along the transect to capture footage of the habitat and communities present. Position along the transect was subsequently determined by comparing the time on the video to the time the GPS points were recorded.

Transects were filmed parallel to the shore across the proposed site at approximately 3 m, 5 m and 15 m depths (adjusted to chart datum). Based on seabed topography, these depths corresponded to three zones: the shallow nearshore, the shoulder of the shallow shelf and the base of the drop-off near the outer face of the wharf. A further transect was filmed in each of the adjacent bays, Big Bay and Dirty Bay. These transects started from the edge of the shallow shelf and extended around the bays parallel to the shore in approximately 3 m depth, following the shape of the bays.

Video images were recorded in digital format on Sony mini DV tapes and assessed later in the laboratory to describe substrate types and major marine biological communities and species present.

2.4 Benthic infauna

Benthic infauna samples were collected at six sites within the proposed development zone (Figure 2). Duplicate samples were collected from all sites, giving a total of 12 samples. Benthic infauna samples were collected remotely using a Van Veen grab, an apparatus that samples a 0.07 m^2 area of seabed during each deployment.

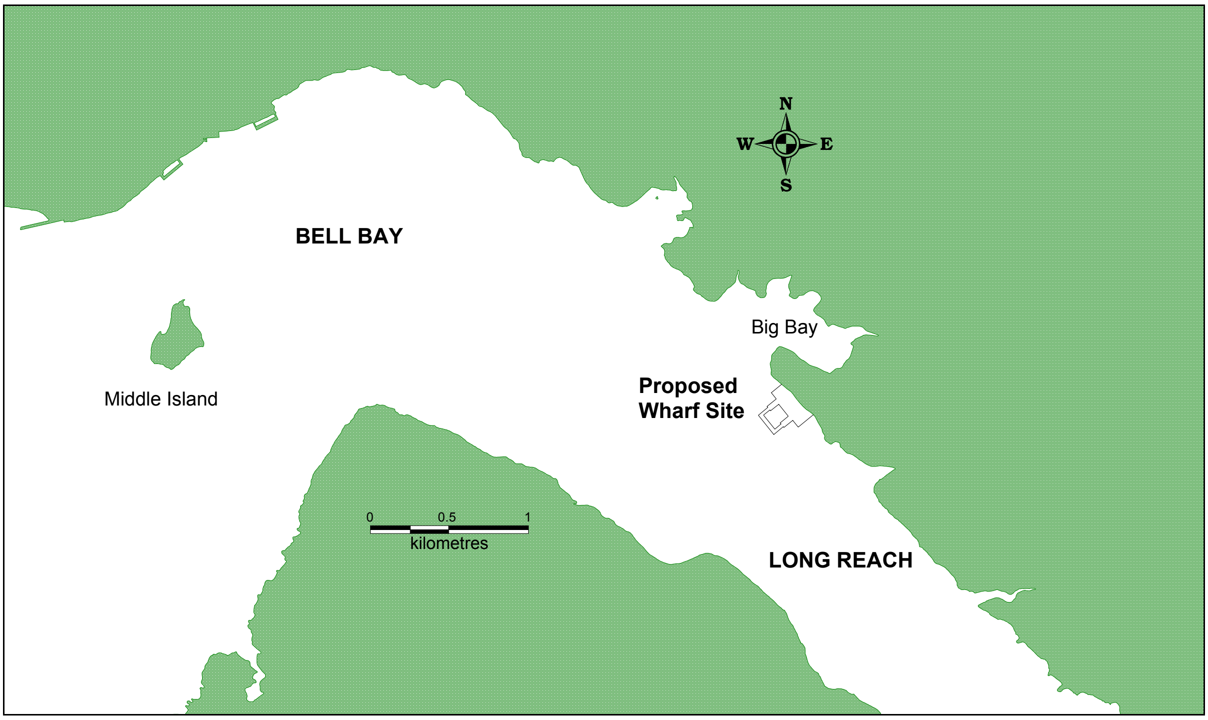


Figure 1 Map of the proposed wharf site in the Tamar Estuary.

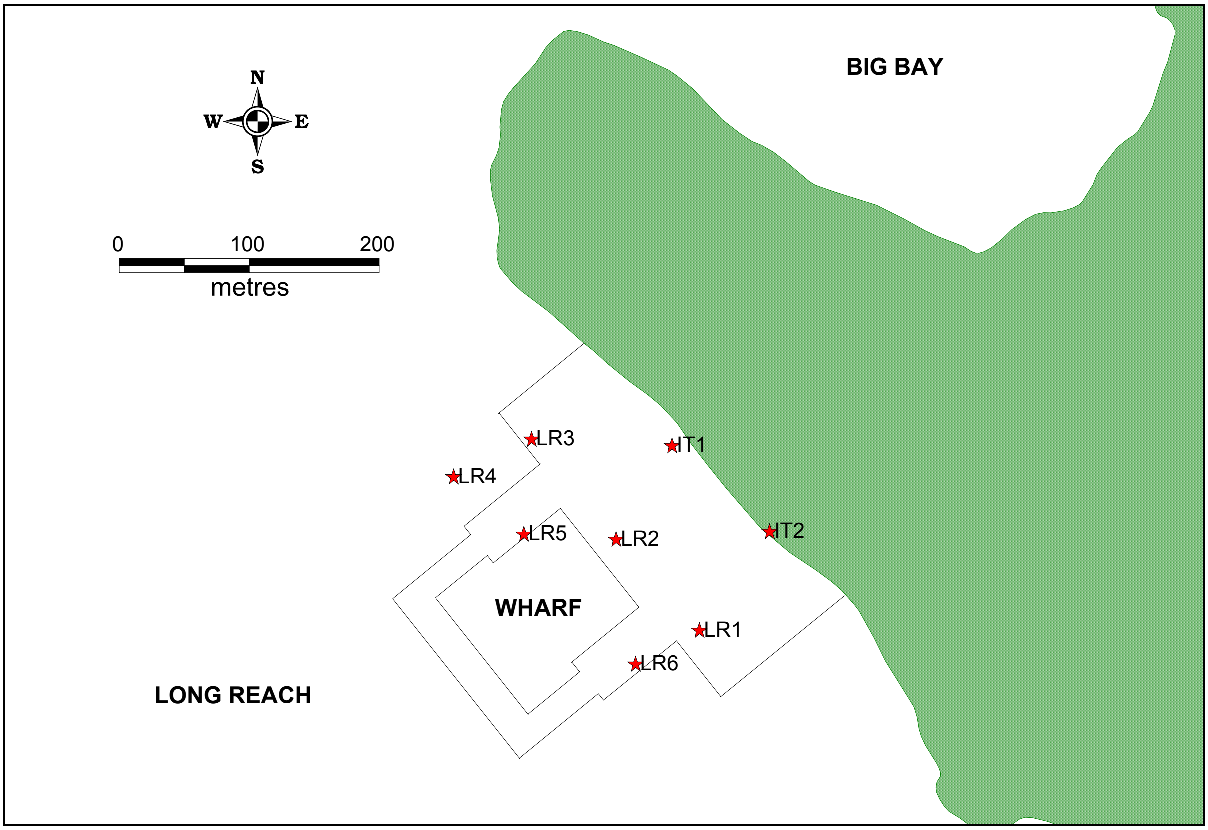


Figure 2 Map of the sampling sites for rocky intertidal transect surveys (IT1 and IT2), and benthic infauna and sediment assessments (LR1 to LR6) at the proposed wharf site.

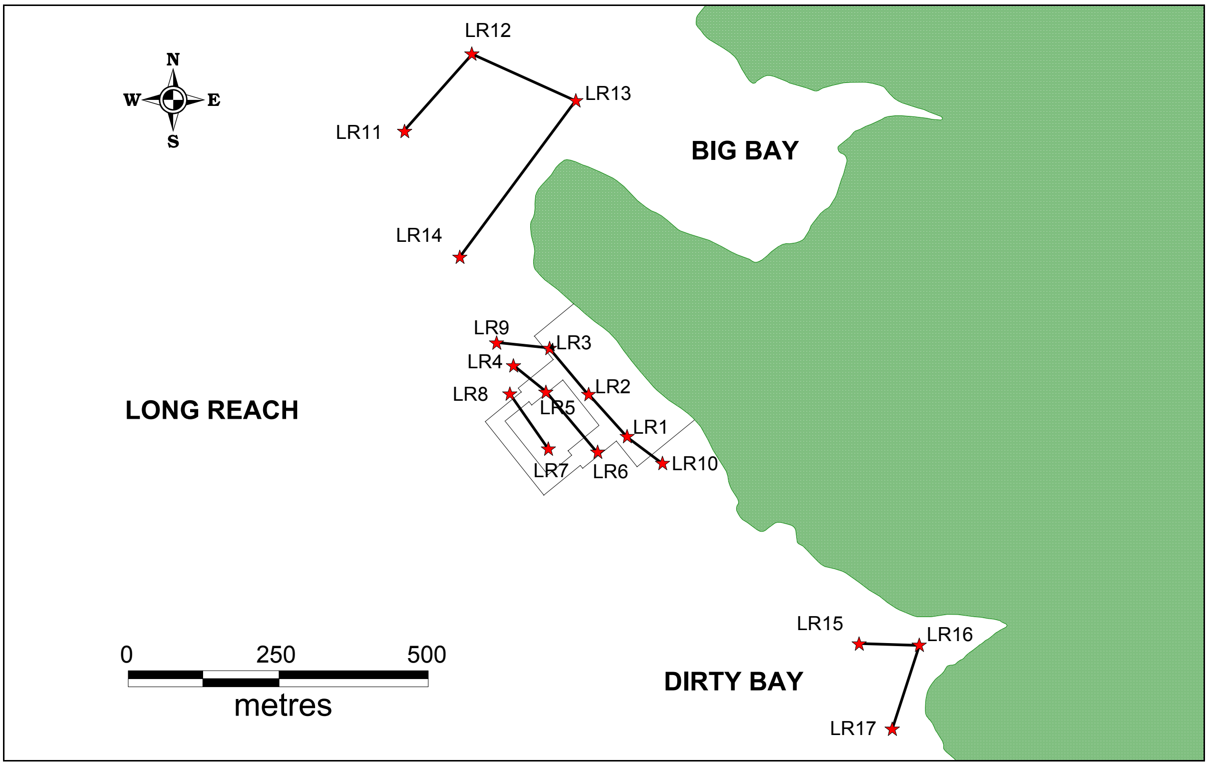


Figure 3 Map of remote video tow routes used in habitat surveys at the proposed wharf site and in neighbouring bays, Big Bay and Dirty Bay.

The grab samples were washed through an aluminium funnel into polypropylene bags with a mesh size of 0.8 mm. The bagged samples were then labelled and placed into a 20 L drum of 10% buffered formalin for a minimum of 3 days. In the laboratory, collected material was washed through a 1 mm sieve and the retained material was sorted under a dissecting microscope to separate animals from other material. The animals were subsequently counted and identified to the taxonomic level of family, with the exception of any introduced marine pests or threatened species, which were identified to species level. All specimens were placed in labelled vials and preserved in 70% alcohol for longer term storage.

Benthic infauna data were analysed using a variety of univariate and multivariate statistical methods. The following five indices were calculated to provide information on benthic infauna density and diversity at sites sampled:

Family number, F
Where F equals the number of families or equivalent taxonomic units collected at a site.

Individuals, N
Where N equals then number of individuals of all species collected at a site.

Diversity (Shannon-Wiener), $H' = -\sum_i \rho_i(\log \rho_i)$
Where ρ_i is the proportion of the total count arising from the $_i$th family.

Evenness (Pielou's), J' = H'(observed)/H'$_{max}$
Where H'$_{max}$ is the maximum possible Shannon diversity which could be achieved if all families contained the same number of individuals (=log F).

Richness (Margalef's), d = (F-1)/log N
Where d is a measure of the number of families present for a given number of individuals.

K-dominance curves were calculated for each site sampled, based on pooled replicates. K-dominance curves rank the families collected at each site from most abundant to least abundant and allow easy determination of levels of faunal dominance.

Multivariate analysis included cluster analysis and multi-dimensional scaling (MDS), as conducted by the PRIMER program (Carr 1996), in order to produce the best graphical depictions of faunal similarities between samples. For these analyses, the data matrix showing total abundance of families in each sample was double root-transformed and then converted to a symmetric matrix of biotic similarity between pairs of sites using the Bray-Curtis similarity index. These procedures follow the recommendations of Faith *et al*. (1987) and Clarke (1993) for data matrices with numerous zero records. The usefulness of the two dimensional MDS display of relationships between sites is indicated by the stress statistic, which if <0.1 indicates that the depiction of relationships is good, and if >0.2 that the depiction is poor (Clarke 1993).

2.5 Intertidal communities

Surveys of rocky intertidal habitats were performed at two representative transect sites (Figure 2) within the proposed development zone, and digital photographs were taken of the area to record pre-development habitat characteristics. At each site, a transect line was placed on the shore, extending from the supralittoral fringe (boundary between intertidal and terrestrial habitats) to the sublittoral fringe (boundary between intertidal and subtidal habitats). The transect line was marked at 1m intervals, starting at 0 m at the supralittoral fringe. All biota found within 0.5 m either side of the transect line were identified and counted for three representative 1m sections of the transect at three tidal heights (high, mid and low). This provided species/abundance data for nine 1 m^2 quadrats on each transect. For species that could not be identified *in situ*, one individual was collected and preserved in formalin for subsequent identification in the laboratory. For extremely common species, such as *Bembicium auratum* and *B. melanostomum*, counts were made within the uppermost 20 cm of each 1 m length of transect, and subsequently extrapolated to estimate numbers for the 1 m section.

2.6 Sediment characterisation

2.6.1 Sample collection

Sediment samples were collected from six sites (Figure 2) using two techniques. Firstly, samples were collected using the grab apparatus during sampling for benthic infauna (described in Section 2.4 above). At each site, one 250 ml jar and two 77 ml jars were filled with sediment collected using the grab, one jar for heavy metal analysis and two jars for particle size analysis respectively. Secondly, sediment samples were collecting by divers on SCUBA using cores consisting of 1m lengths of 100 mm diameter Bipex PVC pipe.

For the coring technique, a metal handle was attached to the top of the core and the latter was driven into the sediment by alternatively rotating the handle clockwise and anti-clockwise. A sledge hammer was used to drive the pipe into the sediment to a depth of approximately 90 cm and a cap was placed on the top of the core to seal it. Using the metal handle, the core was then levered out of the seabed and the bottom of the core was capped just before it emerged from the seabed surface. The sealed core was returned to the boat by the divers, labelled, taped at both ends and kept upright prior to analysis. Core samples were subsequently extruded intact and their lengths measured, since some samples compact more than others following collection, resulting in variation in core sample length. Redox potential measurements were taken from the cores using the methods described in Section 2.6.3, prior to extracting subsamples for particle size, heavy metal and settling rate analysis. Separate subsamples were taken for the 0-50 cm and >50 cm depth sections of the cores, with two 250 ml samples taken from each, one for heavy metal analysis, and the other for particle size and settling rate analysis. All samples were homogenised prior to analysis.

Samples collected from grabs provided information for the top 10 cm of sediment, where the benthic infauna primarily occur. Analyses of these samples therefore contribute to the interpretation of benthic infauna data, but do not provide sufficient data for assessment of sedimentary material that may be disturbed during construction of the proposed wharf. The core samples provided information for deeper sediments (up to 90 cm) and are more representative of sediments that may be disturbed during construction activities. These deeper samples also profile much, if not all, of the sedimentary material deposited during the last 100 to 200 years, and therefore reflect most of the anthropogenic-related heavy metal deposition (B. Wood pers. comm.). Particle size distributions, settling rates and heavy metal concentrations were specifically analysed in these sediments to assess the potential for dispersion of heavy metals during construction.

2.6.2 Particle size distribution

Particle size analyses were performed for three samples at each of the sites surveyed: the top 10 cm sample collected via the grab apparatus and the 0-50 cm and >50 cm depth samples collected using the coring apparatus. In each case, 77 ml of sediment was required to perform the particle size analysis. The sediment was washed through a stack of sieves by shaking them under a moderate water spray. The sieve aperture sizes were 4 mm, 2 mm, 1 mm, 500 µm, 250 µm, 125 µm and 63 µm. The contents of each sieve were drained and transferred to a 100ml measuring cylinder containing 20 ml of water, starting with the coarsest fraction and working through to the finest. The cumulative volume in the measuring cylinder was recorded after the contents of each sieve were transferred. The percentage by volume of each fraction was then calculated for the original sample. The combined percentage of measured fractions was subtracted from 100 to give the percentage of the <63 µm fraction.

2.6.3 Redox potential

Redox potential was recorded in sediments from each of the sediment core samples, with measurements taken at 0 cm, 50 cm and the bottom (deepest section) of each core.

Redox potential was measured in millivolts using a WTW pH 320 meter with an Mettler Toledo Ag/AgCl combination pH / redox probe, with. The standard potential of the Ag/AgCl reference cell of the probe is 218 mV at 10°C, the approximate temperature of the samples during measurement. Calibration and functionality of the meter were checked before each test using a Redox Buffer Solution (220 mV at 25°C). Measurements were made within 10 minutes of the core samples being extruded from the coring apparatus, and within approximately three hours of samples being collected. Corrected redox potential values were calculated by adding the standard potential of the reference cell to the measured redox potential and are reported in millivolts.

In all cases, the lowest reading observed was recorded as the redox value. In low permeability, muddy sediments this is recorded when the reading is stable or dropping less than 1 mV per second.

2.6.4 Heavy metals

Similar to particle size analyses, heavy metals analyses were performed for three samples at each of the sites surveyed: the top 10 cm sample collected via grab apparatus and the 0-50 cm and >50 cm depth samples collected using the coring apparatus.

Heavy metals analysed included: arsenic, barium, beryllium, cadmium, cobalt, chromium, copper, manganese, nickel, lead, vanadium, zinc and mercury. The analyses were conducted by the ALS Environmental (Melbourne) laboratories using the following test methods:

- EG005T: Total metals by ICP-AES
- EGO35T: Total mercury by FIMS

2.6.5 Settling rates

Settling rate analyses were conducted for the 0-50 cm and >50 cm samples collected from each site using the coring apparatus. The aim of these analyses was to provide information on the dispersive abilities of sedimentary material by measuring the rate at which suspended particles settle out of the water column.

For each analysis, 77 ml of sediment was mixed with a standard volume of 1.5 L of seawater and poured into a 36 mm ID clear perspex tube approximately 1 m tall. The height of dense material that settled in the base of the tube was measured after 1 minute in cm and subsequently converted to a volume in mL. Remaining fine material settled into a slurry of suspended particles in the mid to bottom sections of the water column (above the dense, clearly settled sediment at the base of the tube), leaving relatively clear water, low in sedimentary material, above. The depth of clear water above the turbid slurry was measured against time, using a standard set of time intervals (1, 5, 15, 30 and 60 minutes), to give an indication of the settling rate for fine sediments.

3 RESULTS

3.1 Bathymetry

A bathymetry map for the proposed wharf site is presented in Figure 4, based on 5 m contours. Bathymetry data indicate that much of the proposed wharf site, and the sampling sites surveyed in the current study, are located in approximately 5 m of water or less. However, the outer habitat video tow routes (extending from site LR7 to LR8, Figure 3) and proposed structures are located in deeper water, with the outer edge of the wharf positioned around the 20 m depth contour. Note that the wharf location and dimensions are based on a general sketch of the development provided by GHD, and the bathymetry of the site should be re-assessed for engineering purposes once a detailed plan of the site is developed.

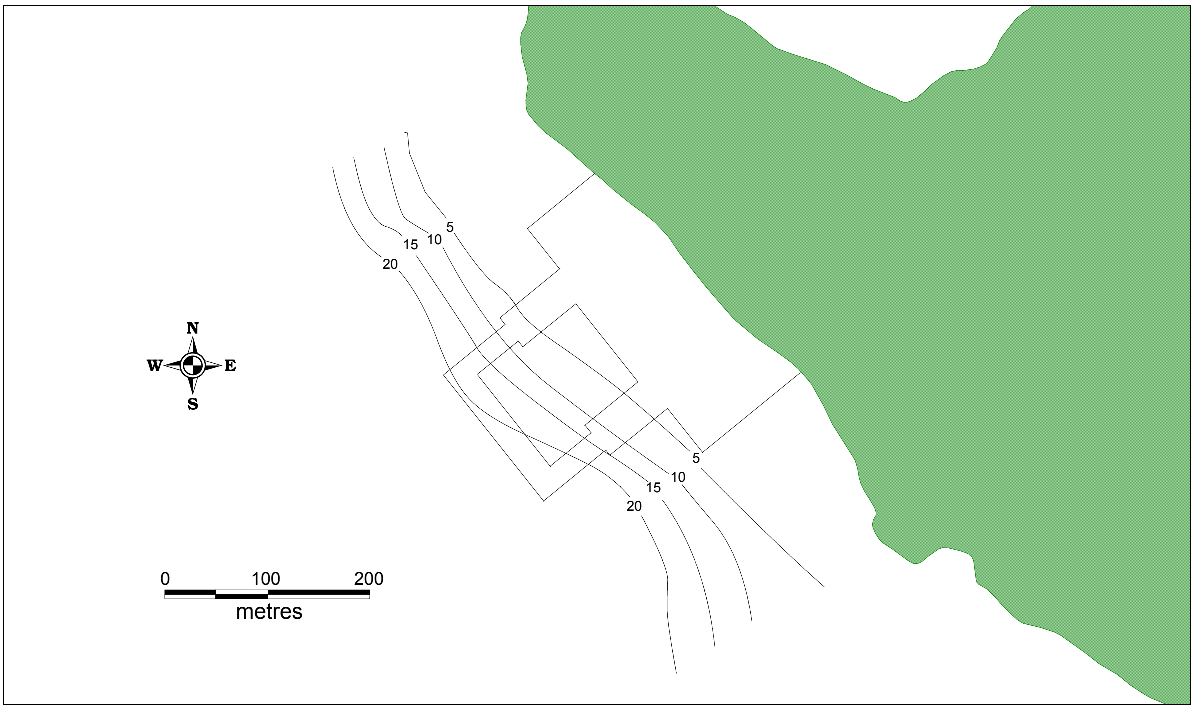


Figure 4 Bathymetry map for the proposed wharf site.

3.2 Seabed habitats and epi-benthic communities

3.2.1 Overview of habitats and communities

Remote video tows were performed to record habitat types and associated epi-benthic communites at the wharf site and in neighbouring bays (Figure 3). A summary of habitats and communities observed is provided below in addition to the detailed video notes for each tow provided in Section 3.2.2.

Shallow parts of the wharf site (sites LR1 to LR3, <5 m depth) were dominated by fine soft sediments, speckled with shell grit and potted with burrows. A green benthic algal mat was observed growing on the seabed, with surface cover ranging from 10 to 50%. Isolated clumps of red algae were also observed on the seabed. Fauna recorded consisted of the sand flathead *Platycephalus bassensis*. At the most northern end, clumps of the Pacific oyster *Crassostrea gigas* were also observed on the seabed and supported growth of occasional sponges.

In the vicinity of the 5 m contour (sites LR4 to LR6), the seabed resembled that described above, with a soft sediment substrate, patchy benthic algal mat and occasional clumps of oysters. However, at greater depths (10-15 m, sites LR7 to LR8) the seabed had a dense covering of oysters and dead oyster shells, in addition to sea stars and encusting species such as bryozoans and sponges growing on the oysters.

Seabed habitats at the wharf site therefore consisted of two main types: soft sediment in depths up to 5-10m and dense oyster beds with associated encrusting biota at greater depths.

In neighbouring Big Bay (Figure 3), the substrate consisted of soft sediment with dead bivalve shells and mound-forming burrows. The seagrass *Zostera tasmanica* occurred in sparse and dense patches, with up to 90% cover recorded in some areas. Other sections of the seabed supported a green benthic algal mat, comprising up to 50% cover in places, and occasional patches of red, green or brown algae. The smooth toadfish *Torquigener glaber* was the most visible fish species.

In Dirty Bay, located upstream of the proposed wharf site (Figure 3), the seabed consisted of fine sand mixed with dead bivalve shells and shell grit. The seagrass *Zostera tasmanica* provided 30-80% cover, while occasional algae and fish (smooth toadfish *Torquigener glaber* and sand flathead *Platycephalus bassensis*) were observed.

Observations of seagrass in Big Bay and Dirty Bay are consistent with previous studies in Long Reach. Aquenal (2001a, 2002) identified the seagrass *Zostera tasmanica* in Donovans Bay (1.2 km downstream of the wharf site) and Dirty Bay (0.5 m upstream of the wharf site), whilst Ritz *et al.* (1980) previously recorded the seagrass *Zostera muelleri* in the intertidal zone in Big Bay, immediately downstream of the wharf site. This suggests the possible presence of two seagrass species in Big Bay, although no intertidal surveys for *Z. muelleri* were conducted in the current investigation.

Based on a review of literature, seagrass species recorded in the Tamar Estuary include *Posidonia australis*, *Halophila australis* and *Amphibolis antractica* in addition to species mentioned above, *Zostera muelleri* and *Zostera tasmanica* (Rees 1994). In a statewide study of estuaries, Low Head in the Tamar Estuary was the only site found to support *Posidonia* (Edgar *et al.* 1999), although this species has previously been recorded from other sites in northern Tasmania (Rees 1994). Most seagrass beds occur near the mouth of the estuary, extending upstream to waters off George Town, and it seems likely that *Z. muelleri* and *Z. tasmanica* are the only seagrass species occurring in Long Reach. The seagrass beds in the Tamar Estuary, particularly those near the estuary mouth, provide an important breeding ground for many commercially fished and non-commercial species, and are also an important source of food and shelter for juvenile fish (Pirzl and Coughanowr 1997).

Habitat observations in the current study suggest that, while no seagrass beds occur at the site, they occur in neighbouring bays that have the potential to be affected by sediment disturbance at the wharf site. Given the estimated decline in seagrass cover of 19% in the Tamar Estuary between 1950 and 1990 (Rees 1994), the affects of construction on these communities should be considered in impact assessment studies.

3.2.2 Video notes

Descriptions of video footage collected at the proposed wharf site and in Big Bay and Dirty Bay are provided below. For localities of site numbers, refer to Figure 3.

Wharf, Site LR1

Seabed: Fine sand and silt potted with burrows forming small mounds. Fine shell grit present in the sediments.

Flora and fauna: Green-tinged benthic algal mat growing on the surface ranging from 10-50% cover. Red algae observed in patches in addition to intermittent brown algae. A sand flathead, *Platycephalus bassensis*, was observed.

Wharf, Site LR2

Seabed: Fine sand and silt potted with burrows and speckled with fine shell grit.

Flora and fauna: Green-tinged benthic algal mat present on the clearer silt bottom, with 10-30% cover. Isolated clumps of red algae growing on the sand/silt bottom.

Wharf, Site LR3

Seabed: Fine sand and silt potted with burrows and speckled with fine shell grit.

Flora and fauna: Green-tinged benthic algal mat present on the clearer silt bottom, with 10-30% cover. Clumps of red and brown algae attached to intermittent clumps of Pacific oysters, *Crassostrea gigas*. Isolated clumps of red algae growing on the clearer sand/silt bottom. A yellow sponge was observed growing on the oyster clumps. A sand flathead, *Platycephalus bassensis*, was observed.

Wharf, Sites LR4 – LR6

Seabed: Fine soft sand and silt on a flat bottom covered with large burrow craters and small surface burrows.

Flora and Fauna: Occasional patches of oysters *Crassostrea gigas* covered with red and brown algae and yellow sponges. Green benthic algal mat covering the bottom in patches. A sand flathead, *Platycephalus bassensis*, was observed. A seastar, *Astrostole scabra*, was observed.

Wharf, Sites LR7– LR8

Seabed: Fine soft mud and silt.

Flora and fauna: Bottom covered with dense patches of Pacific oysters, *Crassostrea gigas*. Encrusting species such as bryozoans and sponges growing on the oysters. Occasional brown algae growing on the oysters. A seastar, *Astrostole scabra*, was observed. A biscuit star, *Tosia* sp., was observed.

Wharf, Site LR9

Seabed: Fine sand and silt potted with burrows and speckled with fine shell grit.

Flora and fauna: Green-tinged benthic algal mat present on the clearer silt bottom, with 10-30% cover. Clumps of red and brown algae attached to intermittent clumps of Pacific oysters, *Crassostrea gigas*. Isolated clumps of red algae growing on the clearer sand/silt bottom. A yellow sponge was observed growing on the oyster clumps.

Big Bay Entrance

Seabed: Fine soft sand mixed with fine shell grit and the occasional dead bivalve. Several burrows present in the sediments.

Flora and fauna: Seagrass, *Zostera tasmanica*, observed along the entire length of the transect, grading between sparse and dense patches. Red algae observed growing amongst the seagrass and also as individual clumps. A green benthic mat, grading from sparse to dense patches, was observed on the seabed. Occasional plants of the green alga *Codium* sp. (?*mulleri*/*harveyi*) were also observed.

Big Bay, Site LR11

Seabed: Fine soft sand covered in a high density of burrow mounds.

Flora and fauna: Green benthic algal mat on the seabed, with 50% cover in places. Red and brown algae present in patches. Stunted seagrass, *Zostera tasmanica*, present in patches.

Big Bay, Site LR12

Seabed: Fine soft sand mixed with fine shell grit and the bottom littered with dead bivalve shells. Several burrows present forming mounds.

Flora and fauna: Seagrass, *Zostera tasmanica*, very common with a density of 30-90%. Occasional red and brown algae observed growing amongst the seagrass. A smooth toadfish *Torquigener glaber*, was observed.

Big Bay, Site LR13

Seabed: Fine rippled sand mixed with shell grit. Dead bivalve shells common in patches. Burrows fairly common, some with clay sediments around the entrances.

Flora and fauna: Occasional tufts of red and green algae growing out of the rippled bottom with increasing density in patches. Some brown algae also observed. Tinges of green benthic algae on occasion. Seagrass, *Zostera tasmanica*, appearing in patches. A smooth toadfish *Torquigener glaber*, was observed.

Dirty Bay, Site LR15

Seabed: Undulating surface of fine soft sand with fine shell grit. Dead bivalve shells common. Burrows very common, forming mounds and cavities.

Flora and fauna: Seagrass, *Zostera tasmanica*, forming beds of 30-80% cover. Occasional red and brown algae observed.

Dirty Bay, Site LR16

Seabed: Fine sand and silt mixed with shell grit and dead bivalves.

Flora and fauna: Stunted seagrass, *Zostera tasmanica*, at a density of 30-70%. A very small patch of reef was observed. A smooth toadfish *Torquigener glaber*, and a sand flathead *Platycephalus bassensis* were observed.

3.3 Benthic infauna

The full set of benthic infauna results, indicating composition and abundances of invertebrate families found in each sample collected, is included in Appendix 2. A total of 56 families was recorded from the 12 samples analysed, comprised of 984 individuals. Across all sites, the benthic infauna was dominated numerically by polychaetes (464), followed by crustaceans (383) and molluscs (87), while echinoderms, sipunculids, ascidians and nemerteans were represented by smaller numbers of individuals. However the largest number of families was recorded for crustaceans (24), followed by polychaetes (18) and molluscs (8). Per sample, family numbers ranged from 11 (sample LR6-2) to 30 (sample LR4-2), while abundance ranged from 36 (sample LR6-2) to 145 (sample LR1-1).

Calculations of density and diversity indices (Figure 5) were based on pooled data for each site. Number of families per site ranged from 23 (LR6) to 37 (LR4), while animal abundance ranged from 98 (LR6) to 250 (LR1). Margalef's richness (d), which is a measure of the number of families present relative to number of individuals, was higher at LR4 and LR5, and uniformly reduced at the other four sites. Pielou's evenness (J') and Shannon-Wiener diversity (H') were also highest at LR4, with evenness lowest at LR5 and diversity relatively uniform across the remaining five sites (Figure 5).

The results of multi-dimensional scaling (MDS) analysis are presented in Figure 6, with the stress statistic for the plot (0.13) indicating that the depiction of relationships among samples is acceptable. Samples from sites LR1 to LR3 group in the top right section of the plot, while samples from LR4 to LR6 group are grouped loosely in bottom left section. This reflects variation in the benthic infauna on the basis of depth, with sites LR1 to LR3 (depths 2.0 to 3.4 m) representing shallower depths than sites LR4 to LR6 (depths 4.7 to 7.1 m).

K-dominance curves indicate that the most dominant family at each site comprised between approximately 15 % (LR6) and 25% (LR4) of animals present (Figure 7). Faunal dominance overall was highest at LR6 and lowest at LR4, based both on the y-intercept values (most dominant family, referred to above) and the shape of the curves. This is consistent with the species diversity indices, which suggested highest diversity at LR4 and lowest diversity at LR6 (Figure 5). Despite the reduced diversity at the latter site, the K-dominance plot does not reflect stressed communities at any of the sites surveyed, with dominance levels lower than recorded elsewhere by Aquenal in degraded environments.

One introduced species, the east Asian bivalve *Theora lubrica*, was recorded at four sites (LR2, LR3, LR4 and LR6) during the benthic infauna survey. Numbers of this species per sample were low, varying from 1 to 8 where it was detected. *T. lubrica* was not dominant in the samples and, while it may have contributed to the even smaller numbers of native species belonging to the same family, it is unlikely to be significantly impacting on benthic infauna diversity at the wharf site.

Aquenal has previously surveyed benthic infauna communities at a range of sites in Long Reach, including Donovans Bay, Cummings Creek, Dirty Bay and sites just upstream of the woodchip wharf operated by Gunns. The latter sites were surveyed from 2002 to 2004 to monitor the estuarine environment in the vicinity of a small outfall associated Gunn's woodchip operations, and continued on from a previous monitoring program that had been operating since 1997. The monitoring design was revised by Aquenal to include sites at varying distances from the outfall and also at two more distant 'control' sites, so that the program was able to assess impacts of the outfall as well as describe temporal variation. In the most recent survey of the outfall (Aquenal 2004a), a total of 658 individuals, representing 45 species, was collected from eight sampling sites, six in the vicinity of the outfall and two at more distant control locations. The communities were dominated by polychaetes (46% of species, 73% of individuals), with smaller numbers of molluscs, crustaceans and other taxa, a result that was consistent with

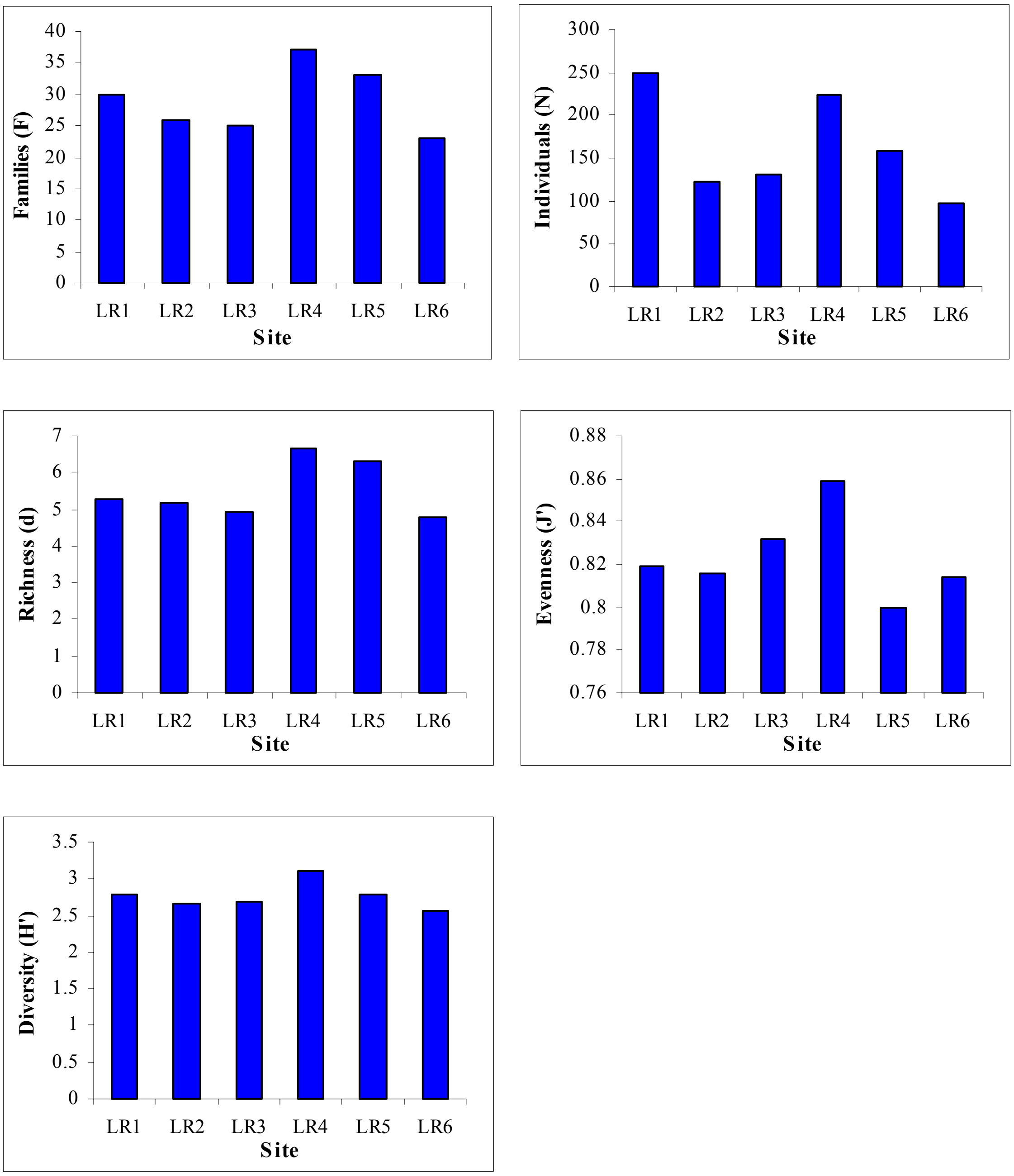


Figure 5 Density and diversity indices for benthic infauna samples collected at the proposed wharf site. F = Number of families, N = Number of individuals, J' = Pielou's evenness index, d = Margalef's richness index, H' = Shannon-Wiener diversity index.

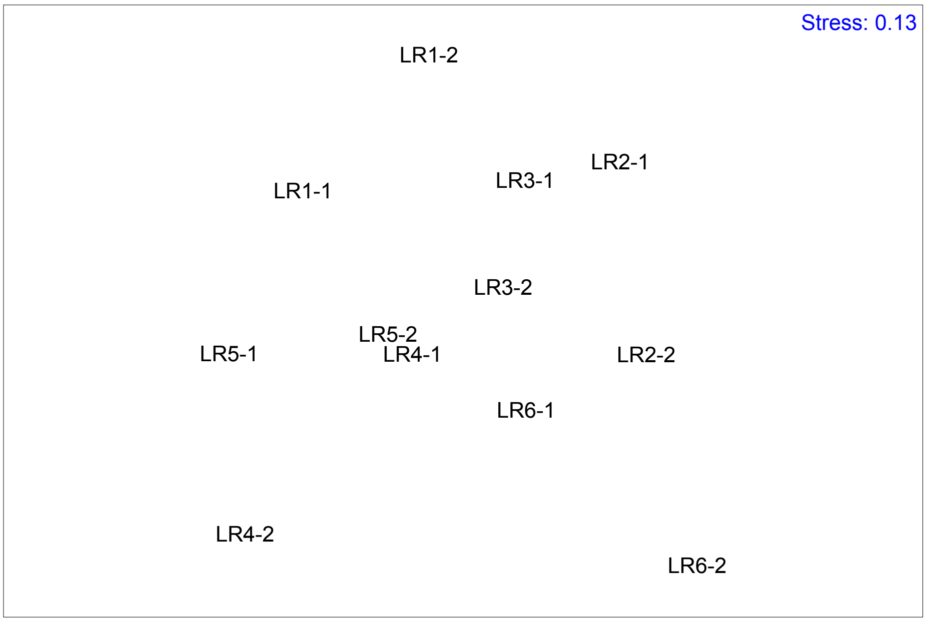


Figure 6 Multi-dimensional scaling (MDS) analysis of benthic infauna data for duplicate samples collected from six sites at the proposed wharf location.

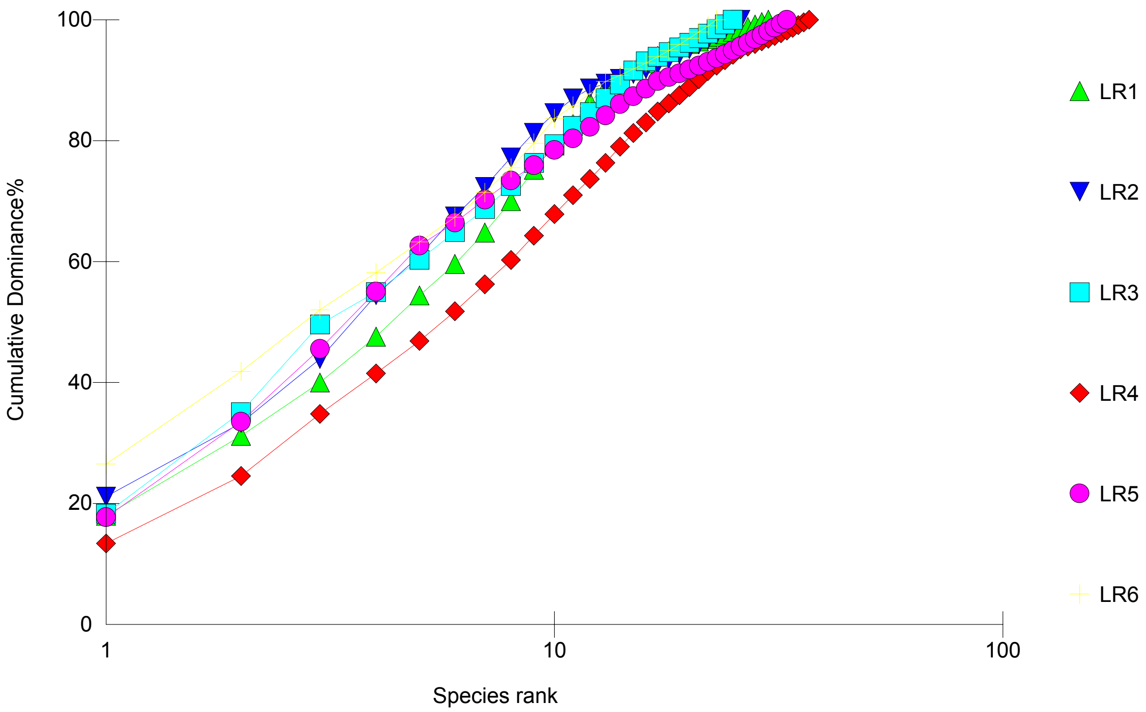


Figure 7 K-Dominance curves using benthic infauna data from six sites at the proposed wharf location, based on pooled replicate samples at each site.

previous surveys of the outfall. Based on diversity indices, K-dominance plots and multi-dimensional scaling analysis, the study concluded that there was no clear relationship between benthic infauna composition and distance from the outfall. Similarly, the communities observed did not exhibit characteristics of stressed communities, suggesting that the impact of outfall discharges is low. However, the prevalence of woodchips on the seabed was raised as a separate issue, since it is possible that communities in the area, including those at the control sites, have been altered due to substrate modification.

Benthic infauna in the Tamar Estuary were also assessed by Edgar *et al*. (1999) as part of a statewide assessment of estuarine habitats. The Tamar Estuary was classified as a Class A estuary, the highest conservation ranking prescribed by the study, due in part to its exceptionally high diversity of macroinvertebrates. Samples taken from Low Head contained a total of 116 macroinvertebrate species, a number surpassing that recorded at all other Tasmanian estuaries sampled, with the exception of North East Inlet (120 species). A large portion of the species found were not recorded from any other sites, and were thought to be predominantly marine in origin (Edgar *et al.* 1999). A separate study of intertidal macroinvertebrates at Deceitful Cove recorded 81 species, depicting a relatively high species diversity despite elevated concentrations of metals in the sediments (Miedecke and Partners 1993). Sites sampled by Edgar *et al.* (1999) further upstream (at Paper Beach, just upstream of the Batman Bridge) recorded lower diversities, with approximately 30 species of macroinvertebrates collected. The 45 species recorded by Aquenal (2004a) near the existing Gunns woodchip wharf is consistent with the general trend of reduced macroinvertebrate species with distance upstream of the estuary mouth.

3.4 Intertidal communities

Representative photographs of rocky intertidal habitat at the wharf site are provided in Figure 8 and reflect the dominance of boulders and rocks, although the substrate underlying surface rocks consisted of soft muddy sediments. The full results for rocky intertidal surveys at two transect sites, including data for each 1 m interval of shore surveyed, are presented in Appendix 4, whilst a summary of results is provided below in Table 1.

A total of 34 species was recorded during the survey, whilst 28 species were recorded at each transect site (Table 1). Species were dominated by molluscs (18 species) and crustaceans (12 species), with individual echinoderm, polychaete, cnidarian (anemone) and urochordate (ascidian) species also identified. None of the species recorded are listed as threatened, whilst one species, the Van Diemen's land siphon shell (*Siphonaria diemenensis*), belongs to a family of limpets that is protected under the *Fisheries (General and Fees) Regulations 1996* established through provisions of the Tasmanian *Living Marine Resources Management Act 1995*. Two species, the New Zealand half crab *Petrolisthes elongatus* and the Pacific oyster *Crassostrea gigas*, are introduced, with the latter classified as a target pest.

Whilst the diversity of intertidal species at the wharf site is relatively high, the intertidal habitat is considered highly modified. This is primarily due to the high abundance of Pacific oysters in the mid and low parts of the shore where clusters of oysters dominate the site visually (Figure 8) and have altered the structure of the intertidal habitat.

Figure 8 Photographs of rocky intertidal habitat at the proposed wharf site.

Table 1 Rocky intertidal species recorded at two transect sites (IT1 and IT2) surveyed at the proposed wharf location.

Species	IT1	IT2
Crustacea		
Alpheus euphrosyne	X	
Brachynotus spinosus	X	X
Cyclograpsis granulosis	X	X
Elminius covertus	X	X
Heloecius cordiformis	X	
Ibla quadrivalvis	X	X
Macrophthalmus latifrons		X
Paragrapsus gaimardii	X	X
Paragrapsus quadridentatus		X
Petrolisthes elongatus	X	X
Pilumnopeus serratifrons	X	X
Tetraclitella purpurascens	X	X
Mollusca		
Agnewia tritoniformis	X	X
Austrocochlea concamerata	X	X
Austrocochlea constricta	X	
Bembicium auratum	X	X
Bembicium melanostomum	X	X
Bembicium nanum	X	X
Chiton pelliserpentis	X	X
Cominella eburnea	X	X
Cominella lineolatus		X
Crassostrea gigas	X	X
Lasaea australis	X	X
Nerita atramentosa	X	X
Nodilittorina praetermissa	X	
Nodilittorina unifasciata	X	
Notoacmea flammea		X
Onchidella patelloides	X	X
Siphonaria diemenensis	X	X
Xenostrobus inconstans	X	X
Echinodermata		
Patiriella exigua	X	X
Cnidara		
Anthothoe albocincta	X	
Polychaeta		
Galeolaria caespitosa		X
Urochordata		
Pyura stolonifera		X
TOTAL SPECIES	28	28

Intertidal communities recorded were similar to those previously documented by Aquenal in nearby parts of Long Reach, including Donovans Bay, Dirty Bay and Cummings Creek (Aquenal 2004b). Species of rocky intertidal invertebrates at these sites varied between 19 and 34 over 4 years of monitoring, and were also dominated by molluscs and crustaceans.

3.5 Sediment characterisation

3.5.1 Particle size distribution

Particle size data are included in Appendix 5 (grab samples, representing 0-10 cm sediment depth) and Appendix 6 (core samples, representing 0-50 cm and >50 cm sediment depth), while the results are graphically presented in Figure 9 (grab samples) and Figure 10 (core samples) below. Note that because the core sample collected from site LR2 had a compacted length of only 50 cm following extraction, the >50 cm sediment sample for this site was extracted from the bottom of the 50 cm core. Results illustrated below are based on pooled data for duplicate grab samples, while results for cores are based on individual samples from each site.

Samples collected from grab samples were consistent in their particle size distributions across the six sites surveyed (Figure 9). There were negligible volumes of coarse material (i.e. gravel, shell grit >2 mm) and coarse sand (>0.25 mm), with all samples dominated by medium sands, silts/clays and, to a lesser extent, fine sand. The well sorted fine to medium sediments in the samples suggest relatively constant, moderate levels of water movement across the study area.

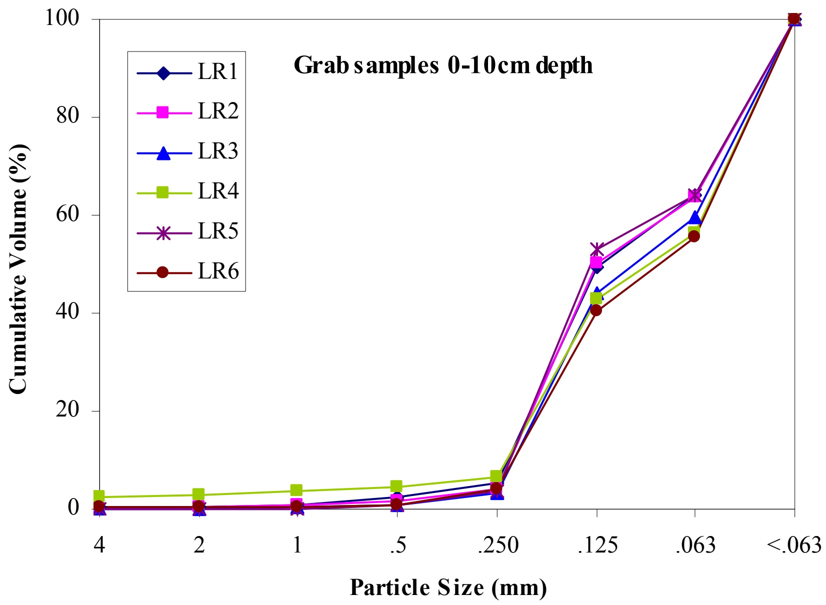
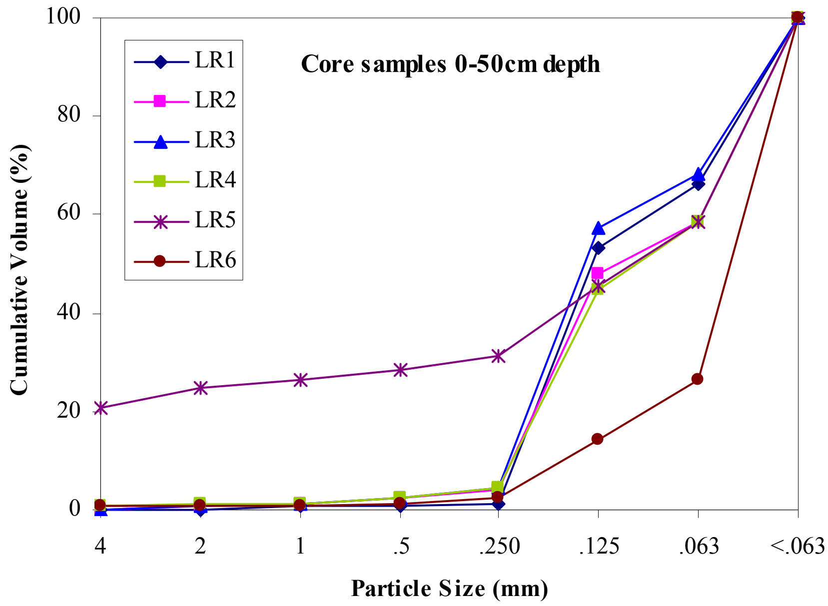


Figure 9 Particle size distributions for sediment samples collected using the grab (top 10 cm).



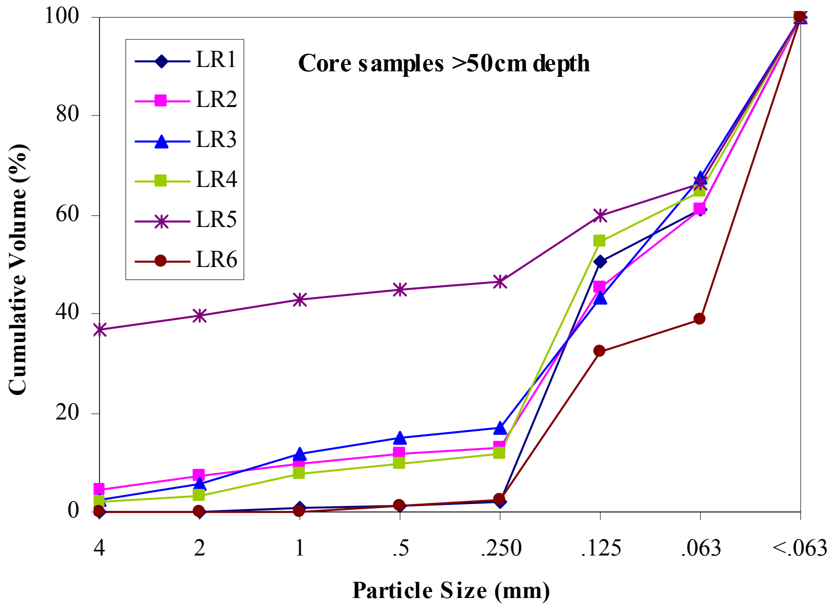


Figure 10 Particle size distributions for sediment samples collected using cores (0-50 cm and >50 cm).

Results for the top 50 cm of cores mirrored those for the grab samples at all sites except two of the deeper sites, LR5 and LR6. At LR5, the main difference was the inclusion of 20% coarse material in the form of dead shells and shell grit, which replaced a portion of the medium sands. In contrast, 0-50 cm depth sediments at LR6 were characterised by a larger portion of silts/clays (<0.063 mm, 'fines') than shallow surface sediments collected from the same site. The 0-50 cm sediments at LR6 included 73% of silts/clays, compared with 32-42% at the other sites surveyed. These results reflect historical variation in patterns of sedimentary deposition, and subsequent entrapment of deeper sediments that differ in composition to those near the surface at LR5 and LR6.

Similar results were obtained for the >50 cm samples collected using cores, with sediments closely resembling those recorded in the 0-50 cm sediments, with the exception of small increases in volumes of coarse shell material and coarse sands at sites LR2, LR3 and LR4. Much of the shell material belonged to native oysters and associated bivalves, suggesting that, historically, either these species were more common in the area than they are now or were influenced by different deposition patterns.

3.5.2 Redox potential

Results of redox potential measurements are presented in tabular form in Table 2 and graphically in Figure 11. Redox values generally declined with increasing sediment depth, reflecting reduced oxygen levels further from the water/sediment interface. However no anoxic conditions (i.e. reflected by negative redox values) were recorded at the sediment depths sampled. This suggests that disturbance to those depths will not result in anoxic or hypoxic conditions in the water column as a consequence of the redox state of sediments.

Table 2 Corrected redox potential of sediments in core samples from the proposed wharf location (sites LR1 to LR6).

Site	Core length (cm) = bottom depth	Redox (mV)		
		0cm	50cm	Bottom
LR1	60	254	19	60
LR2	50	136	113	(113)
LR3	70	204	113	91
LR4	62	283	104	110
LR5	55	125	105	113
LR6	90	100	69	61

3.5.3 Heavy metals

The full set of results for heavy metals analyses of sediment samples is presented in Appendix 7, while a summary of the results is provided in Table 3 below. The summary indicates value ranges for each metal and, where all values for a parameter were at or above the detection level, mean and standard deviation values. In addition, Table 4 presents ANZECC & ARMCANZ (2000) guidelines for heavy metal concentrations in sediments, although these guidelines are only available for a subset of the metals analysed in wharf site sediments.

There are currently few reliable data on sediment toxicity for Australian environments from which independent sediment quality guidelines can be derived. The recommended guideline values provided by ANZECC & ARMCANZ (2000) are therefore tabulated as interim sediment quality guideline (ISQG) values, and the low and high values (see Table 4) correspond to the range-low and –median values used by the National Oceanic and Atmospheric Administration in the USA (Long *et al.* 1995).

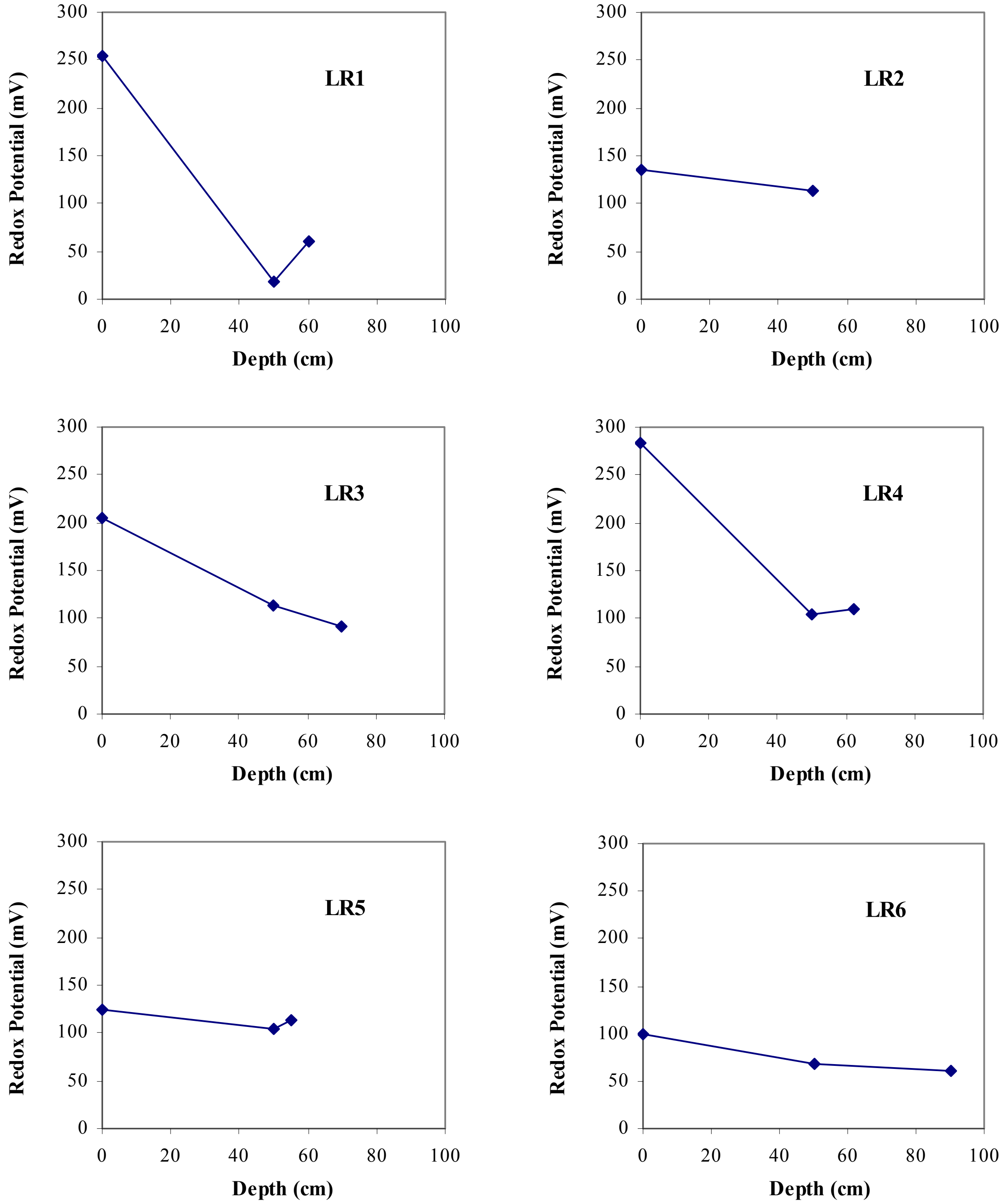


Figure 11 Redox potential values at 0 cm, 50 cm and bottom (variable between samples) depths in cores collected at the six sites sampled (LR1 to LR6).

Table 3 Heavy metal concentrations in sediment samples collected from three sediment depths, across six sites, at the proposed wharf location.

Analyte	Unit	Detection Limit	Range Recorded	Average	Standard Deviation
Top 10 cm collected with a grab					
Arsenic	mg/kg	5	<5 to 8		
Barium	mg/kg	10	<10		
Beryllium	mg/kg	1	<1		
Cadmium	mg/kg	1	<1		
Chromium	mg/kg	2	4 to 15	10.67	3.98
Cobalt	mg/kg	2	<2 to 3		
Copper	mg/kg	5	<5 to 9		
Lead	mg/kg	5	<5 to 11		
Manganese	mg/kg	5	82 to 527	298.17	150.00
Nickel	mg/kg	2	2 to 8	5.83	2.40
Vanadium	mg/kg	5	6 to 18	12.83	4.49
Zinc	mg/kg	5	17 to 61	44.33	16.54
Mercury	mg/kg	0.1	<0.1 to 0.2		
0-50 cm collected with a core					
Arsenic	mg/kg	5	9 to 24	13.33	5.50
Barium	mg/kg	10	<10 to 10		
Beryllium	mg/kg	1	<1		
Cadmium	mg/kg	1	<1 to 1		
Chromium	mg/kg	2	17 to 38	22.50	7.74
Cobalt	mg/kg	2	5 to 9	6.00	1.55
Copper	mg/kg	5	11 to 34	16.17	8.86
Lead	mg/kg	5	11 to 20	14.00	3.41
Manganese	mg/kg	5	210 to 1060	561.50	296.52
Nickel	mg/kg	2	10 to 21	12.67	4.18
Vanadium	mg/kg	5	21 to 52	28.17	11.86
Zinc	mg/kg	5	64 to 148	85.83	31.26
Mercury	mg/kg	0.1	<0.1 to 0.3		
>50 cm collected with a core					
Arsenic	mg/kg	5	6 to 18	9.00	4.52
Barium	mg/kg	10	<10		
Beryllium	mg/kg	1	<1		
Cadmium	mg/kg	1	<1		
Chromium	mg/kg	2	19 to 33	24.50	4.85
Cobalt	mg/kg	2	4 to 7	5.17	0.98
Copper	mg/kg	5	<5 to 29		
Lead	mg/kg	5	<5 to 15		
Manganese	mg/kg	5	71 to 283	169.67	87.93
Nickel	mg/kg	2	10 to 18	12.83	2.79
Vanadium	mg/kg	5	20 to 41	26.27	7.34
Zinc	mg/kg	5	26 to 117	58.83	32.38
Mercury	mg/kg	0.1	<0.1 to 0.1		

Table 4 ANZECC & ARMCANZ (2000) guidelines for heavy metal concentrations in sediment.

Analyte	ISQG-Low (Trigger value) mg/kg dry wt	ISQG-High mg/kg dry wt
Arsenic	20	70
Cadmium	1.5	10
Chromium	80	370
Copper	65	270
Lead	50	220
Mercury	0.15	1
Nickel	21	52
Zinc	200	410

Based on available guidelines, values for most metals were below trigger values, although there were several exceptions relating to mercury, arsenic and nickel. In the case of mercury, three samples each in the top 10 cm (grab) and 0-50 cm (core) contained concentrations exceeding the ISQG-Low trigger value. In the grab samples, these elevated concentrations were found at sites LR2, LR3 and LR6, while in the 0-50 cm core samples, they were found at sites LR2, LR4 and LR6 (Appendix 7). One 0-50 cm sample from site LR6 contained an arsenic concentration exceeding the trigger value, whilst the same sample recorded a nickel concentration equivalent to the trigger value.

When examining the distribution of elevated heavy metal concentrations in light of particle size data, there is no clear relationship between percentage of fines (silts/clays) and mercury concentration in the grab samples, since samples from all six sites had similar proportions of fines (Figure 9). However, the elevated concentrations in mercury, arsenic and nickel in the 0-50 cm core sample from site LR6 are consistent with particle size data. At this sediment depth, LR6 contained a much higher proportion of fines than all other sediment samples collected (Figure 10), reflecting a higher surface area for absorption of contaminants such as heavy metals. The heavy metal results indicate that low levels of contamination occur in some sections of the proposed wharf site, particularly where fine sediments are trapped beneath surface layers.

3.5.4 Settling rate

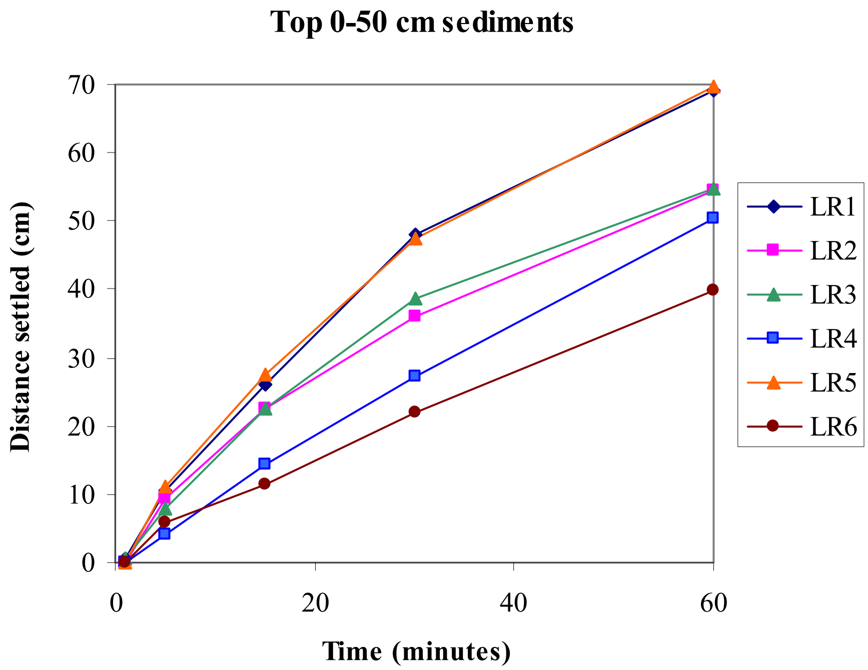
The results of settling rate experiments are presented Table 5 below. The height of dense material settling in the bottom of the 1m column after one minute was measured and converted to a percentage of total sediment volume (n.b. collecting jars at the base varied in size between tubes, hence separate calculations were conducted for each experiment). The primary focus of the experiments was, however, on the settling rates for the fine material that remained in suspension. The settling rate for the fines was calculated by measuring the distance from the top of the 1 m water column to the front between clear water and the turbid water (i.e. height of the clear water zone), at set time intervals. The height of clear water after one hour was used as an estimate of the settling rate per hour. This should be considered a minimum settling rate since experiments were conducted under still laboratory conditions, whilst water movement at the site is likely to extend the suspension period for particles and hence slow the settling rate. However, increased dilution rates *in situ* will reduce the density of suspended material in the water column.

The quantity of dense sediment that settled within the first minute of the experiment ranged from 29.5% to 50%. This range applies across all samples, and also applies to both the top (0-50 cm) and bottom (>50 cm) subsets of samples. Ranges at each site (across samples) were generally less, although top and bottom samples differed by up to 14.3% at any one site. The results indicate that 50% or more of sediment in the areas sampled is fine material that will be carried in suspension following sediment disturbance.

Table 5 Results of sediment settling rate experiments for 0-50 cm (T) and >50 cm (B) sediments collected in cores from six sites at the proposed wharf location.

Site/sample	Sediment depth after 1 minute (cm)	% Dense material (settled after 1 minute)	Height of clear water above turbid water (cm)				
			1 min	5 min	15 min	30 min	60 min
LR1-T	3.5	41.3	0.5	10.5	26.0	48.0	69.2
LR1-B	4.0	50.0	0.0	4.5	11.3	16.9	43.5
LR2-T	3.0	35.4	0.0	9.5	22.5	35.9	54.5
LR2-B	3.0	34.4	0.0	5.5	14.3	25.5	41.8
LR3-T	3.5	41.3	0.5	8.0	22.5	38.7	54.7
LR3-B	2.5	29.5	0.0	2.3	7.7	13.9	27.5
LR4-T	4.0	50.0	0.0	4.0	14.3	27.1	50.4
LR4-B	3.5	41.3	0.0	3.3	8.4	14.3	25.8
LR5-T	3.5	40.1	0.0	11.0	27.5	47.5	69.8
LR5-B	3.0	35.4	0.0	4.6	15.8	27.8	47.1
LR6-T	2.5	29.5	0.0	6.0	11.5	21.9	39.7
LR6-B	3.5	43.8	0.5	6.5	14.0	23.6	38.8

The settling rates for fine sediments are depiected graphically in Figure 12, with separate graphs provided for top (0-50 cm) and bottom (>50 cm) sediments. Settling rates varied from 39.7 to 69.2 cm/hour, at an average of 56.4 cm/hour, in top sediments and 25.8 to 47.1 cm/hour, at an average of 37.4 cm/hour, in bottom sediments. Given the depths at the wharf site and the likely volume of material to be disturbed during construction, this indicates that sediment disturbance will result in turbid plumes that will last many hours. The results also suggest that disturbing the seabed below a sediment depth of 50 cm will increase the proportion of very fine material that will remain in suspension for long periods.



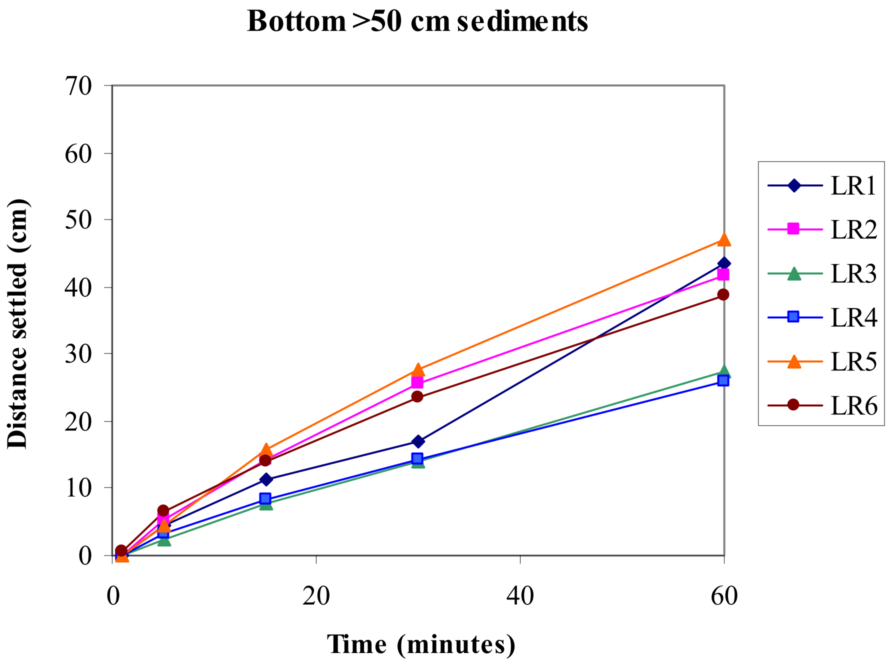


Figure 12 Settling rates for 0-50 cm and >50 cm sediment samples collected in cores from the six sites at the proposed wharf location.

Relationships between sediment particle size (Section 3.5.1) and settling rate are apparent. For example, 0-50 cm sediments at LR6 contained the highest percentage of <0.063 mm particles (silts/clays) in particle size analyses and also had the slowest settling rate across all sites surveyed. This suggests that a significant poroprtion of the <0.063 mm particles consisted of colloidal material as opposed to larger silt particles. The above results are also consistent with the higher heavy metal concentrations in this sample, since fine colloidal material provides a higher surface area for absorption of contaminants. Based on the slow settling rate observed, metals from this site have the potential to be carried large distances in the estuary following sediment suspension at the wharf site. Naturally, dilution factors will apply to heavy metal concentrations in the water column and should be incorporated in impact assessment studies.

3.6 Fish

The brief of the current study did not include field surveys of fish, with the exception of observations made during remote video tows (see Section 3.2.1), however some information is provided by available literature. The critical conservation rating prescribed by Edgar *et al.* (1999) for the Tamar (see Section 3.3 above in relation to benthic infauna) can also be attributed to the high diversity of fish species in the estuary. Fish sampling data presented by Edgar *et al.* (1999), incorporating a dataset provided by Last (1983), revealed a higher number of species in the Tamar (41) than in other Tasmanian estuaries studied. A small number of the species recorded are known only from Tasmanian estuaries. Two of these (*Pugnaso curtirostris* and *Siphonognathus radiatus* – the pug-nosed pipefish and long-rayed rock whiting respectively) were limited to the Tamar samples, and are generally associated with seagrass beds. A number of other fish species were unique to the Tamar, or had restricted geographical ranges that included the Tamar Estuary. In general terms, Edgar *et al.* (1999) found that patterns of fish species richness were strongly, positively, correlated to the presence of seagrass. The estuary mouth is clearly a more important area for seagrass and associated fish communities than Bell Bay or Long Reach, however the diversities recorded by Edgar *et al.* (1999) suggest that a wide range of fish species potentially occur in the vicinity of the proposed wharf site.

The study of Edgar *et al.* (1999) was confined to the estuary mouth, however compiled data for the broader Tamar Estuary has revealed the presence of at least 110 species of fish (Tasmania Parks, Wildlife and Heritage 1991). Some of the most common species recorded include mullet (*Aldrichetta forsteri*), garfish (*Hyporhamphus melanochir*) and various cod and flounder species (see Pirzl and Coughanowr 1997).

The Tamar Estuary is a protected shark nursery for school (*Galeorhinus galeus*) and gummy (*Mustelus antarcticus*) shark and, on the basis of previous surveys of the Bell Bay area, significant numbers of shark pups have been recorded in the estuary (Olsen 1954, CSIRO 1993). Under the Fisheries Rules of the *Living Marine Resources Management Act 1995*, it is prohibited to take school or gummy shark from any part of the Tamar Estuary and, in accordance with other sections of the Act, impacts on the nursery habitats of these species must be minimised. Both school and gummy shark are ovoviviparous (i.e. produce live young), giving birth to litters of up to 40 pups after a gestation period of 12 months. Studies have revealed that pregnant school sharks move into nursery areas in Tasmania between November and January to give birth to young, with the young remaining in the nurseries during summer and moving to deeper waters during winter (Olsen 1954, CSIRO 1993). The sharks are sensitive to sound waves and vibrations in the water column, such that their migration patterns may be influenced by disturbances in coastal and estuarine waters (J. Stevens, CSIRO, pers. comm.).

A threatened fish species, the Australian grayling (*Prototroctes maraena*), spends its adult life in freshwater habitats but has a marine life stage and is likely to occur in Long Reach as larvae and juvenile fish, as described in Section 3.8.1.

3.7 Commercial fisheries

The Tamar Estuary Marine Farming Development Plan (DPIWE 2000) provides for two marine farming zones where marine farming activities may occur. One zone is located at Rowella, 1.7 km upstream of the proposed wharf site, which allows for the culture of finfish species. A marine farming lease, which is currently used for the culture of salmonids, has been allocated within this zone. The second zone is located at Beauty Point and allows for the culture of sygnathids and planktonic species and is not currently used.

Two land-based marine farming operations, drawing waters from the Tamar, are located on the adjacent coast of the estuary. A seahorse farm is situated at Beauty Point and an abalone farm at Clarence Point.

There is limited commercial fishing of wild species in the Tamar Estuary, with five commercial fishing licences documented. Catches over the period between 1995 and 1999 were dominated by (in order of largest to smallest catch size) flounder, wrasse, garfish, mullet, blue warehou and Australian salmon (DPIWE fish database, unpub.). These species have been predominantly caught using beach seine nets, spears, grab-all nets and small mesh nets, with handlines and fish traps also commonly used in the case of wrasse. Several fishers are known to temporarily hold fish in nets in the vicinity of Beauty Point (B. Wood pers. comm.). Recreational fishing is widespread in the middle and lower reaches of the Tamar, downstream of Tamar Island (Pirzl and Coughanowr 1997), but is limited in Long Reach due to the distance to boat ramps, inability to use nets, strong currents and exposure to strong winds (DPIWE 2000).

3.8 Threatened and protected species

3.8.1 Threatened species

The Australian grayling (*Prototroctes maraena*) is listed by Bryant and Jackson (1999) as being a possible inhabitant of the Bell Bay / Long Reach area, and is listed as vulnerable under both the *Tasmanian Threatened Species Protection Act 1995* (TSPA) and the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBCA). The Australian grayling has not been specifically recorded in the vicinity of the proposed wharf site, however it has a marine life stage, and is therefore likely to occur in Long Reach as larvae and juvenile fish. Spawning of the Australian grayling takes place in late spring/early summer, with larvae probably swept to sea and returned as whitebait 4-5 months later (Bryant and Jackson 1999).

The Gunns screw shell (*Gazameda gunnii*) is a turritellid mollusc that has been recorded around much of the Tasmanian coastline on the basis of beach wrack collections (Richmond 1990). However its numbers have declined rapidly, the suspected result of the spread and prolification of an introduced turritellid, the New Zealand screw shell *Maoricolpus roseus*. As a result, it has recently been listed as vulnerable under the TSPA. This species occurs in marine soft sediments and therefore requires consideration in marine developments impinging upon soft sediment habitats. However, the Gunns screw shell was not recorded during the benthic infauna survey at the wharf site, and is unlikely to occur in this area due to pre-existing disturbance and distance from the estuary mouth.

Marine manmmals also visit the lower reaches of the Tamar Estuary, with Australian sea lions *Neophoca cinerea* and fur seals *Arctocephalus pusillus doriferus* observed at the mouth of the estuary, and cetaceans (dolphins, humpback whales *Megaptera novaengliae* and southern right whales *Eubalaena australis*) regularly entering the lower reaches (Pirzl and Coughanowr 1997). The Australian sea lion is listed as vulnerable under the EPBCA whilst the Australian fur seal is not listed as threatened but is considered to be of high conservation significance. All cetacean species within Australian waters are protected by State and Commonwealth legislation, while the humpback whale and southern right whale are also listed as endangered under the TSPA and vulnerable and endangered, respectively, under the EPBCA. Whale and pinniped species are likely to be infrequent visitors to Bell Bay and Long Reach.

3.8.2 Other protected species

In addition to listed threatened species, there are a number of marine species protected under the *Fisheries (General and Fees) Regulations 1996*, regulations established through provisions of the Tasmanian *Living Marine Resources Management Act 1995*. Protected species that occur in northern Tasmania and Bass Strait include limpets belonging to the superfamilies Fissurellacea, Patellacea and Siphonariacea, fish species belonging to the families Syngnathidae and Brachionichthyidae, fish belonging to the genus *Forsterygion* and a number of shark species.

One species recorded during the current survey, the limpet *Siphonaria diemenensis*, is protected under the above State legislation. Given the presence of small patches of seagrass in Long Reach, pipefishes and other members of the family Syngnathidae are also likely to occur in the area, although the larger areas of seagrass near the estuary mouth provide more suitable habitat for these species.

The Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBCA) also lists a number of marine species (additional to threatened species) to ensure their long term conservation. Listed species that occur in the Tamar Estuary include occasional visitors such as seals and sea lions as well as resident members of the family Syngnathidae, the latter also protected under State legislation as described above.

Note that seabirds are not included in the brief of the current study. Any protected or high conservation value species that may occur in the vicinity of the development, such as white bellied sea eagles and little penguins, are considered elsewhere in the IIAS documentation.

3.9 Introduced species

Three introduced marine species were recorded in the current survey of the proposed wharf site, the Pacific oyster *Crassostrea gigas*, east Asian bivalve *Theora lubrica* and the New Zealand half crab *Petrolisthes elongatus*. Previous studies in Long Reach have revealed the presence of several additional introduced species, including the Asian bivalve *Musculista senhousia*, the polychaete *Euchone limnicola*, the green alga *Codium fragile* ssp. *tomentosoides* and ricegrass *Spartina anglica* (Aquenal 2001b, 2004b). *M. senhousia* was recorded in shallow muddy intertidal habitat in Donovans Bay and on wharf pylons, *C. fragile* ssp. *tomentosoides* was found on wharf pylons and *E. limnicola* was recorded as a solitary individual in Donovans Bay benthic infauna (Aquenal 2001b, 2004b). *S. anglica* occurs in large meadows in the Tamar Estuary, but most of these are in the upper estuary (Hedge 1998), and only small patches occur in Long Reach in Donovans Bay and Big Bay. A number of other cryptogenic fouling species (cryptogenic = unclear if they are native or introduced), including amphipods, bryozoans and algae, have also been recorded at the Bell Bay Power Station and woodchip wharves (Aquenal

2001b). Of the species described above, *C. gigas* and *M. senhousia* and have been categorised as target marine pests by the Australian Introduced Marine Pests Advisory Council (AIMPAC). *S. anglica* is not categorised in this way because it is not a fully marine species, but is nevertheless regarded as a significant pest.

Additional introduced species have been found in other parts of the Tamar Estuary, and whilst less likely to occur in the vicinity of the wharf site, may still occur in neighbouring areas. The introduced mosquito fish *Gambusia holbrooki* was first discovered in the Tamar Estuary in 2000 (Keane and Neira 2004), and occurs primarily in the upper estuary. The European green crab *Carcinus maenas*, categorised as a target marine pest by AIMPAC and as a noxious fish under the Tasmanian *Living Marine Resources Management Act 1995*, has been recorded at Deviot and in the lower reaches of the estuary (Aquenal 2001b, C. Proctor, CSIRO, pers. comm.). Toxic dinoflagellate blooms have not been documented in the Tamar, however a non-toxic strain of the introduced dinoflagellate *Alexandrium tamarense* has been recorded in Bell Bay (Aquenal 2001b).

A compiled list of introduced species recorded in the Tamar Estuary is provided in Table 6. This table is limited to introduced species, and does not include cryptogenic species recorded during the survey of Aquenal (2001b).

Table 6 Introduced marine species identified in the Tamar Estuary (* = designated AIMPAC target marine pest, ♦ = designated AIMPAC target pest, however Tamar Estuary populations investigated so far are non-toxic and may not be introduced).

Species	Common name
Musculista senhousia *	Asian bag mussel
Carcinus maenas *	European green crab
Alexandrium tamarense ♦	Dinoflagellate
Crassostrea gigas *	Feral Pacific oyster
Theora lubrica	East Asian bivalve
Petrolisthes elongatus	New Zealand half crab
Euchone limnicola	Polychaete
Codium fragile ssp. tomentosoides	Green 'sea fingers' alga
Spartina anglica	Ricegrass
Gambusia holbrooki	Mosquitofish

4 SUMMARY AND CONCLUSIONS

The site of the proposed wharf development in Long Reach retains a range of natural features and values, although it has been modified by various historical and present-day disturbances. Nearby parts of Bell Bay have been reclaimed and support large-scale shipping operations, while Long Reach supports additional shipping operations and receives cooling water discharges from the Bell Bay Power Station. Land-based industrial and stockpile sites bordering the estuary, as well as activities further upstream in catchments, provide additional sources of wind- and water-born inputs. While the industrial activities above are regulated under environmental legislation, the cumulative effect of past and present disturbances has resulted in some modification of habitats and biological community structure in the vicinity of the proposed wharf site.

The development site includes intertidal and subtidal habitat, with the majority of the subtidal area located on a shallow shelf 0-5 m depth, but the outer section located on a steep drop-off reaching approximately 20 m.

The intertidal habitat is dominated by boulders and rocks, although soft muddy sediments underlie surface rocks in the mid-low parts of the shore. The rocky substrates provide natural habitats for a diverse range of intertidal invertebrates, however the site has been impacted by the introduction and proliferation of feral Pacific oysters (*Crassostrea gigas*). The oysters, which are listed nationally as a target pest, dominate the mid-low sections of the shore visually and have resulted in modification of intertidal habitats. An additional introduced species, the New Zealand half crab (*Petrolisthes elongatus*), also occurs in the intertidal zone, while the Asian bag mussel (*Musculista senhousia*), another target introduced marine pest species, occurs in more protected muddy intertidal habitats in adjacent bays. Studies in nearby areas of Long Reach have revealed intertidal habitats and communities very similar to those at the wharf site, with relatively diverse faunas recorded despite high oyster densities. Intertidal species include some limpets listed as protected under the Tasmanian *Living Marine Resources Management Act 1995*, such as the the Van Dieman's land siphon shell (*Siphonaria diemenensis*).

Subtidal seabed habitats at the wharf site consist of two main types: soft sediment on the shallow 0-5 m shelf, extending into the 5-10 m depth zone, and dense oyster beds with associated encrusting biota at greater depths. Filming indicates that soft sediments at the wharf site do not support seagrass beds, however sparse to dense patches of the seagrass *Zostera tasmanica* occur in neighbouring bays, Big Bay and Dirty Bay. The density of the seagrass varies considerably, with it being absent in some areas and achieving 90% cover in others, however it was recorded at the entrance to Big Bay and therefore persists in patches close to the proposed wharf site.

Benthic infauna communities at the wharf site are comparable to those recorded in nearby areas of Long Reach, with variation in samples mostly attributable to differences in sampling depth. While species diversites are not as high as those recorded closer to the mouth of the estuary, a wide range of families are represented and communities do not exhibit characteristics of stress associated with environmental degradation. One introduced species was recorded, the east Asian bivalve (*Theora lubrica*), but occurred in low numbers. The threatened Gunns screw shell (*Gazameda gunnii*) was not recorded at the wharf site and is unlikely to occur in this area due to adjacent disturbances and distance of the site from the estuary mouth.

Surveys found that subtidal soft sediments at the proposed wharf site are dominated by well sorted medium sands to fine silts/clays, reflecting fairly constant, moderate levels of water movement. Sediments were surveyed up to 90 cm depth, with particle size distributions in deeper sediments resembling those of surface sediments in most cases. There were some exceptions however, with increased coarse material in deeper sediments at a number of sites, as well as a large increase in silts/clays with depth at one site. The increase in coarse material is the result of dead shells from native oysters and other bivalve species, suggesting that these species were once more common at the wharf site than they are now. Alternatively, or additionally, the accumulation of shell debris in deeper sediments may be the result of historically different deposition patterns, with deposition since altered as a result of channel modification works and other disturbances in the estuary.

The large increase in silts/clays with sediment depth at one site located at the southern end of the proposed wharf site, in a depth of 7.1 m, supports the suggestion that deposition patterns have been modified over time. The very fine, deep sediments at this site were also linked to elevated heavy metal concentrations, although ANXECC & ARMACANZ (2000) sediment trigger values were only slightly exceeded or equalled for three metals. In samples from other sites, only the trigger value for mercury was exceeded, with values of 0.2 mg/kg recorded in a number of surface and 0-50 cm sediment samples, compared with a trigger value of 0.15 mg/kg. While recommended trigger values do not exist for many of the metals analysed, on the basis of available guidelines, levels of heavy metal contamination at the site are regarded as low.

Redox potential measurements suggest that anoxic conditions do not occur at the site at sediment depths up to 90 cm. This will help to reduce biological impacts of construction activities in the estuary, since disturbance of anoxic sediment can result in anoxic or even hypoxic conditions in the water column. However, disturbance will result in suspension of sedimentary material and settling rate experiments conducted here suggest that sediments at the wharf site contain a significant colloidal fraction. These fine colloidal particles have the potential to remain in suspension for many hours following disturbance, and hence could result in extensive turbid plumes. The severity of these plumes will depend on dilution rates and tidal incursion scenarios and should be considered further in environmental impact assessment studies. It is notable that the finest sediments, and hence those with the slowest settling rates, also contain the highest metal concentrations. Given likely dilution rates and relatively low levels of metal contamination in the sediments, it is likely that increases in total suspended solids in the water column will be of more concern than increases in heavy metal concentrations. Nevertheless, the issue of heavy metals requires further assessment on the basis of more detailed information about wharf construction.

It should be noted that sediment surveys in the current study were limited to a depth of 90 cm and to a set area determined from initial diagrams of the wharf structure. It is expected that the top 90 cm of sediment represents the majority of the deposition influenced by anthropogenic inputs of contaminants, and that concentrations recorded are representative of similar habitats in Long Reach. However, if the construction zone is relocated or is likely to disturb sedments to > 90 cm depth, results here may not apply and it is recommended that additional sediment sampling be conducted.

Fish species at the proposed wharf site include a range of marine/estuarine species as well migratory species that utilise both fresh and marine waters during different stages of their life cycle. For the migratory species, movement between these fresh and marine habitats occurs primarily in spring, making them particularly vulnerable during this period. Summer is also important for fish migration in the estuary, since this is when pregnant sharks enter the estary waters to pup. The proximity of shark pupping grounds to the wharf site is unknown, but shark pups have been recorded in Bell Bay (CSIRO 1993). Breeding in the threatened Australian grayling (*Prototroctes maraena*) takes place in freshwater in late spring/early summer. Hence, larvae of this species may occur in the vicinity of the wharf site around that time, while juveniles are belived to migrate back to freshwater environments 4-5 months later. There are no other known threatened aquatic species that occur seasonally, or reside, at the wharf site, however cetaceans and pinnipeds may occur as occasional visitors to Bell Bay and Long Reach.

The nearest commercial fishing operation to the wharf site is the salmonid farm located 1.7 km upstream at Rowella. However, additional land-based facilities extract water from the Tamar Estuary at Beauty Point and Clarence Point for the culture of sea horses and abalone respectively. These industries rely on a water supply of suitable quality, and hence the affect of disturbance at the wharf site on the above operations requires assessment. Recreational fishing is believed to be limited in the vicinity of the wharf site, but nevertheless also requires consideration given that recreational species, such as sand flathead (*Platycephalus bassensis*), occur at the site.

In addition to introduced marine species recorded during the current survey, previous surveys have revealed a range of introduced species occurring on wharf pylons and in sediments at Long Reach. It is possible that these species will invade new wharf structures or colonise sediments that are disturbed during construction. It is notable that the proposed wharf development does not present a new risk in relation to introduced species. The wharves already located in Long Reach receive shipping from temperate parts of Asia, the highest risk area in terms of new introductions to Tasmania. However, volume of shipping traffic also affects risks, as does the management of new wharf facilities, and therefore should be considered in impact assessment studies. A similar statement applies to assessment of oil spill risk, since similar shipping activities already exisit in the area, but suitable management strategies are required by all facilities to prevent elevated risks.

While the current study does not comprise an environmental impact assessment, it raises a number of issues relevant to the impact assessment for the wharf development. These include, but are not necessarily limited to:

The effects of construction disturbance or the wharf structure on:

- Seagrass health and survival in adjacent bays
- Seabed habitat quality
- Migration and survival of fish
- Water quality for protection of wild, cultured and recreational species
- Colonisation or spread of introduced marine pests
- Patterns of sediment deposition and erosion
- Risks of oil or other contaminant spills
- Quality and areal extent of rocky intertidal habitat

Impact and mitigation studies have previously been performed for Projects of State Significance on the Tamar Estuary (e.g. Duke Energy pipeline), are are likely to share a number of issues with the current IIAS.

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Appendix 1 Geographical coordinates, depths and survey types for sites sampled at the Long Reach wharf site and in adjacent bays.

Site	Easting	Northing	Depth (m)	Surveys Performed
IT1	492266	5444450	Intertidal	Rocky intertidal transect
IT2	492341	5444384	Intertidal	Rocky intertidal transect
LR1	492400	5444492	2	Benthic infauna, sediment particle size, heavy metals, redox, settling rates, habitat survey (wharf)
LR2	492336	5444562	3.4	Benthic infauna, sediment particle size, heavy metals, redox, settling rates, habitat survey (wharf)
LR3	492271	5444639	3.1	Benthic infauna, sediment particle size, heavy metals, redox, settling rates, habitat survey (wharf)
LR4	492211	5444610	4.7	Benthic infauna, sediment particle size, heavy metals, redox, settling rates, habitat survey (wharf)
LR5	492265	5444566	6.3	Benthic infauna, sediment particle size, heavy metals, redox, settling rates, habitat survey (wharf)
LR6	492351	5444466	7.1	Benthic infauna, sediment particle size, heavy metals, redox, settling rates, habitat survey (wharf)
LR7	492269	5444471	15.2	Habitat survey (wharf)
LR8	492205	5444563	13.6	Habitat survey (wharf)
LR9	492183	5444648	5.2	Habitat survey (wharf)
LR10	492459	5444447	3.1	Habitat survey (wharf)
LR11	492030	5445001	3.2	Habitat survey (Big Bay)
LR12	492142	5445130	2	Habitat survey (Big Bay)
LR13	492315	5445052	2	Habitat survey (Big Bay)
LR14	492122	5444791	4.9	Habitat survey (Big Bay)
LR15	492786	5444146	3	Habitat survey (Dirty Bay)
LR16	492886	5444144	2.5	Habitat survey (Dirty Bay)
LR17	492841	5444004	5.4	Habitat survey (Dirty Bay)

Appendix 2 Benthic infauna families recorded in grab samples.

Family	LR1-1	LR1-2	LR2-1	LR2-2	LR3-1	LR3-2	LR4-1	LR4-2	LR5-1	LR5-2	LR6-1	LR6-2
Ascideacea	0	0	7	1	2	1	4	0	0	4	4	0
Ampithoidae	0	0	1	0	0	0	0	0	0	0	0	0
Caprellidae	11	2	1	0	2	2	1	0	5	10	0	0
Corophidae	1	0	0	0	0	0	1	5	0	0	0	0
Dexaminidae	4	0	1	0	0	0	0	0	0	0	0	0
Isaeidae	10	7	5	1	3	0	6	3	8	11	4	0
Ischyroceridae	0	0	0	0	0	0	0	2	1	0	0	0
Lysiannassidae	0	0	0	1	0	0	0	0	0	0	0	0
Melitidae	7	6	0	0	2	3	0	4	1	1	1	1
Oedicerotidae	5	8	1	0	1	5	1	0	2	1	1	0
Phoxocephalidae	0	1	0	0	0	0	0	1	0	0	2	0
Podoceridae	0	0	0	0	0	0	1	0	0	0	0	0
Diastylidae	2	0	0	0	0	0	3	3	2	1	0	0
Alpheidae	6	4	8	5	2	3	1	2	0	1	1	0
Callianassidae	16	29	10	5	5	14	6	5	2	4	8	7
Crangonidae	0	0	0	0	0	0	0	1	0	0	0	0
Hymenosomatidae	3	0	0	0	0	0	0	0	1	0	0	0
Leucosidae	0	0	0	0	1	0	0	0	0	0	0	0
Palaemonidae	0	0	0	0	0	0	0	3	1	0	0	0
Processidae	0	0	0	0	0	0	0	0	1	0	2	2
Anthuridae	0	1	0	0	1	0	0	0	1	0	0	0
Cirolanidae	0	0	1	0	0	0	0	0	0	0	0	0
Mysidae	1	0	1	0	0	0	1	0	1	0	1	0
Leptochelidae	0	0	0	0	0	0	0	1	0	0	0	0
Ostracoda	9	13	0	1	1	0	2	5	0	2	2	3
Synaptidae	1	2	0	0	0	0	0	0	0	0	0	0
Amphiuridae	0	0	0	1	0	0	1	4	2	2	4	0
Retusidae	6	0	0	1	0	3	4	11	15	10	0	1
Naticidae	1	0	0	0	0	0	0	0	0	0	0	0
Trigoniidae	0	0	0	0	0	0	0	0	1	0	0	0
Cardiidae	0	0	0	0	0	0	0	0	0	0	1	0
Montacutidae	0	2	0	0	0	1	0	0	0	0	0	0
Semelidae	6	3	0	0	0	0	0	0	0	0	0	0
Semelidae (*Theora lubrica*)	0	0	0	5	0	1	4	8	0	0	1	1
Veneridae	0	0	0	0	0	0	0	0	1	0	0	0
Nemertea	0	0	1	0	0	1	1	2	1	0	0	1
Capitellidae	14	5	8	5	10	14	7	3	3	3	1	5
Maldanidae	1	0	0	0	2	3	2	0	0	0	1	0
Lumbrineridae	1	0	0	1	0	0	0	1	1	1	0	0
Opheliidae	1	0	0	0	0	0	0	0	0	0	0	0
Orbinidae	10	3	5	3	4	3	15	8	2	3	7	3
Glyceridae	1	0	0	0	0	0	1	1	0	1	0	0
Hesionidae	1	0	0	0	0	1	1	0	0	1	0	0
Nephytidae	18	15	16	10	6	16	10	20	11	17	15	11
Nereididae	0	0	1	1	0	2	0	0	0	0	1	0
Phyllodocidae	5	4	4	2	3	4	4	2	7	5	1	0
Polynoidae	3	0	1	0	1	0	1	7	1	0	0	0
Syllidae	0	0	0	1	0	0	0	0	1	0	0	0
Sabellidae	0	0	0	0	0	0	0	3	0	0	0	0
Magelonidae	0	0	0	0	0	0	0	1	0	0	0	0
Spionidae	0	0	0	0	0	3	6	3	2	1	1	0
Ampharetidae	0	0	0	0	0	0	0	1	1	0	0	0
Cirratulidae	0	0	2	1	1	0	0	0	0	0	0	0
Terebellidae	1	0	2	2	1	3	4	21	2	1	3	1
Trichobranchidae	0	0	0	0	0	0	0	3	0	0	0	0
Sipunculida	0	0	0	0	0	0	0	2	0	1	0	0

Appendix 3 Rocky intertidal species recorded in three representative 1 m shore intervals at three tidal heights (H = high, M = mid, L = low) on Transect 1 (site IT1).

Species	Distance from supralittoral 0 m mark (m)									Total
		H			M			L		
	1-2	3-4	5-6	8-9	10-11	12-13	17-18	19-20	21-22	
Crustacea										
Alpheus euphrosyne									1	1
Brachynotus spinosus				4	7	1	9		2	23
Cyclograpsis granulosis		8	3	1	1					13
Elminius covertus		300	60	20						380
Heloecius cordiformis				1						1
Ibla quadrivalvis			18				1			19
Paragrapsus gaimardii					3		3	1	2	9
Petrolisthes elongatus							6		8	14
Pilumnopeus serratifrons							1			1
Tetraclitella purpurascens			42	35						77
Mollusca										
Agnewia tritoniformis		1	2				1			4
Austrocochlea concamerata		2								2
Austrocochlea constricta							3			3
Bembicium auratum		5	460	1115	765	820				3165
Bembicium melanostomum	310	230								540
Bembicium nanum			1							1
Chiton pelliserpentis		3	10	9	5	2	7	6		42
Cominella eburnea							1	2		3
Crassostrea gigas				2	8	32	92	62	44	240
Lasaea australis			1		3	52				56
Nerita atramentosa	5	4	1	1	7	1				19
Nodilittorina praetermissa	2									2
Nodilittorina unifasciata	32									32
Onchidella patelloides							1	1		2
Siphonaria diemenensis				2				1		3
Xenostrobus inconstans			5	4	2					11
Echinodermata										
Patiriella exigua							16	2	10	28
Cnidara										
Anthothoe albocincta				2						2
TOTAL										4693

Appendix 4 Rocky intertidal species recorded in three representative 1 m shore intervals at three tidal heights (H = high, M = mid, L = low) on Transect 2 (site IT2).

Species	Distance from supralittoral 0 m mark (m)									Total
		H			M			L		
	2-3	4-5	6-7	8-9	10-11	12-13	14-15	16-17	18-19	
Crustacea										
Brachynotus spinosus	3	3	6	6	5	3	3	4	1	34
Cyclograpsis granulosis	12	3		1		1		2		19
Elminius covertus	400	100	1000	2			5			1507
Ibla quadrivalvis					5	4	26			35
Macrophthalmus latifrons			1							1
Paragrapsus gaimardii	2		1	1	1	2	2	2	4	15
Paragrapsus quadridentatus			5	1	2	4	3	2		17
Petrolisthes elongatus						4	14	12	9	39
Pilumnopeus serratifrons				2	1	1	3			7
Tetraclitella purpurascens	26	2								28
Mollusca										
Agnewia tritoniformis			1							1
Austrocochlea concamerata	5		2							7
Bembicium auratum	100	59	380	520	575	640	590	715		3579
Bembicium melanostomum	25	42	6	70						143
Bembicium nanum			1	1						2
Chiton pelliserpentis	7	7	5	12	7	5	4	7	2	56
Cominella eburnea								3	1	4
Cominella lineolatus									2	2
Crassostrea gigas	1	3	5	39	51	47	100	148	35	429
Lasaea australis		4		4	18	1				27
Nerita atramentosa	7	1	4							12
Notoacmea flammea	2		1							3
Onchidella patelloides	2	3	1	2	2	1				11
Siphonaria diemenensis		1		1			1	5		8
Xenostrobus inconstans		8	3	11	7					29
Polychaeta										
Galeolaria caespitosa						1				1
Urochordata										
Pyura stolonifera									3	3
Echinodermata										
Patiriella exigua				1		6	10	14	3	34
TOTAL										6053

Appendix 5 Particle size data for duplicate (0-10 cm sediment depth) grab samples collected from the six survey sites.

	Sieve mesh size (mm)							
Sample	4	2	1	.5	.250	.125	.063	<.063
LR1-1	0.0	0.0	0.6	1	5	43	19	31
LR1-2	0.6	0.0	0.6	1	1	45	10	40
Mean	0.3	0.0	0.6	1	3	44	15	36
Std Dev	0.5	0.0	0.0	0.0	2.3	1.8	6.4	6.4
Cumulative %	0.3	0.3	1.0	2	5	49	64	100
LR2-1	0.0	0.6	0.6	1	1	48	14	34
LR2-2	0.0	0.0	0.0	1	3	44	13	39
Mean	0.0	0.3	0.3	1	2	46	14	36
Std Dev	0.0	0.5	0.5	0.5	1.4	2.8	0.9	3.7
Cumulative %	0.0	0.3	0.6	2	4	50	64	100
LR3-1	0.0	0.0	0.6	1	3	38	19	39
LR3-2	0.0	0.0	0.0	1	2	44	12	42
Mean	0.0	0.0	0.3	1	2	41	16	40
Std Dev	0.0	0.0	0.5	0.0	0.5	4.6	5.5	1.8
Cumulative %	0.0	0.0	0.3	1	3	44	60	100
LR4-1	0.6	0.6	0.6	1	3	35	10	49
LR4-2	3.9	0.6	0.6	1	1	38	17	38
Mean	2.3	0.6	0.6	1	2	36	14	44
Std Dev	2.3	0.0	0.0	0.5	0.9	1.8	4.6	8.3
Cumulative %	2.3	2.9	3.6	5	6	43	56	100
LR5-1	0.0	0.0	0.0	1	3	50	12	35
LR5-2	0.0	0.0	0.0	1	3	49	10	36
Mean	0.0	0.0	0.0	1	3	50	11	36
Std Dev	0.0	0.0	0.0	0.0	0.5	0.5	0.9	0.9
Cumulative %	0.0	0.0	0.0	1	4	53	64	100
LR6-1	0.0	0.0	0.0	1	1	44	14	40
LR6-2	0.6	0.0	0.0	1	5	30	16	49
Mean	0.3	0.0	0.0	1	3	37	15	44
Std Dev	0.5	0.0	0.0	0.0	2.3	9.6	0.9	6.0
Cumulative %	0.3	0.3	0.3	1	4	41	56	100

Appendix 6 Particle size data for individual 0-50 cm and > 50 cm samples collected using cores at the six survey sites.

			Sieve mesh size (mm)							
Site	Sample depth	Parameter	4	2	1	.5	.250	.125	.063	<.063
LR1	0-50 cm	Volume (ml)	0.0	0.0	0.6	0	1	52	13	34
		Cumulative %	0.0	0.0	0.6	1	1	53	66	100
	>50 cm	Volume (ml)	0.0	0.0	0.6	1	1	49	10	39
		Cumulative %	0.0	0.0	0.6	1	2	51	61	100
LR2	0-50 cm	Volume (ml)	0.0	0.6	0.6	1	1	44	10	42
		Cumulative %	0.0	0.6	1.3	3	4	48	58	100
	>50 cm	Volume (ml)	4.5	2.6	2.6	2	1	32	16	39
		Cumulative %	4.5	7.1	9.7	12	13	45	61	100
LR3	0-50 cm	Volume (ml)	0.0	0.6	0.6	1	2	53	11	32
		Cumulative %	0.0	0.6	1.3	3	5	57	68	100
	>50 cm	Volume (ml)	2.6	3.2	5.8	3	2	27	24	32
		Cumulative %	2.6	5.8	11.7	15	17	44	68	100
LR4	0-50 cm	Volume (ml)	0.6	0.6	0.0	1	2	40	14	42
		Cumulative %	0.6	1.3	1.3	3	5	45	58	100
	>50 cm	Volume (ml)	1.9	1.3	4.5	2	2	43	10	35
		Cumulative %	1.9	3.2	7.8	10	12	55	65	100
LR5	0-50 cm	Volume (ml)	20.8	3.9	1.9	2	3	14	13	42
		Cumulative %	20.8	24.7	26.6	29	31	45	58	100
	>50 cm	Volume (ml)	37.0	2.6	3.2	2	2	13	6	34
		Cumulative %	37.0	39.6	42.9	45	47	60	66	100
LR6	0-50 cm	Volume (ml)	0.6	0.0	0.0	1	1	12	12	73
		Cumulative %	0.6	0.6	0.6	1	3	14	27	100
	>50 cm	Volume (ml)	0.0	0.0	0.0	1	1	30	6	61
		Cumulative %	0.0	0.0	0.0	1	3	32	39	100

Appendix 7 Heavy metal concentrations in sediment samples collected from six sites (LR1 to LR6) at the proposed wharf location. Samples were analysed in the top 10 cm from grab samples (G), from 0-50 cm from cores (T) and > 50 cm from cores (B).

Analyte	Unit	Detection Limit	LR1-G	LR2-G	LR3-G	LR4-G	LR5-G	LR6-G
Arsenic	mg/kg	5	<5	8	8	5	<5	6
Barium	mg/kg	10	<10	<10	<10	<10	<10	<10
Beryllium	mg/kg	1	<1	<1	<1	<1	<1	<1
Cadmium	mg/kg	1	<1	<1	<1	<1	1	<1
Chromium	mg/kg	2	8	15	12	12	4	13
Cobalt	mg/kg	2	<2	3	3	2	<2	3
Copper	mg/kg	5	<5	9	6	7	<5	8
Lead	mg/kg	5	5	11	8	8	<5	10
Manganese	mg/kg	5	249	527	393	257	82	281
Nickel	mg/kg	2	4	8	6	7	2	8
Vanadium	mg/kg	5	9	18	14	14	6	16
Zinc	mg/kg	5	32	61	50	51	17	55
Mercury	mg/kg	0.1	<0.1	0.2	0.2	0.1	<0.1	0.2
			LR1-T	**LR2-T**	**LR3-T**	**LR4-T**	**LR5-T**	**LR6-T**
Arsenic	mg/kg	5	10	14	12	11	9	24
Barium	mg/kg	10	<10	10	<10	<10	<10	<10
Beryllium	mg/kg	1	<1	<1	<1	<1	<1	<1
Cadmium	mg/kg	1	<1	<1	<1	<1	<1	1
Chromium	mg/kg	2	19	21	17	21	19	38
Cobalt	mg/kg	2	5	6	5	6	5	9
Copper	mg/kg	5	11	13	11	15	13	34
Lead	mg/kg	5	13	16	12	12	11	20
Manganese	mg/kg	5	318	1060	621	535	625	210
Nickel	mg/kg	2	10	12	10	12	11	21
Vanadium	mg/kg	5	23	27	21	24	22	52
Zinc	mg/kg	5	69	85	73	76	64	148
Mercury	mg/kg	0.1	<0.1	0.3	0.1	0.2	0.1	0.2
			LR1-B	**LR2-B**	**LR3-B**	**LR4-B**	**LR5-B**	**LR6-B2**
Arsenic	mg/kg	5	6	7	7	7	9	18
Barium	mg/kg	10	<10	<10	<10	<10	<10	<10
Beryllium	mg/kg	1	<1	<1	<1	<1	<1	<1
Cadmium	mg/kg	1	<1	<1	<1	<1	<1	1
Chromium	mg/kg	2	21	24	24	19	26	33
Cobalt	mg/kg	2	5	5	5	4	5	7
Copper	mg/kg	5	14	12	7	11	<5	29
Lead	mg/kg	5	12	9	5	9	<5	15
Manganese	mg/kg	5	104	283	266	120	71	174
Nickel	mg/kg	2	11	13	12	10	13	18
Vanadium	mg/kg	5	26	25	23	20	25	41
Zinc	mg/kg	5	58	70	44	38	26	117
Mercury	mg/kg	0.1	<0.1	0.1	0.1	<0.1	<0.1	0.1