Rosslyn Bay Boat Harbour - Marine Audit and Assessment of Dredge Related Impacts

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Fitzroy Basin Association
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Marine Audit and Dredge Related Impacts

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Executive summary

Marine and estuarine environments are highly dynamic ecosystems, constantly influenced by natural, physical and anthropogenic disturbances such as strong storm events, runoff from urban and industrial development and dredging. Dredging is an important maintenance process used to maintain access channels for ease of day to day marine transportation activities and the safety and efficiency of port operations. Dredging can alter the hydrodynamics of a waterway and resuspended/disperse particulate and pore-water contaminants into the adjacent marine environment, affecting natural resident flora and fauna.

In September 2006, dredging activities commenced at the Rosslyn Bay Boat Harbour Marina, situated south of Yepoon on the Central Queensland coastline. The Fitzroy Basin Association (FBA) and Queensland Transport (QT) commissioned the Centre for Environmental Management, CQU to conduct an investigation into the effects of dredge related activities on the adjacent marine environment. Water quality, macroinvertebrate assemblages, metal concentrations in sediments and resident oysters and coral community health were assessed immediately before the dredging commenced and two weeks after dredging ceased operations at the dredge location, adjacent to the dredge location and at a reference location in close geographical proximity to the dredge location using a Before/After Control Impact (BACI) experimental design.

Significant changes in water quality, sediment physico-chemical parameters and macrobenthic assemblages were observed following post-dredge sampling at the Marina and adjacent locations. Conversely, there were no significant changes at the reference location, suggesting that the affected areas were due to dredge related activities as opposed to natural or seasonal disturbances.

Macrobenthic biodiversity and community assemblages were modified following post-dredge sampling, possibly due to changes in organic content and particle sizes in the affected areas. A reduction in sediment metal concentrations in the dredge locations during post-dredge sampling was probably attributed to sediment resuspension and transport during dredging activities as this was reflected by the increase in certain metals in resident oysters, probably due to suspended particulate metals being filter fed by the oysters.

There were no significant changes in coral community assemblages or condition following post-dredge sampling, possibly due to the large distances between the dredge site, spoil grounds and the coral reef.

This study has demonstrated that dredge related activities can impact upon resident macrobenthic organisms and alter the structure and dynamics of sediment properties and contaminant loads to immediate and extended dredge affected areas. It is important to understand changes in biological communities and identify complex interactions between disturbances in varying environmental conditions and resident organisms including their rates of recovery to predict community responses and aid in future management decisions.

1.0 Introduction

Marine and estuarine environments are highly dynamic ecosystems, which are constantly influenced by natural physical disturbances such as strong currents, winds and waves (Lohrer and Wetz 2003; Miller et al. 2002; Skilleter et al. 2006). Marine and estuarine sediments are constantly being shifted and reworked by process of movements, erosion and deposition. Macrobenthic organisms, which live in highly dynamic systems, have adapted to these constant changing dynamic environments (Miller et al. 2002; Skilleter et al. 2006), however, large-scale anthropogenic disturbances, such as dredging of marine soft sediment habitats, can alter macrobenthic and subsequent vertebrate communities (Miller et al. 2002; Roberts et al. 1998; Robinson et al. 2005; Skilleter et al. 2006).

Dredging is an important maintenance process by which access channels, marinas and berthing areas are properly maintained to facilitate day to day marine transportation activities and improve the safety and efficiency of port operations (Pollice *et al.* 1996), however, dredging events far exceed normal rates of sedimentation and deposition encountered in the environment, often leading to complete loss of organisms in the areas being dredged and subsequent recolonisation of altered communities dominated by pioneering species (Miller *et al.* 2002; Skilleter *et al.* 2006). Furthermore, fine-grain sediments, such as silts and clays, commonly found in marinas and ports, have strong binding properties that bind to a number of contaminants such as trace metals and nutrients, thus sediments act as sinks for these contaminants (Lohrer and Wetz 2003; van den Berg *et al.* 2001). Dredging facilitates the release, mobilisation and bioavailability of these contaminants into the overlaying water column, which can lead to potential toxicity in resident biota (Lohrer and Wetz 2003; van den Berg *et al.* 2001; van den Hurk *et al.* 1997).

In September 2006, dredging commenced at the Rosslyn Bay Boat Harbour Marina (Figure 1). The Rosslyn Bay Marina is situated south of Yeppoon on the Central Queensland coastline. The marina is maintained by Queensland

Transport (QT) and is designed to provide shelter for recreational and commercial vessels. Construction to the marina began in the early 1990's and by April 1996, the first 190 berths of the marina were opened (http://www.keppelbaymarina.com.au). Natural siltation and sedimentation processes have persisted and therefore resulted in a reduction in depth of the marina. Maintenance dredging started at Rosslyn Bay in 1985 and has previously required maintenance dredging every five years of about 30,000 m^3 of sediment removal to maintain safe passage for marine vessels (GHD 2005). As a result, maintenance dredging commenced in early September and terminated in early December 2006 at the Rosslyn Bay Marina.

Figure 1. Dredging activity at Rosslyn Bay Marina. Photo courtesy of FBA and QT.

The Fitzroy Basin Association (FBA) and Queensland Transport (QT) commissioned the Centre for Environmental Management (CEM) to conduct an investigation on the effects of dredge related impacts on the immediate and adjacent surrounding environment where dredging activities occurred. Water quality, macrobenthic assemblages, sediment characterisation, metal levels in sediments and resident oysters, and coral community health was investigated immediately before and immediately after the dredge event at the proposed dredge location (Rosslyn Bay Marina), adjacent to the dredge location and at a reference location.

The following Hypotheses were tested: There were no significant changes in (a) water or sediment physico-chemical parameters, (b) macrobenthic assemblages, (c) metal burden in sediments or oysters, and (d) condition or cover of corals at *a priori* determined locations before or after the dredging event at the Rosslyn Bay Marina.

2.0 Materials and Methods

2.1 Experimental design

Dredge related impacts were monitored using an asymmetrical data analysis approach, based on a Before/After, Control, Impact (BACI) design (Underwood 1991; Underwood 1997). The analysis is designed to detect changes in community assemblages where environmental disturbances, such as dredging events, have occurred and relate them to changes in assemblages that occur naturally in areas unaffected by the disturbance. Sites and locations were selected at the proposed dredge site, adjacent to the dredge site and at a reference location in close proximity to the dredge site. The following locations were established for sampling; Boat Harbour and Private Marina (dredge locations); Wreck Point and Bluff Rock (adjacent to impact location) and Monkey Point (reference location). At each location, three sites were selected except for Boat Harbour, which had four sites to account for the marina entrance. See Table 1 for GPS coordinates; Figure 3 and Maps 1-4 for study locations and sites. Pre-dredge sampling occurred one week prior to the commencement of dredge activities in early September 2006 and post-dredge sampling commenced two weeks after dredge activities had ceased in early December 2006. At each site, temperature, conductivity, salinity, dissolved oxygen, pH, and turbidity were measured using a YSI-multiprobe water quality meter. Sediment and oyster tissue samples were collected at each site for metal analyses and grab samples were collected for macrobenthic community assemblages. Two pre-calibrated turbidity loggers (2h intervals) were deployed at Rosslyn Bay Headland and Monkey Point (Table 1; Maps 1 & 4) using SCUBA to collect turbidity data during the course of the marine dredging activities (Figure 2).

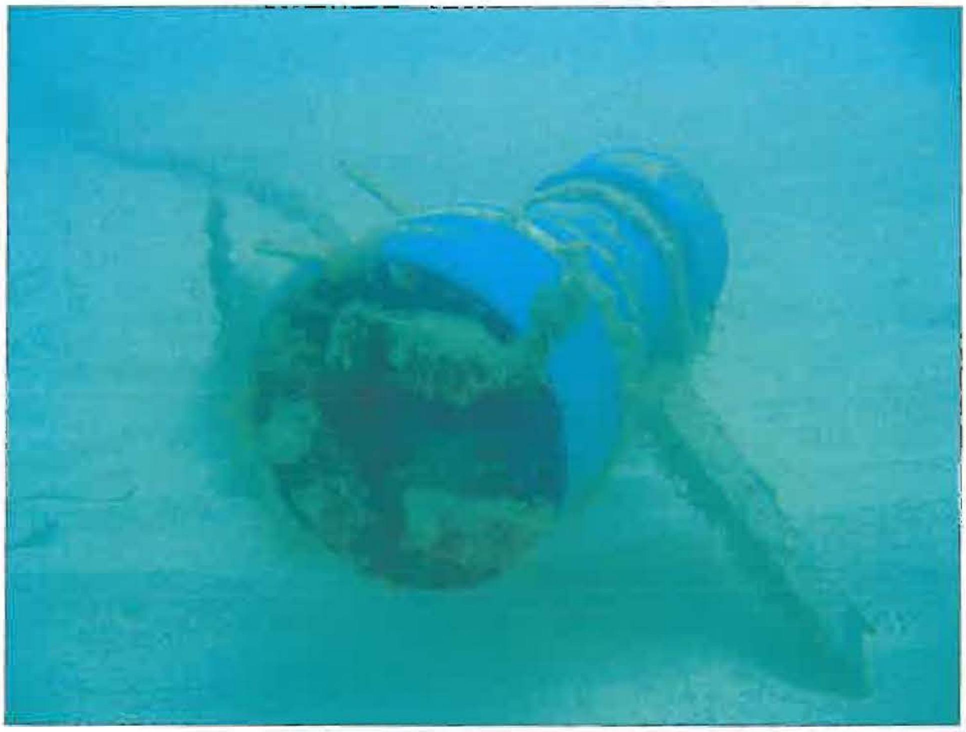

Figure 2. Turbidity logger deployed at Monkey Point.

Figure 3. Locality map of the Yepoon/Rosslyn Bay headland and Keppel Islands showing study locations and spoil ground plumes.

Map 1. Rosslyn Bay marina showing Boat Harbour and Private Marina study sites.

Map 2 Study sites of Bluff Rock.

Map 3. Study sites of Wreck Point.

Map 4. Study sites of Monkey Point.

Table 1. GPS coordinates of sites and locations for dredge activity monitoring at Rosslyn Bay.

Location	Site 1	Site 2	Site 3	Site 4
Boat Harbor	S 23º09.756, E 150º47.319	S 23º09.695, E 150º47.317	S 23º09.636, E 150º47.400	S 23º09.567, E 150º47.295
Private Marina	S 23º09.631, E 150º47.113	S 23º09.580, E 150º47.174	S 23º09.603, E 150º47.273	-
Bluff Rock	S 23º10.297, E 150º48.199	S 23º10.256, E 150º48.287	S 23º10.353, E 150º48.343	-
Wreck Point	S 23º08.336, E 150º45.698	S 23º08.350, E 150º45.858	S 23º08.561, E 150º45.959	-
Monkey Point	S 23º11.898, E 150º56.299	S 23º11.946, E 150º56.270	S 23º11.953, E 150º56.387	-
Turbidity logger 1 Rosslyn Bay	S 23º09.664, E150º47.617	-	-	-
Turbidity logger 2 Monkey Point	S 23º11.893, E150º56.333	-	-	-

Figure 4. Coral transect survey at Monkey Point using SCUBA (Photo by Ashley Campbell).

2.2 Sediment and tissue samples

Triplicate sediment samples were randomly collected from each site during pre and post-dredge sampling events. Surface sediments were collected on SCUBA using acid-washed (10% nitric acid and rinsed three times in milli-Q water; 18 MΩ/cm) polyethylene corers and stored on ice before being transported to the laboratory for further analysis. Oyster tissue samples were also collected from each site at the low water intertidal level. Oysters were shucked and rinsed in milli-Q water (18 MΩ/cm) in the laboratory before acid digestion.

A sub-sample of sediment was taken from each site for carbon content and particle size analysis. Sediment and oyster tissue samples were oven dried to a constant temperature of 40 ºC. Sediments were sieved to <2 mm particle size to remove large shell grit and gravel. Sediment organic content was measured as percent loss on ignition (%LOI) using a muffle furnace at 550 ºC for 3h. Sediment particle sizes were determined gravimetrically by wet sieving sediments on an agitated stack of Endecott test sieves with apertures of 2 mm, 1 mm, 500 µm, 250 µm, 125 µm and 63 µm and expressed as a percent of the total sample weight. Sediments and oyster tissue samples were digested using a hot mixture (2:1) of concentrated nitric acid (HNO_3) and hydrogen peroxide (H_2O_2) as described by the method by Krishnamurty *et al.* (1976). Sediment and oyster tissue digests were analysed for the following metals; aluminium (Al), arsenic (As), chromium (Cr), Cadmium (Cd), cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), selenium (Se) and zinc (Zn) using an Inductive Coupled Plasma Mass Spectrometer (ICPMS; Varian 820-MS, Melbourne Australia) and an Inductive Coupled Plasma Atomic Emission Spectrometer (ICP-AES; Varian Liberty Series II, Melbourne Australia). Blanks and spiked samples were run throughout the digestion and analysis protocols with minimal variation among samples (Coefficient of Variation < 7%).

2.3 Macroinvertebrate assemblages

Triplicate grab samples were collected at each site using a van-Veen grab sampler (0.005 m^2) to determine macroinvertebrate community assemblages. Sediments and associated macroinvertebrates were bagged and sent to the laboratory for further analysis. Samples were sieved through a 1 mm mesh and the retained organisms were preserved, sorted and identified, where possible, to the lowest taxonomic level (species level).

2.4 Coral surveys

Corals were surveyed using SCUBA by deploying triplicate 50 m transect lines at Bluff Rock and Monkey Point. At each 5 m interval, coral cover and coral type were documented and photographed using a digital camera (Canon A630; lens: 7.3-29.2 mm) in an underwater housing (Canon WP-DC8; Figures 4 & 5). Photographs were taken one metre above the substrate to standardise each photograph and taken parallel to the substratum to minimise parallax error. Random point count methodology was used to estimate community demographics of coral substrates and other pavements and sands using a Coral Point Count Estimate (CPCe) program (Kohler and Gill 2006). Twenty points were randomly distributed along the frame and substrate cover was identified beneath each point by visual observation. Each point was entered and stored as a data code for each frame and calculated as percent (%) substrate cover for each frame and total transect. Although coral surveys were performed at Monkey Point and Bluff Rock during pre-dredge sampling, Bluff Rock was not re-surveyed during the post-dredge sampling event due to bad weather and poor visibility.

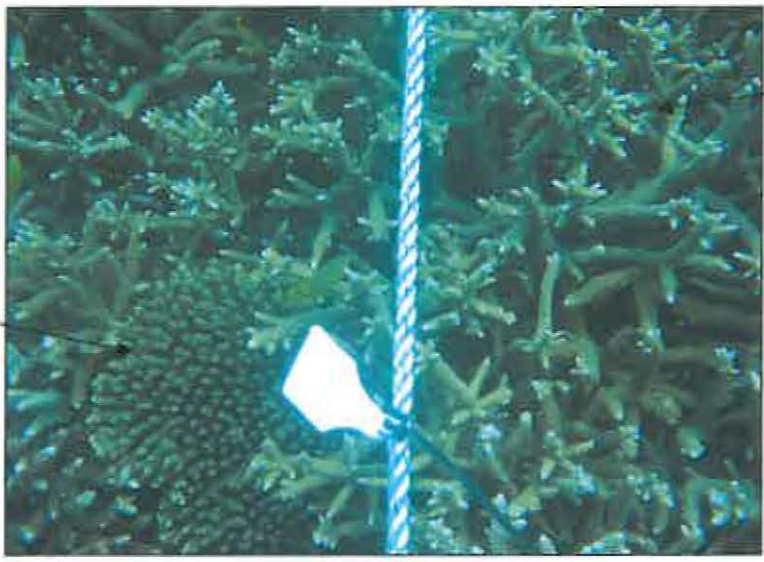

Figure 5. Image of quadrat used to calculate percent (%) substrate cover along a transect line showing main coral species encountered at Monkey Point (Photo by Ashley Campbell).

2.5 Data analysis

Differences ($P < 0.05$, 95% confidence intervals) in (a) macrobenthic biodiversity and (b) metal levels in (i) sediments and (ii) oyster tissues among sites, locations and sampling periods were determined using one and two-way Analysis of Variance (ANOVA). There were no significant differences ($P > 0.05$) in any of the variables among sites within locations; therefore, sites within each location were pooled. Data were tested for homogeneity of variance and normality. Significance levels were increased ($P < 0.01$, 99% confidence intervals) where data did not meet that criteria (O'Neill 2000; Underwood 1997).

Macrobenthic biodiversity was measured as total abundance (total number of organisms), species richness (total number of taxa), diversity (Shannon-Weiner; the proportion of macroinvertebrates per species) and species evenness (how evenly abundance is spread among the various taxa that make up an assemblage). Diversity values ranged from 0 (indicating low community complexity) to 4 (indicating high community complexity). Species evenness values were between 0 (few species make up the majority of the abundance) and

1 (even number of species making up the total abundance) (Cai *et al.* 2006; Hill 1973; McClatchie *et al.* 1997; Nero and Sealey 2005; Zar 1996).

Macrobenthic community assemblages were plotted using *non-metric* Multi Dimensional Scaling (*n*-MDS). Due to certain outliers in the sample matrix of individual samples causing high unacceptable stress values (> 0.2), mean assemblages were used to test within each treatment for *n*-MDS. Sample points close to each other signify they are similar in community composition. The further the sample points are away from each other, the more dissimilar they are. Analysis of Similarity (ANOSIM) was used to statistically determine dissimilarities in community structure among locations and sampling periods (pre/post-dredge) (PRIMER; Clarke, 1993). Similarity percentages (SIMPER) were used to determine what organisms best described changes in community assemblages among sampling dates and locations (PRIMER; Clarke, 1993). Macrobenthic community structure was examined using Bray-Curtis (B-C) similarity measures (Clarke 1993). Bray Curtis was chosen as the preferred similarity matrix because it performed well in preserving 'ecological distance' in a variety of simulations on different types of data sets. No transformations were made to the data to maintain equal weight among common and rare species.

BIO-ENV was used to analyse relationships among macrobenthic community assemblages by relating similarity matrices with environmental variables (sediment particle size analysis, organic content and metal levels in sediments). Note that linking environmental variables with biological patterns using BIO-ENV is purely observational and not causative. Cause and effect can only be demonstrated using manipulative field experiments (Clarke and Gorley 2001; Clarke and Green 1988).

3.0 Results and discussion

3.1 Water quality

Surface water temperatures, conductivity, salinity and pH were similar throughout locations during pre and post-dredge sampling events (Figure 6a, b, c & e), however, there were significant differences ($P \leq 0.05$) between sampling times within locations. Significant differences ($P \leq 0.05$) among locations and sampling times were detected for dissolved oxygen and turbidity (Figure 6d & f). Dissolved oxygen was lower during post-dredge sampling at Boat Harbour and Private Marina (the dredge location), however oxygen levels increased at Bluff Rock, Wreck Point and Monkey Point (Figure 4d) between sampling times. Turbidity was elevated at all locations during post-dredge sampling (Figure 6f), however, this may have been mainly due to seasonal fluctuations as storm frequency and intensity tends to increase during the later months of the year (Bureau of Meteorology).

Turbidity data collected from the data loggers indicated spikes that were associated with dredge events. Dredge volumes (m^3) were recorded and related to turbidity spikes around the 10th of September 2006 (Figure 7), however storm events, recorded by the dredge vessels log, were associated with increased turbidity levels at Rosslyn Bay Headland and to a lower extent, Monkey Point between the 12th to the 18th of September 2006 (Figure 7), however, there were periods of time where storm events and dredge activities were negligible, indicating a reduction in turbidity at both Rosslyn Bay Headland and Monkey Point (23rd - 28th of September 2006; Figure 7). The results suggest that turbidity fluctuations at the Rosslyn Bay Headland were attributed to both dredge related activities and storm (increased wind and wave action) events.

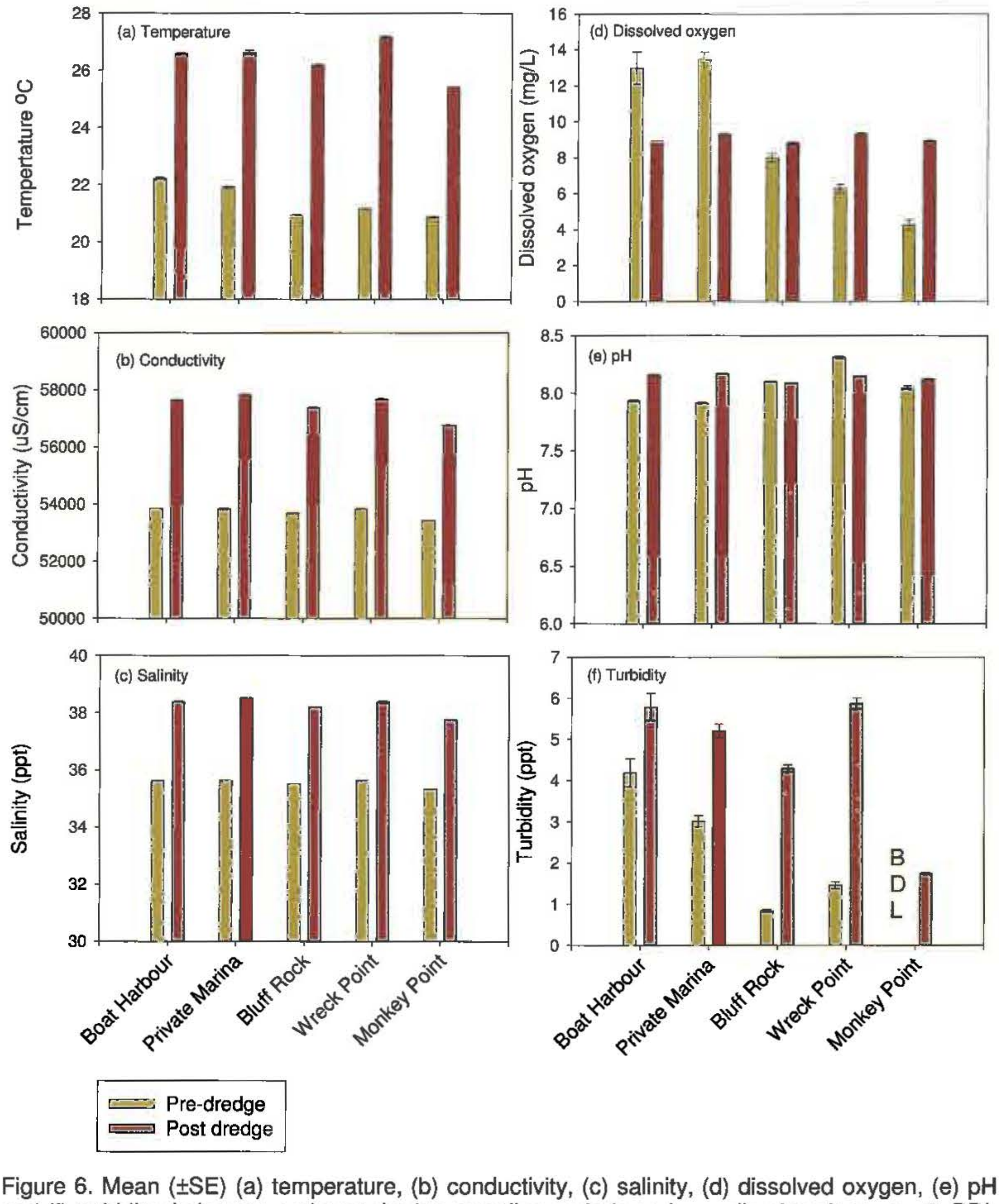

Figure 6. Mean (±SE) (a) temperature, (b) conductivity, (c) salinity, (d) dissolved oxygen, (e) pH and (f) turbidity during pre and post-dredge sampling periods and sampling locations, $n = 9$. BDL indicates below instrument detection limits.

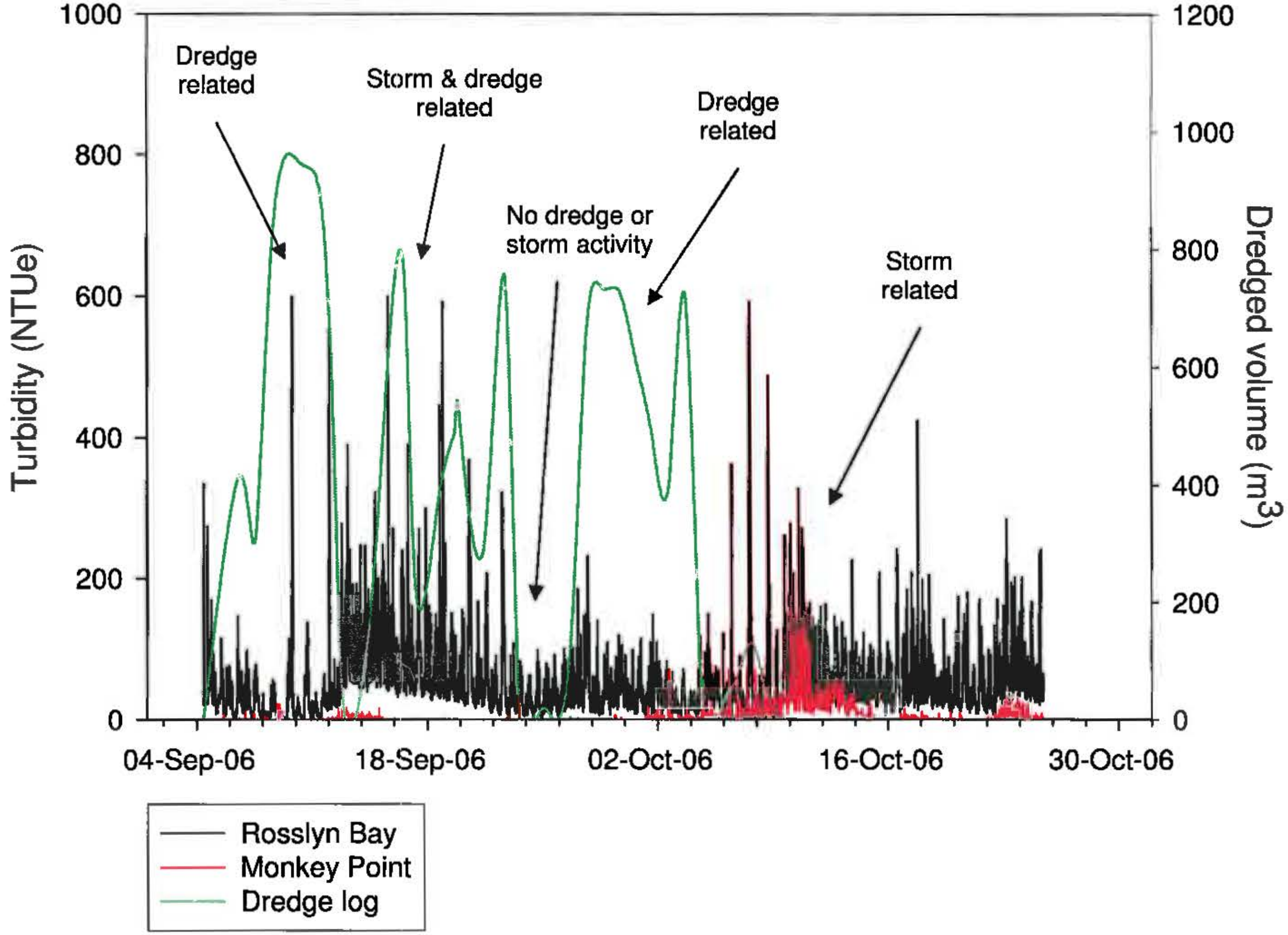

Figure 7. Turbidity logger data at Rosslyn Bay Headland (black) and Monkey Point (red) from the 4^{th} of September to the 25^{th} of October 2006. Green lines indicate when dredge was active and the volume (m^3) of sediment dredged on the day.

3.2 Sediment composition

Sediment organic content was highest at the Marina locations with lowest levels encountered at Wreck Point and Monkey Point (Figure 8). Organic levels were significantly ($P < 0.05$) lower at Boat Harbour, Private Marina and Bluff Rock following the dredge event, however, sediment organic content had significantly increased ($P < 0.05$) at Wreck Point following the dredge event, possibly due to resuspension and transport from the dredge spoil grounds, as studies have reported dredge plums to travel significant distances (Robinson *et al.* 2005), with no significant changes ($P > 0.05$) a Monkey Point (Figure 8). High levels of organic material in sediments from other dredge related studies have shown similar results (van den Hurk *et al.* 1997). For example, a study by van den Hurk *et al.* (1997) reported similarly higher levels of organic carbon in sediments associated with a dredge site as well as the disposal sites (~8-15%) to the present study and significantly lower levels of organic content in sediments from a reference site (~ 1-2%).

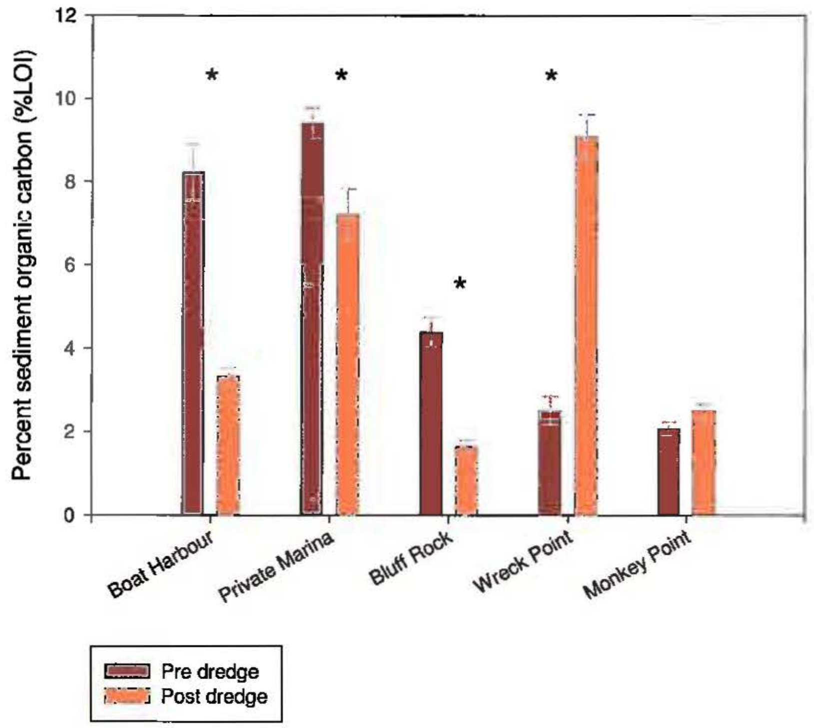

Figure 8. Mean (±se) sediment carbon content at all locations during pre and post-dredge sampling. * Denotes significant differences ($P < 0.05$) among sampling times, $n = 9$.

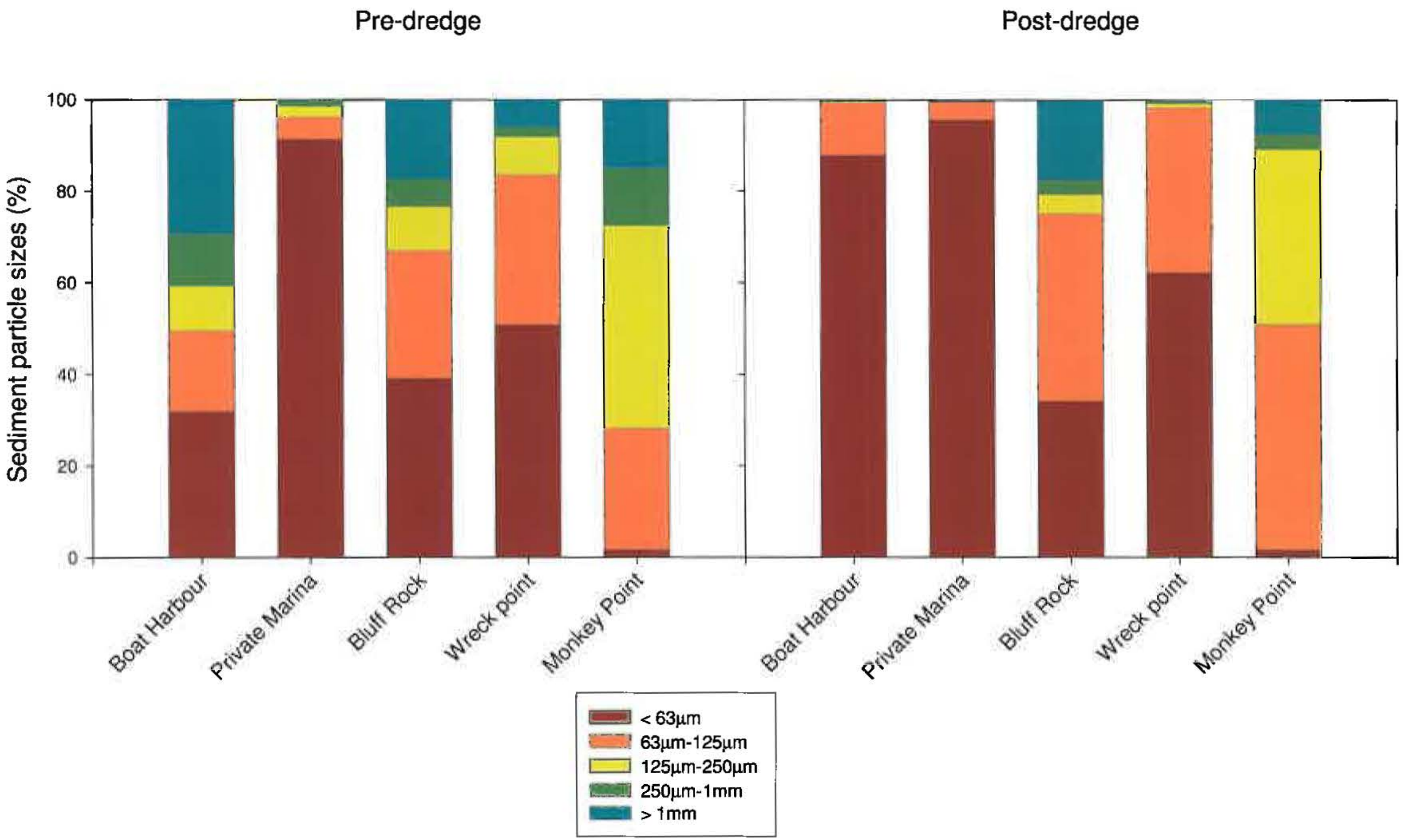

Figure 9. Sediment particle sizes at pre and post-dredge sampling periods for all locations, $n = 9$.

Elevated levels of smaller particle sizes (muds, silts and clays; Figure 9) were encountered following post-dredge sampling compared to pre-dredge sampling (Figure 9), particularly in the dredge affected and adjacent locations for Boat Harbour and Private Marina and to a lesser extent Bluff Rock and Wreck Point with no significant change in sediment composition at Monkey Point (Figure 9). This result is in contrast to a study by Kenny and Rees (1996) who found that following a dredge event, there was an increase in the proportion of course sediments, possibly due to a gravel rich unexposed layer between 0.5-0.7m below the surface. Sediment resuspension, transport and deposition due to dredging activities can alter the sediment characteristics beyond the dredge boundaries to a much wider area of up to several kilometers (Robinson *et al.* 2005). In the present study, an increase in finer sediments may have resulted from silts and clays being re-suspended due to dredging activities at Boat Harbour and Private Marina and re-settlement onto the surface layers. Increased finer sediment portions at Bluff Rock and Wreck Point may have also resulted from deposition of suspended fine sediment particles originating from the near-by dredge spoil grounds.

3.3 Metals in sediments and oyster tissues

3.3.1 Sediment metals

Pollutants can enter waterways via a number of diffusive and point sources including inputs from urban and industrial development. Sediments act as sinks for a number of toxicants including nutrients (Lohrer and Wetz 2003) and metals (van den Berg *et al.* 2001). Studies have found that marina activities such as boat maintenance, fueling activities, vessel motor operations, hull scraping, sanding and antifouling can introduce pollutants, particularly metals and Poly Aromatic Hydrocarbons (PAH's), into the overlaying water column and associated sediments (An and Kampbell 2003; Hinkey *et al.* 2005). It is therefore not surprising that concentrations of sediment metals in the Marina sites (Boat Harbour and Private Marina) were significantly ($P < 0.05$) higher than those from any other sites outside the marina. Aluminium, Co, Cr, Cu, Fe, Ni, Pb and Zn sediment concentrations were significantly ($P < 0.05$) higher at Boat Harbour and Private Marina than Bluff Rock, Wreck Point and Monkey Point during both pre and post-dredge sampling periods (Figures 10-13). Aluminium, Cr, Pb, Zn and particularly Cu concentrations were highest (3-fold; Figure 11c) in sediments at the Private Marina (Figures 10-11, 13), possibly due to point-source anthropogenic boating activities such as boat repairs and applications of metal based anti-fouling paints (An and Kampbell 2003), as a significant number of vessels were moored in the Private Marina at any one time (Pers Obs.). Elevated metal trends have also been reported in other marina studies around the world (An and Kampbell 2003; van den Berg *et al.* 2001; van den Hurk *et al.* 1997). Of the twelve metals investigated, Ni was the only metal in sediments to exceed the national sediment quality low-trigger value (ANZECC/ARMCANZ 2000) during both sampling events (Figure 12c). The national sediment quality guidelines state that metals exceeding the low trigger value have a low probability of causing biological harm (ANZECC/ARMCANZ 2000).

There were no significant changes ($P < 0.05$) in sediment metal concentrations among sampling periods at Monkey Point, however, there were significant changes and interactions ($P < 0.05$; interaction $P < 0.05$) among sites and sampling dates for all other locations. In general, metal concentrations were significantly lower ($P < 0.05$) in the dredge affected areas following post-dredge sampling, particularly for Cd, Co, Cr and Pb (Figures 10c, 11a, b & 13a). Conversely, As levels were significantly elevated at Bluff Rock during post-dredge sampling (Figure 10b). Studies have shown that dredge related disturbances can reduce the amount metals in sediments (van den Berg *et al.* 2001). Arsenic is a metalloid appearing mostly as an oxy-anion in highly oxygenated environments. Arsenic speciation can be governed by a number of geochemical processes influenced by pH and oxidative/reductive states in overlaying water and sediments. Arsenic rarely occurs in its free state and is mainly precipitated and/or adsorbed with Iron, oxygen and sulphur (Jain and Ali 2000; Wang and Mulligan 2006). This may suggest why elevated As levels in sediments were encountered in the adjacent dredge areas in close proximity to the spoil dumping grounds. Most other metals are bound to the finer sediment fraction such as silts and clays and may therefore become resuspended into the water column with the potential to be re-distributed to other parts of the environment (van den Berg *et al.* 2001), hence, this may explain why lower metal concentrations were observed following the post-dredge sampling period in dredge affected and adjacent areas.

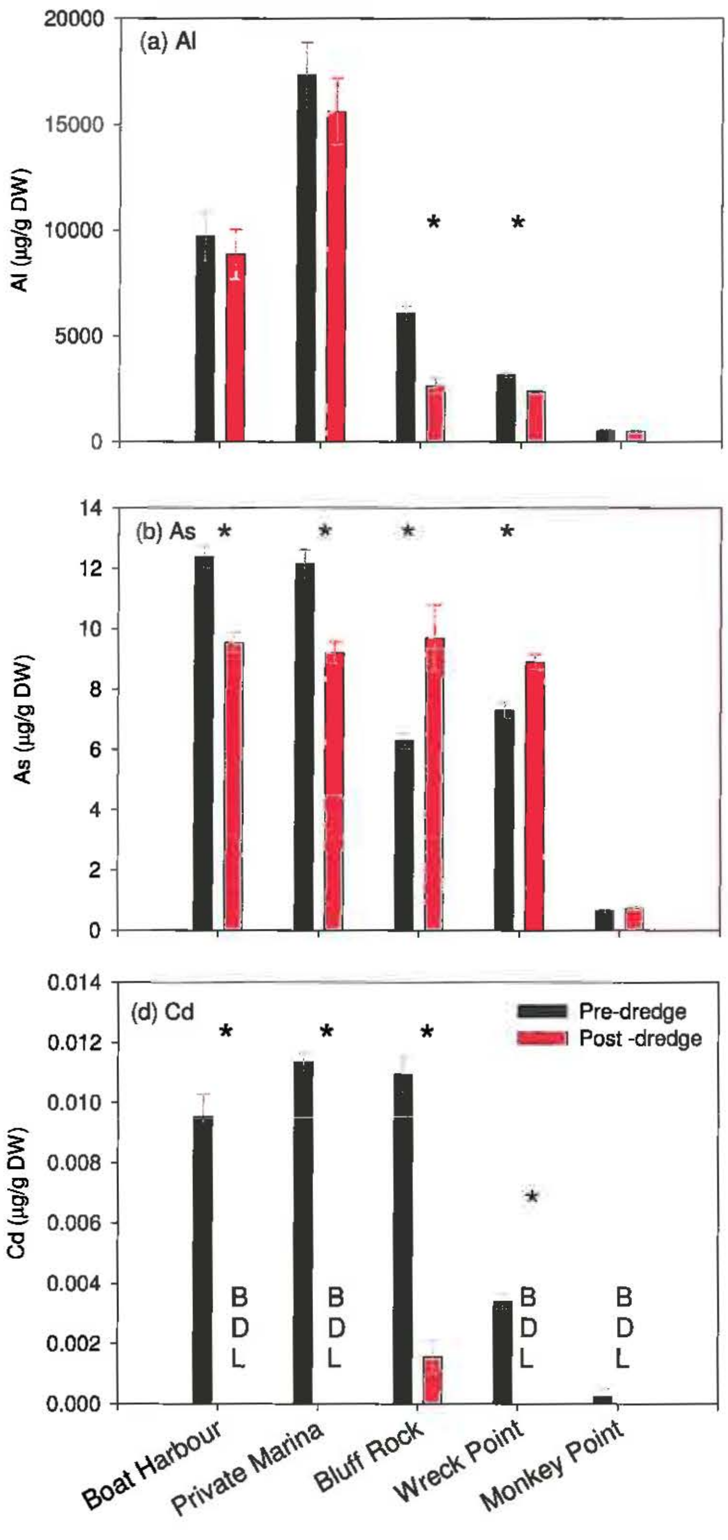

Figure 10. Mean (±se) sediment (a) aluminium, (b) arsenic and (c) cadmium concentrations during pre and post-dredge sampling periods among sites. * Denote significant differences ($P < 0.05$) in sediment metal concentrations among sampling periods. Metal concentrations are in $\mu g.g^{-1}$ dry sediment weight, $n = 9$. BDL indicates below instrument detection limit.

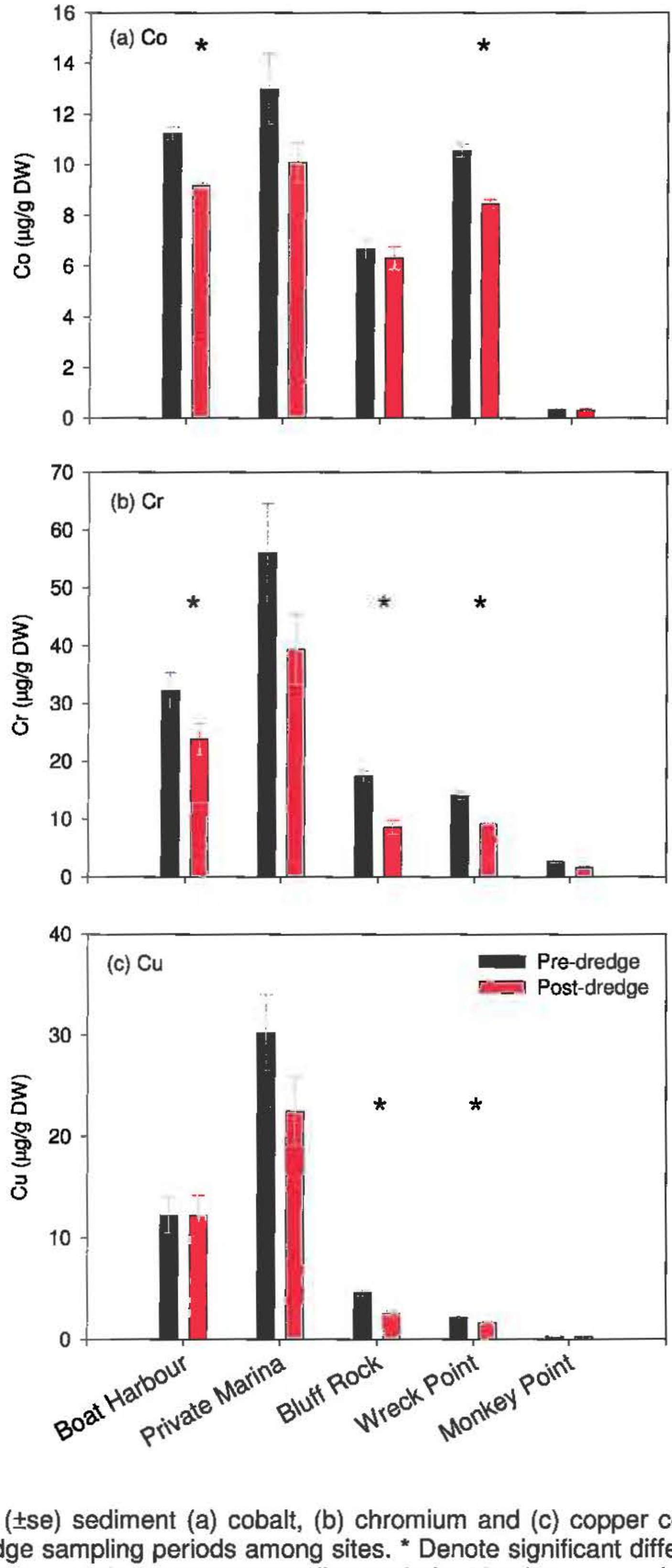

Figure 11. Mean (±se) sediment (a) cobalt, (b) chromium and (c) copper concentrations during pre and post-dredge sampling periods among sites. * Denote significant differences ($P < 0.05$) in sediment metal concentrations among sampling periods. Metal concentrations are in $\mu g.g^{-1}$ dry sediment weight, $n = 9$.

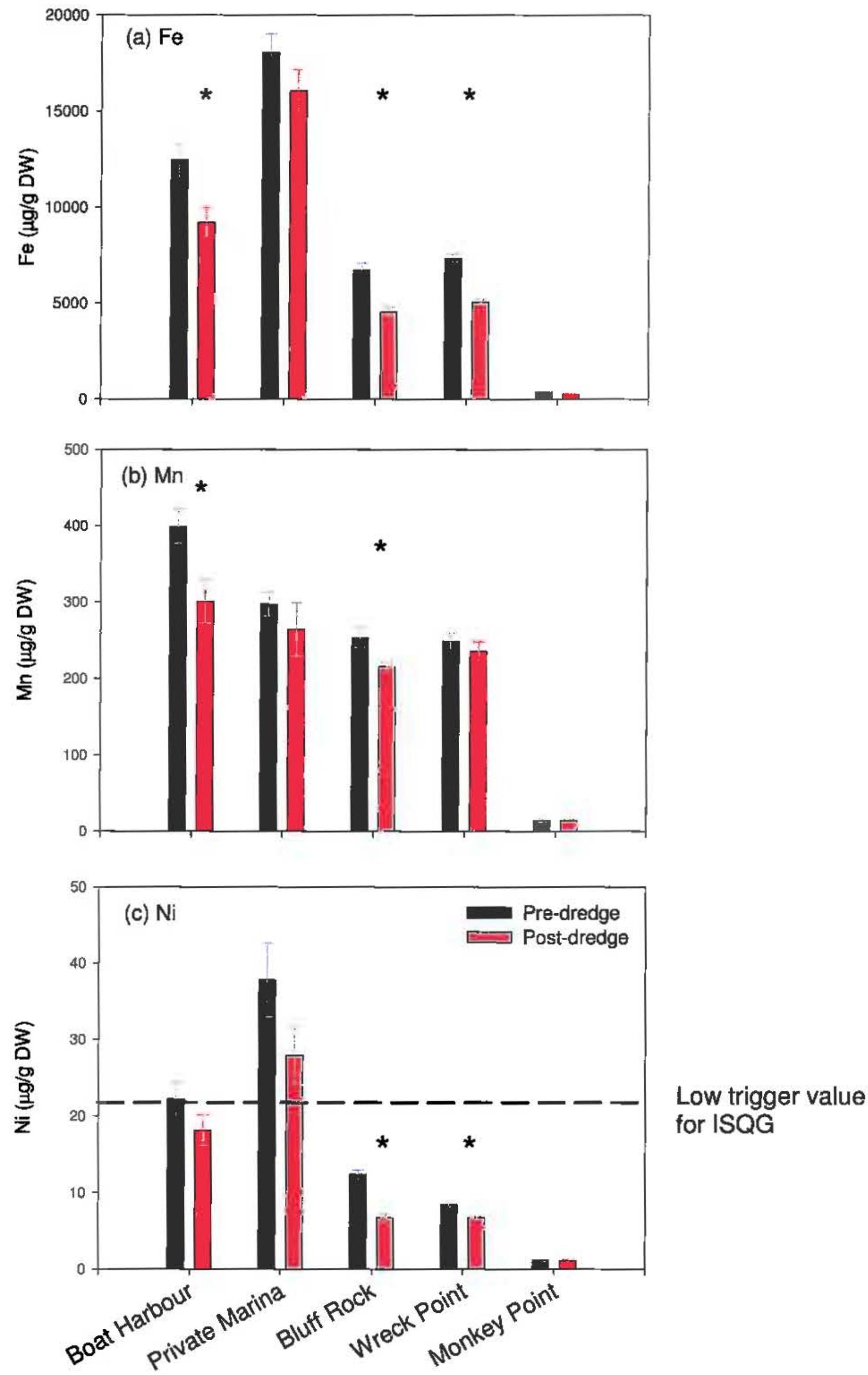

Figure 12. Mean (±se) sediment (a) iron, (b) manganese and (c) nickel concentrations during pre and post-dredge sampling periods among sites. * Denote significant differences ($P < 0.05$) in sediment metal concentrations among sampling periods, $n = 9$. Metal concentrations are in $\mu g.g^{-1}$ dry sediment weight. Dashed line indicated low trigger value for Interim Sediment Quality Guidelines (ISQG-Low; ANZECC/ARMCANZ, 2000).

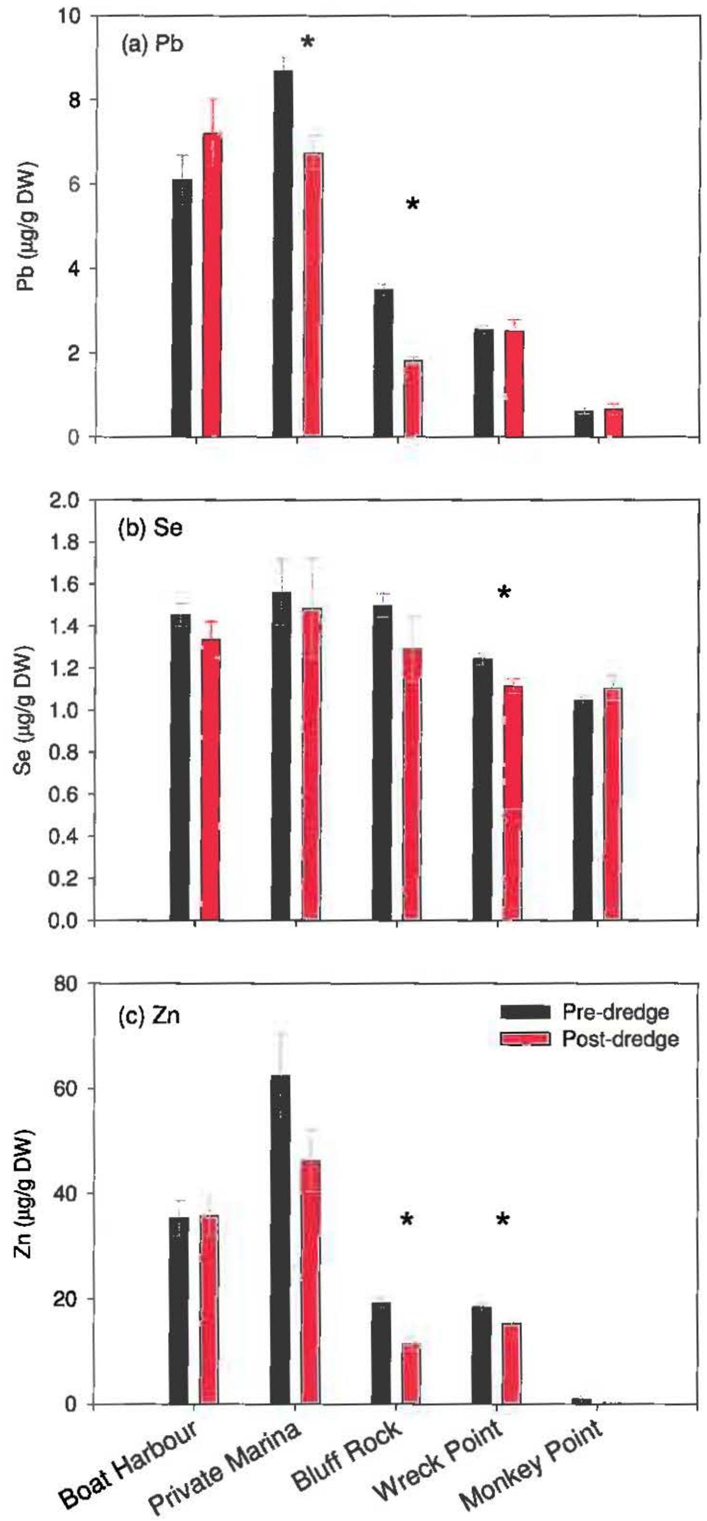

Figure 13. Mean (±se) sediment (a) lead, (b) selenium and (c) zinc concentrations during pre and post-dredge sampling periods among sites. * Denote significant differences ($P < 0.05$) in sediment metal concentrations among sampling periods. Metal concentrations are in $\mu g.g^{-1}$ dry sediment weight, $n = 9$.

3.3.2 Metals in oysters

A number of invertebrate organisms including mussels, oysters, clams, macro-algae and barnacles have been used in the past as bioindicators/biomonitors to determine tissue toxicant relationships with concentrations in the environment (Ke and Wang 2001; Melville and Pulkownik; Olivier *et al.* 2002; Rainbow 2002). In the present study, oysters were used to determine if elevated tissue metal concentrations were attributed to an increase in particulate and/or dissolved metals stemming from dredge related activities. Oysters are filter feeding organisms that take up contaminants via both dissolved (water) and particulate (food) phases and contain one of the highest metal bioaccumulation rates compared to other bivalve species (Ke and Wang 2001). The main oyster species encountered in the present investigation included *Saccostrea glomerata* (Monkey Point), *Crassostrea echinata* (Boat Harbour), *Cecostina glomeri* (Bluff Rock) and *Crassostrea gigas* (Wreck Point). Although there were different species encountered at different locations, the same species were directly compared with each other among sampling times, since different species can accumulate/depurate toxicants at different rates (Alquezar *et al.* 2007; Geffard *et al.* 2002).

Elevated concentrations of Al, Cd and Pb were present in oyster tissue from Boat Harbour (dredge-impacted site) following the dredge event (Figures 14a & c; 16c). This may have resulted from metals bound to sediments being resuspended due to dredging in the area. Although a significant ($P < 0.05$) reduction in Al, As, Cd, Co, Cr, Ni and Se concentrations in oyster tissues from Wreck Point and Monkey Point (reference/adjacent locations) were observed following post-dredge sampling, there were no significant changes in As, Co, Cu, Fe, Ni, Se or Zn oyster tissue concentrations at Boat Harbour and to a lower extent Bluff Rock between sampling times (Figures 14-17).

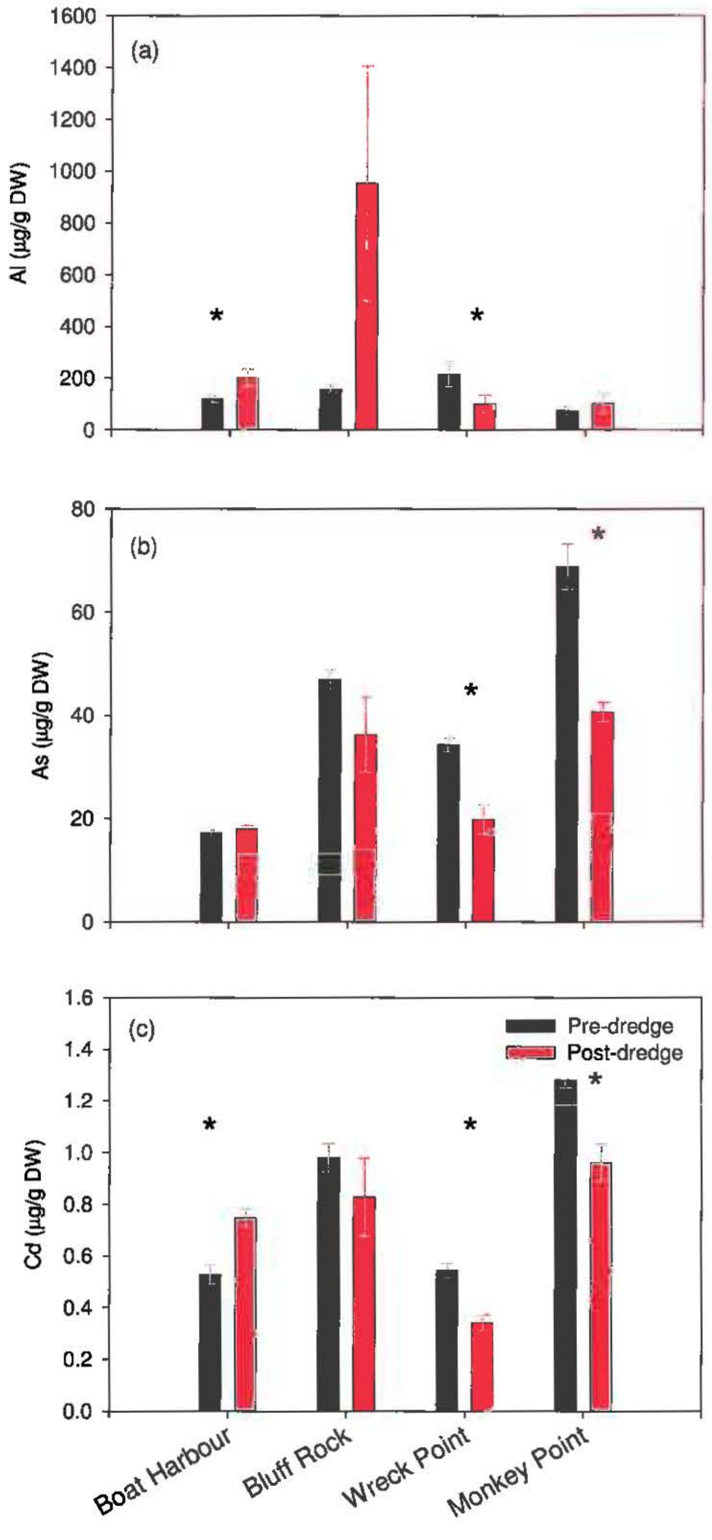

Figure 14. Mean (±se) (a) aluminium, (b) arsenic and (c) cadmium concentrations in oyster tissues during pre and post-dredge sampling periods among sites. * Denote significant differences (P < 0.05) among sampling periods. Metal concentrations are in $\mu g.g^{-1}$ dry tissue weight, $n = 9$.

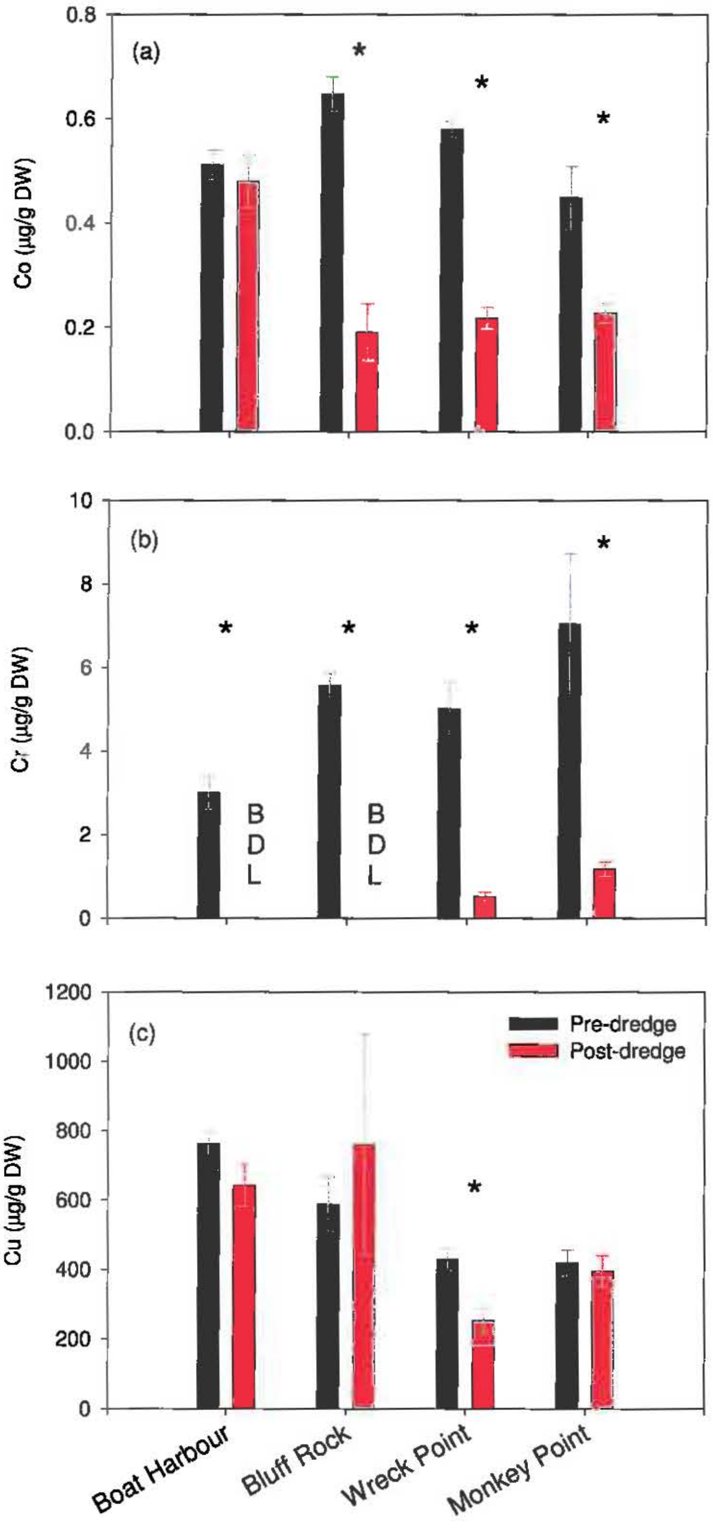

Figure 15. Mean (±se) (a) cobalt, (b) chromium and (c) copper concentrations in oyster tissues during pre and post-dredge sampling periods among sites. * Denote significant differences ($P < 0.05$) among sampling periods. Metal concentrations are in $\mu g.g^{-1}$ dry tissue weight, n = 9. BDL indicated below instrument detection limit.

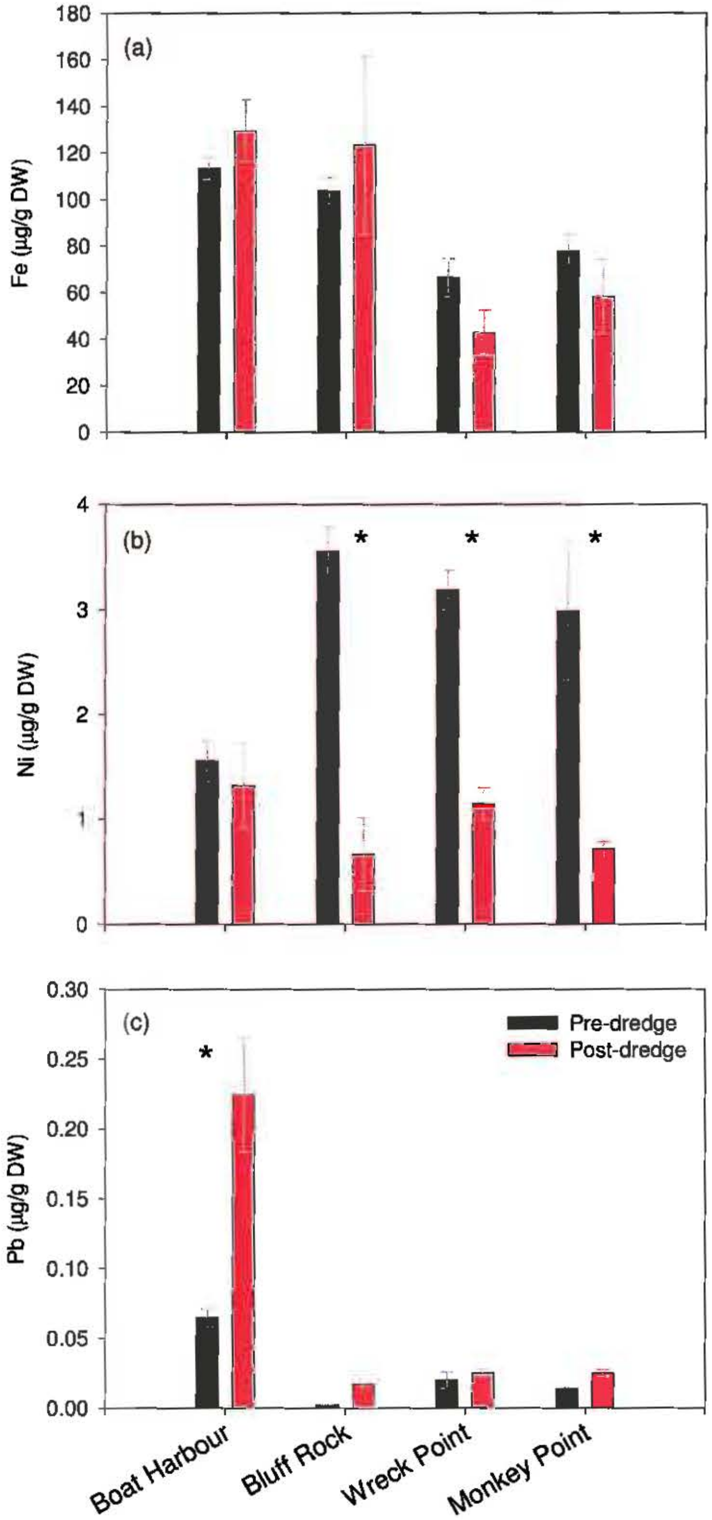

Figure 16. Mean (±se) (a) iron, (b) nickel and (c) lead concentrations in oyster tissues during pre and post-dredge sampling periods among sites. * Denote significant differences ($P < 0.05$) among sampling periods. Metal concentrations are in $\mu g.g^{-1}$ dry tissue weight, $n = 9$.

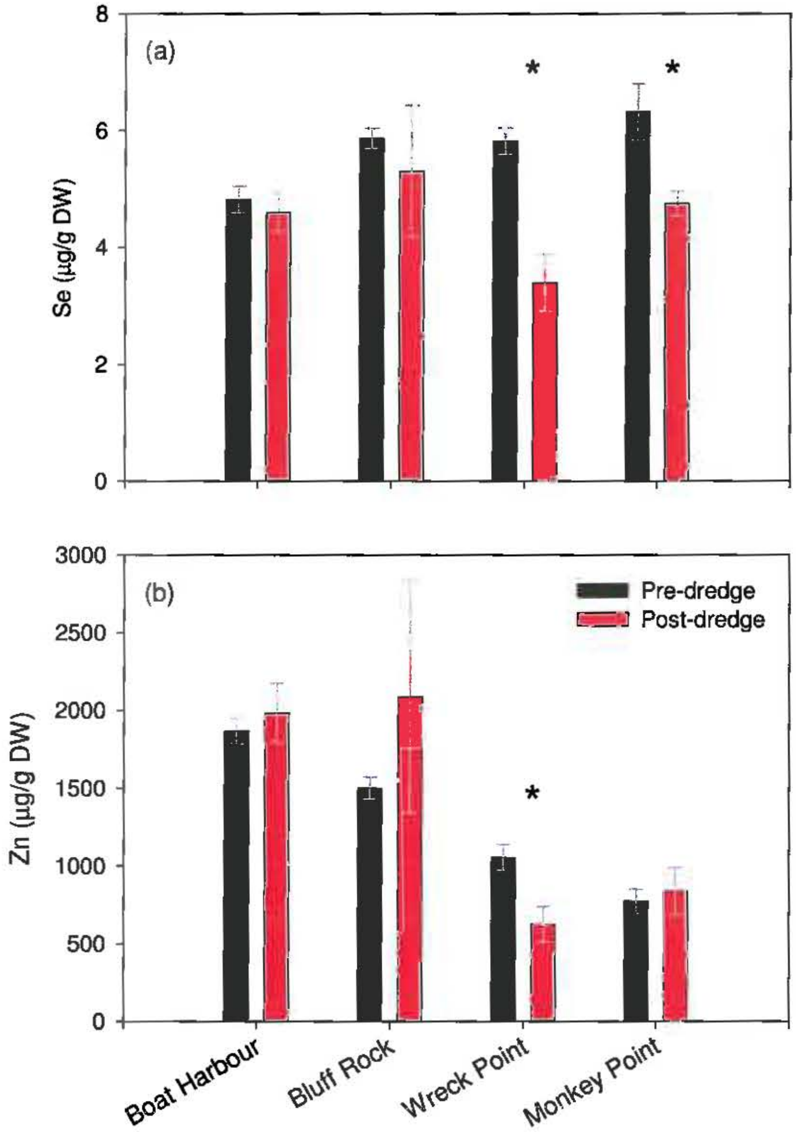

Figure 17. Mean (±se) (a) selenium and (b) zinc concentrations in oyster tissues during pre and post-dredge sampling periods among sites. * Denote significant differences ($P < 0.05$) among sampling periods. Metal concentrations are in $\mu g.g^{-1}$ dry tissue weight, $n = 9$.

Biokinetic studies have shown that both uptake and loss rates in oysters are significantly rapid, with half-lives as rapid as 80-200 days (Geffard *et al.* 2002; Ke and Wang 2001). This may suggest why tissue metal concentrations in oysters residing in the dredge affected areas have elevated or stayed constant, while oysters from reference and adjacent areas showed reduced metal levels following post-dredge sampling, possibly due to naturally occurring lower metals levels in the environment.

3.3 Macroinvertebrate assemblages

A total of 1299 organisms from 134 taxa were collected in van-Veen grab samples during the pre and post-dredge sampling periods. The most common phyla were composed of crustaceans 50%; polychaete 34%; and molluscs 11%, for both sampling periods. See appendix I-III for photographs of the most common organisms encountered at different locations.

Results showed a decrease in macroinvertebrate biodiversity (abundance, species richness and diversity) at the impacted sites and adjacent to impacted sites after the post-dredge event, however, there were no significant changes at the reference location, Monkey Point, between pre or post-dredge sampling periods (Figure 18a, b & c). These results suggest that macrobenthic biodiversity was affected by the Rosslyn Bay dredging as opposed to natural seasonal disturbances. Macrobenthic assemblages were similar in composition at Monkey Point and Bluff Rock but dissimilar at Wreck Point and to a greater extent Boat Harbour and Private Marina between pre and post-dredge sampling periods (Figure 19). These results are consistent with other dredge related studies, with dredging activities being commonly associated with a reduction of macrobenthic biodiversity of up to 70% (Kenny and Rees 1996; Robinson *et al.* 2005; Skilleter *et al.* 2006; Smith and Rule 2001). A study by Skilleter *et al.* (2006) showed a decrease in polychaete densities following a dredge related event in the Noosa River, Southern Queensland. Kenny and Rees (1996) also reported changes in macrobenthic assemblages directly related to dredge related impacts in North Norfolk, United Kingdom. Conversely, not all dredge activities have impacts, a study by Smith and Rule (2001) reported no significant effects of dredge related activities in the Solitary Islands Marine Park, NSW, to shallow soft-sediment related macrobenthic communities, possibly due to dredge material being similar in physical and chemical attributes, minimal contaminant levels and/or the associated biota being able to adapt to extreme changes to their local environment. The taxa most commonly associated with assemblage dissimilarity among pre and post-dredge sampling periods included *Tanaidacea sp.* (9%), *Cerapus sp.* (8%) and *Amphipoda sp.* (6%); and most common polychaetes included *Spionidae sp.* and *Litocorsa sp.* (4% ea). Interestingly, the tube-dwelling polychaete, *Spionidae sp.*, was the most abundant polychaete during pre-dredge sampling at Boat Harbour and Private Marina, however, was not found during post-dredge sampling. Spionid worms are deposit feeders that live in burrows made from fragile mucoid secretions in soft sediment/muddy environments (Day 1967). Dredging activities may have destroyed their fragile burrows and thus affected the local spionid worm population at the Rosslyn Bay Marina.

Species evenness, which is a diversity measure of how evenly the numbers of individuals are spread among the various taxa, increased significantly ($P < 0.05$) after the dredge event at Boat Harbour, Private Marina, Wreck Point and Bluff Rock, however, there was no significant ($P > 0.05$) change in macrobenthic species evenness at Monkey Point during pre or post-dredge sampling times (Figure 18d). Low species evenness is indicative of when some species are represented by many individuals and other species are represented by very few species. In the present study, diversity was composed of some taxa with a large number of individuals comprising the majority of the total abundance; however, other species were represented by only a few individuals during the pre-dredge sampling period, hence, low species evenness. However, post dredging, species evenness increased in the dredge affected areas, which suggests one of two things: (1) The rare species, encountered during pre-dredge sampling may have disappeared and an even number of resilient taxa were encountered following the dredge event (Figure 18b; Private Marina & Boat Harbour) or (2) the disturbance (dredge event) may have benefited the rare species and thus promoted increased abundance and evenness through adult and/or juvenile recruitment, settlement and/or migration (Bolam *et al.* 2004). An example of macroinvertebrate colonization was reported by Dean (1978) who found that nereid polychaetes actively migrate in the water column in search of further niches.

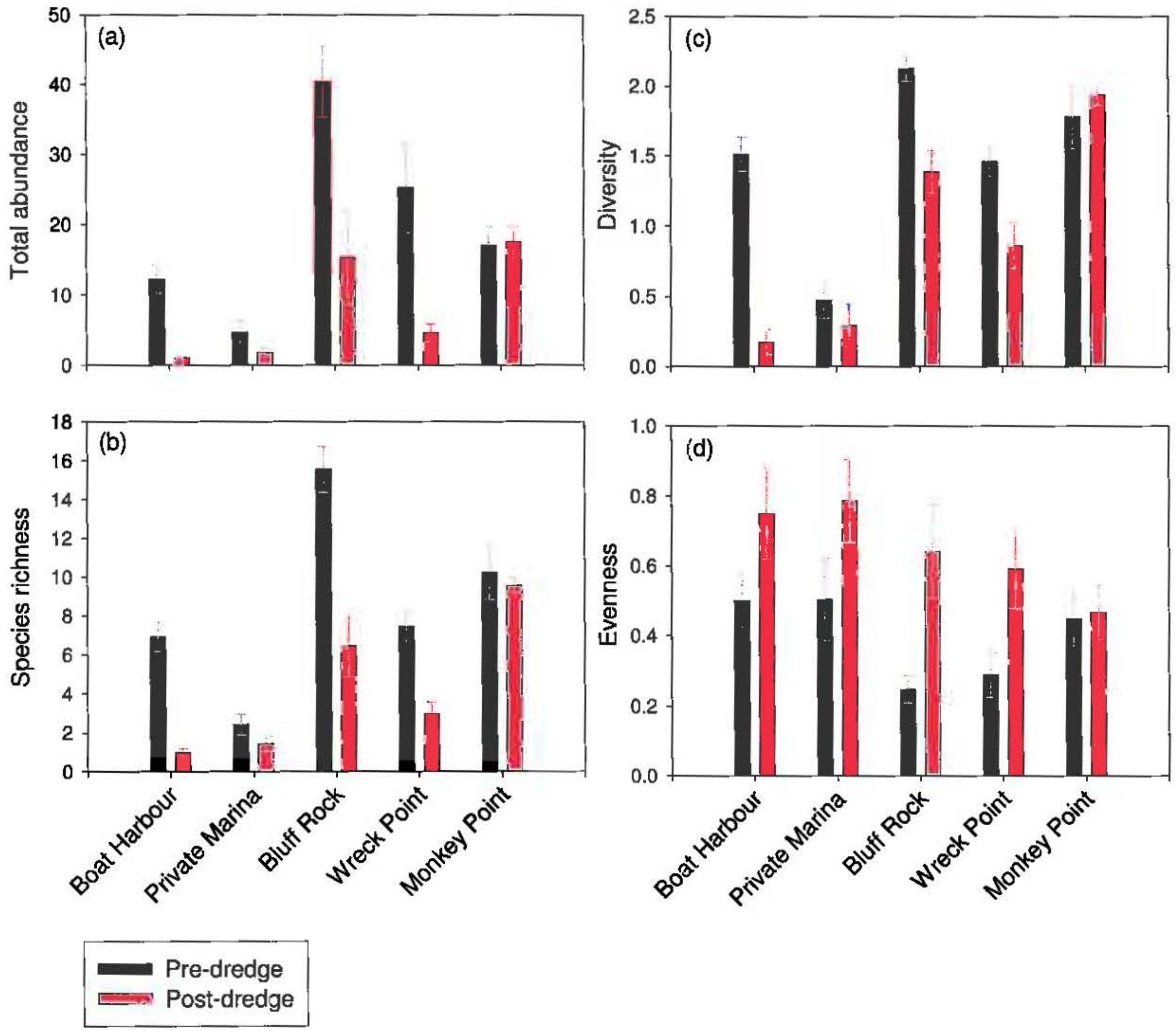

Figure 18. Mean (±se) (a) total abundance, (b) species richness, (c) diversity and (d) species evenness among sampling locations during pre and post-dredge sampling periods, *n* = 9.

BIO-ENV analysis showed that the main abiotic variables that best described the species assemblages during pre-dredge sampling were Cr, Co, Fe and Zn levels in sediments (Table 2). Following post-dredge sampling, the abiotic variables that best described macrobenthic species assemblages were sediment organic content, and particles sizes, mainly gravel and sand (Table 2). Interestingly, macrobenthic community structure were associated with chemical stressors (metals in sediments) during pre-dredge sampling, however following the post-dredge sampling, community assemblages were correlated to physical variables such as particle size and organic content. Although the analysis is purely correlative and not causative, further manipulative experiments are needed to determine the causal links. One such study by Bolam *et al.* (2004) using manipulative experiments, demonstrated that sediment organic content significantly affected intertidal macrobenthic community assemblages. Although the actual mechanisms were not identified, they reported that sediment treatments with higher organic matter had reduced redox potential profiles. Increasing organic matter promotes hetrotrophic bacteria, which may significantly increase oxygen demand in sediments, and thus, affect food availability for macrobenthic organisms (Bolam *et al.* 2004).

Changes in macrobenthic assemblages have also been associated to changes in sediment grain sizes (Skilleter *et al.* 2006), and increased toxicity from contaminants being remobilised back into the water column (Lohrer and Wetz 2003; van den Berg *et al.* 2001). A significant ($P < 0.05$) change in sediment characteristics was reported in the present study, with an increase in soft sediment clays and silts (< 63μm fraction) deposited in the dredge affected areas (Private Marina and Boat Harbour and to a lesser extent, Bluff Rock and Wreck Point), during post-dredge sampling (Figure 9). However, sediment particle size composition was similar among pre and post-dredge sampling periods at Monkey Point (Figure 9). Other studies have shown similar results, where sediment grain sizes have significantly contributed to altered macrobenthic community assemblages (Bolam *et al.* 2004; Munari *et al.* 2003).

Benthic succession following a significant environmental disturbance, such as a dredging event, can have an effect on macrobenthic recolonisation (Long *et al.* 1996; Skilleter *et al.* 2006). A review by Bolam and Rees (2003) reported that macrobenthic invertebrate community assemblage in systems that were periodically (frequently) exposed to disturbances recovered at a faster rate (up to 9 months) than invertebrate communities that resided in relatively unstressed marine environments (between 1-4 years). In ecological succession, organisms fall under two distinct categories. There are r-selected organisms or r-strategists with characteristics of high fecundity and being able to reproduce rapidly, small body sizes, short generation times and the ability to disperse offspring widely. K-selected organisms are organisms that dominate in stable or predictable environments, have larger bodies, longer life spans and produce fewer offspring (Haybach *et al.* 2004; MacArthur and Wilson 1967; Pianka 1970). In environments with a high frequency and/or intensity of disturbances, r-strategists usually dominate due to their opportunistic behavior and ability to reproduce at faster rates, however, as time succeeds, r-selected organisms are gradually replaced with K-selected organisms, which are better suited to competition and limited resources (Haybach *et al.* 2004; Pianka 1970). In the case of Rosslyn Bay dredging, knowing what the rates or macrobenthic recovery and strategies that organisms utilise, may shed some light into predicting future dredge related impacts on local flora and faunal communities.

It is therefore suggested that a one-year follow up study be commissioned to determine macrobenthic community re-colonisation rates in the dredge affected and adjacent/reference areas.

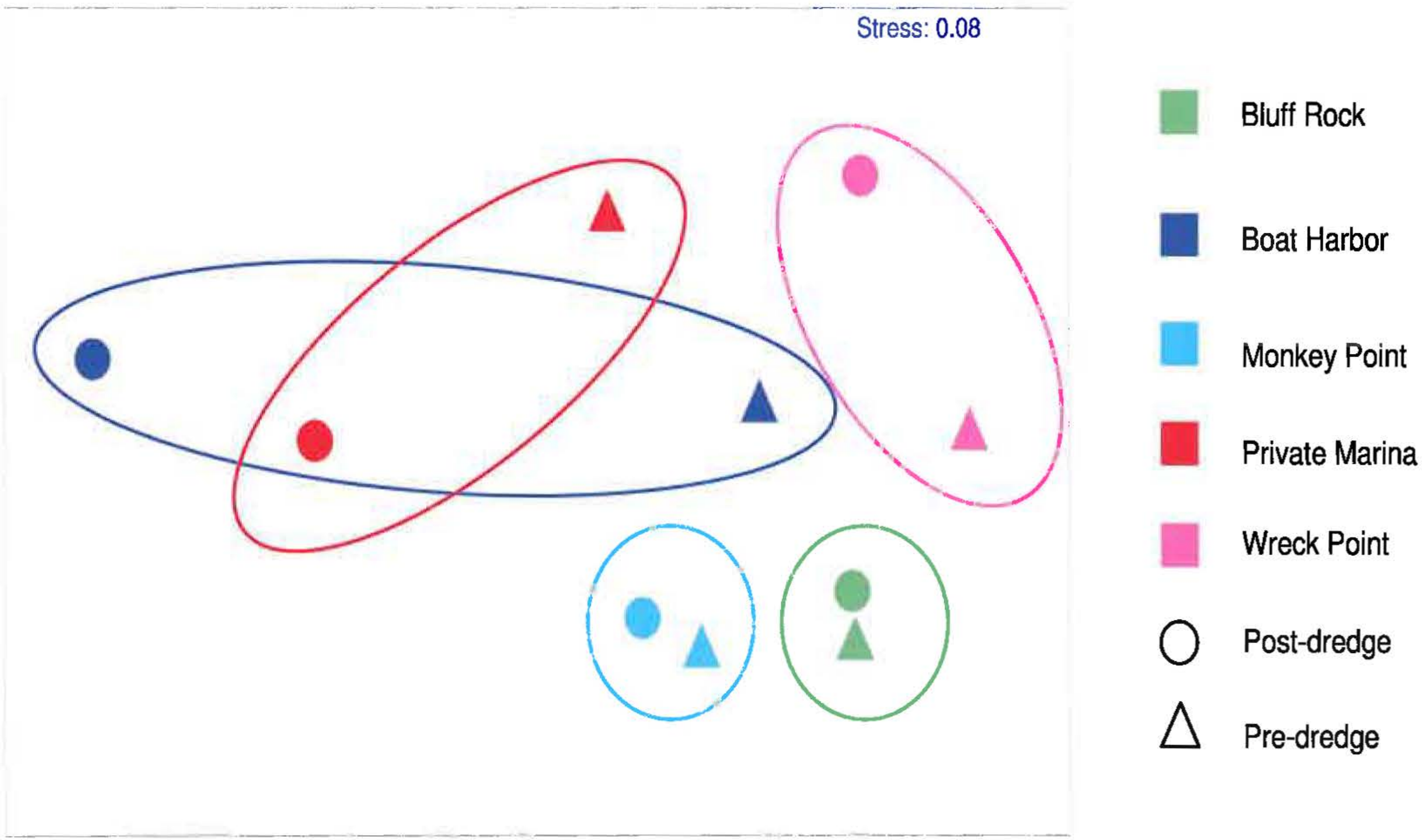

Figure 19. Ordination plots (*n*-MDS) of mean macrobenthic assemblages using Bray-Curtis similarity at different locations during pre (triangles) and post (circles) dredge sampling events. Data were standardised; no data transformations were made.

Table 2. Correlation coefficients from BIO-ENV analysis for comparisons among macrobenthic assemblages and environmental parameters (particle size analyses, sediment carbon content (CC) and metals in sediments) during pre and post-dredge sampling periods.

Single variable Pre-dredge	R	Best combination Pre-dredge	R	Single variable Post-dredge	R	Best combination Post-dredge	R
Mn	0.287	Cr, Fe, Zn	0.309	Gravel	0.374	Gravel, Cd	0.374
Cd	0.286	Co, Cr, Fe, Zn	0.309	CC	0.270	CC, Ca, Cd	0.349
Fe	0.271	Cr, Fe	0.305	Sand	0.267	CC, Ca	0.348
Pb	0.255	Co, Cr, Fe	0.305	Al	0.232	CC, Ca, Pb	0.346
Cu	0.253	Ca, Co, Cr, Fe, Zn	0.303	Pb	0.166	CC, Ca, Cd, Pb	0.346

3.4 Coral and other substrate assessment

Studies have shown that levels of impacts on receiving environments from dredge related activities depend on a number of factors, including the type/makeup of sediment deposited, the levels of contaminants such as nutrient and metal levels in the spoils, the depth at which the sediments are being deposited and the level of resistance/stress the receiving environment can tolerate (Lohrer and Wetz 2003; Long *et al.* 1996; Miller *et al.* 2002; Smith and Rule 2001). There were no significant ($P > 0.05$) changes in coral cover, density or condition at Monkey Point before or after the dredging of the Rosslyn Bay Marina (Figure 20), which signifies that dredge spoils/activity had no significant effects on the adjacent coral reefs. This may have been attributed to the relatively long distance between dredge-activity, spoil grounds and the reef as sediment processes, frequencies and rates of dispersal may have been too distant for any impact to have occurred (Miller *et al.* 2002; van den Berg *et al.* 2001).

Transects along Monkey Point were predominately dominated by hard corals (Figure 20), with the main species being the branching coral *Acropora formosa*, up to 70%, and *A. digitifera* followed by pavement (dead coral with algae) (Figure 4 & 22). The dominant substrates encountered at Bluff Rock were sand and pavement followed by the hard coral *Pavona cactus* (Figure 21 & 23). Macroalgae and gorgonians were also common at Bluff Rock (Figure 21). Water quality, turbidity, temperature, wave action, depth as well as other stressors such as nutrients and contaminants can shape the way coral reefs are formed as well as influence what dominant coral species and morphs would occur (DeVantier *et al.* 1998; Done 1982; Fabricius and De'ath 2004; Veron 2000). *P. cactus* commonly occurs along coastal fringing reefs with low levels of wave action and moderately turbid waters (Veron 2000). This may explain why *P. cactus* predominately occurred at Bluff Rock but not at Monkey Point, since, on average, turbidity levels were significantly higher at Bluff Rock compared to Monkey Point (Figure 6f). Macroalgae and gorgonians also favour areas of elevated suspended particulate matter (Veron 2000).

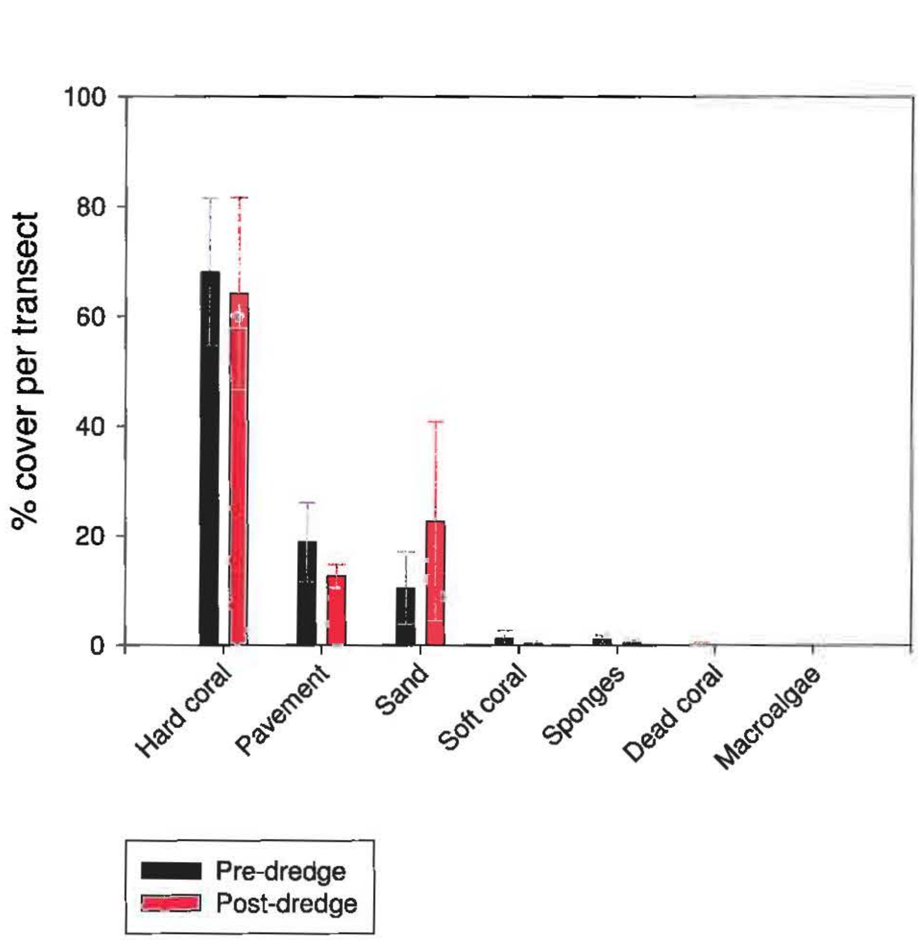

Figure 20. Percent (%) main category substrate cover at Monkey Point during pre and post-dredge sampling periods. Mean (±se), $n = 3$.

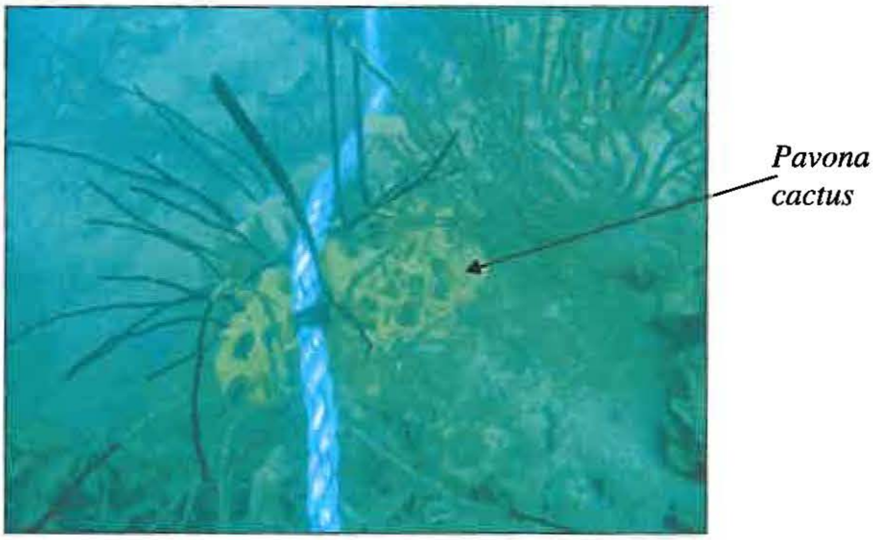

Figure 21. Image of *Pavona cactus* at Bluff Rock surrounded by sea fans and gorgonians along a transect line (Photo by Ashley Campbell).

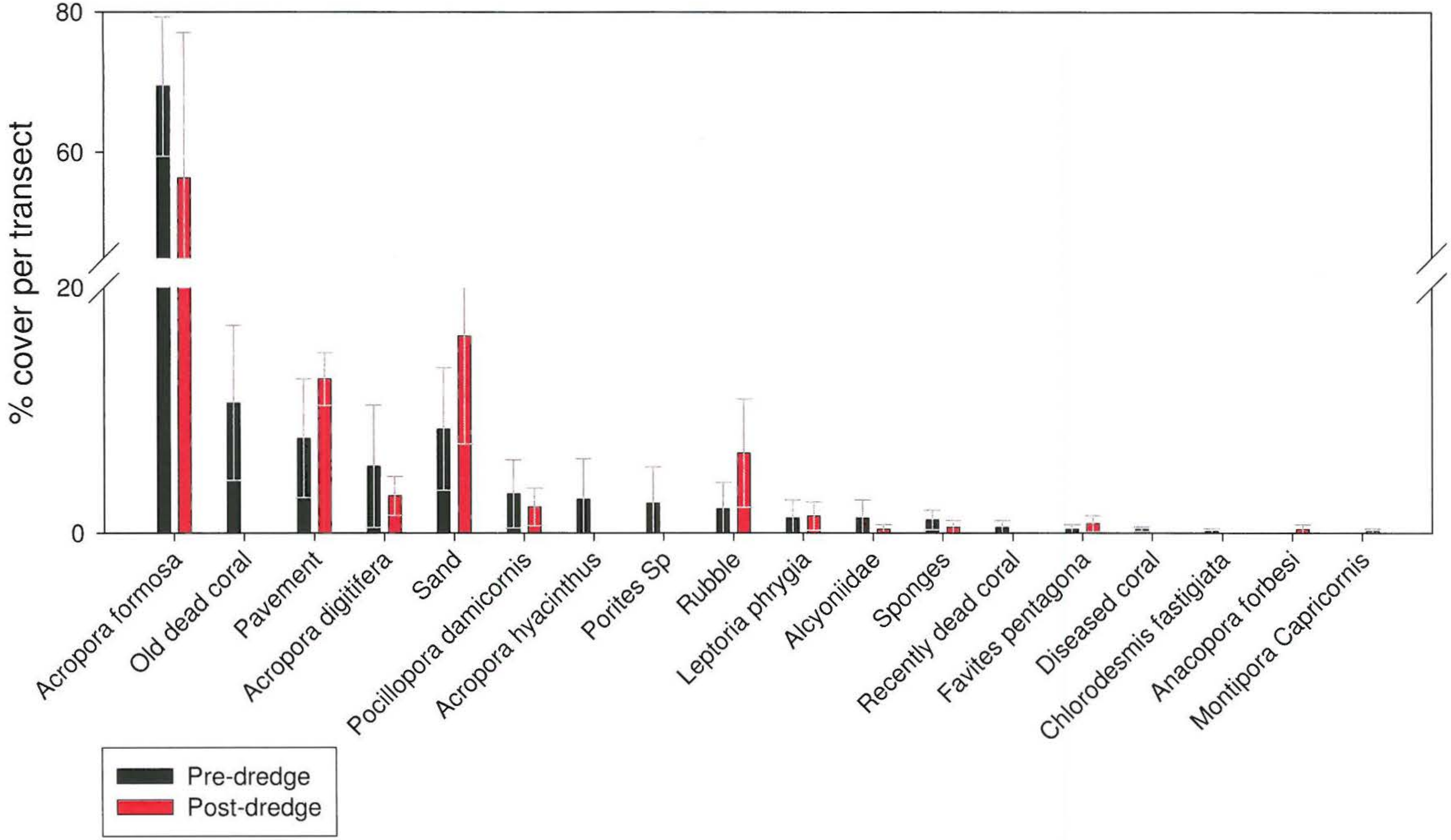

Figure 22. Percent (%) sub-category substrate cover at Monkey Point during pre and post-dredge sampling periods. Mean (±se), n = 3.

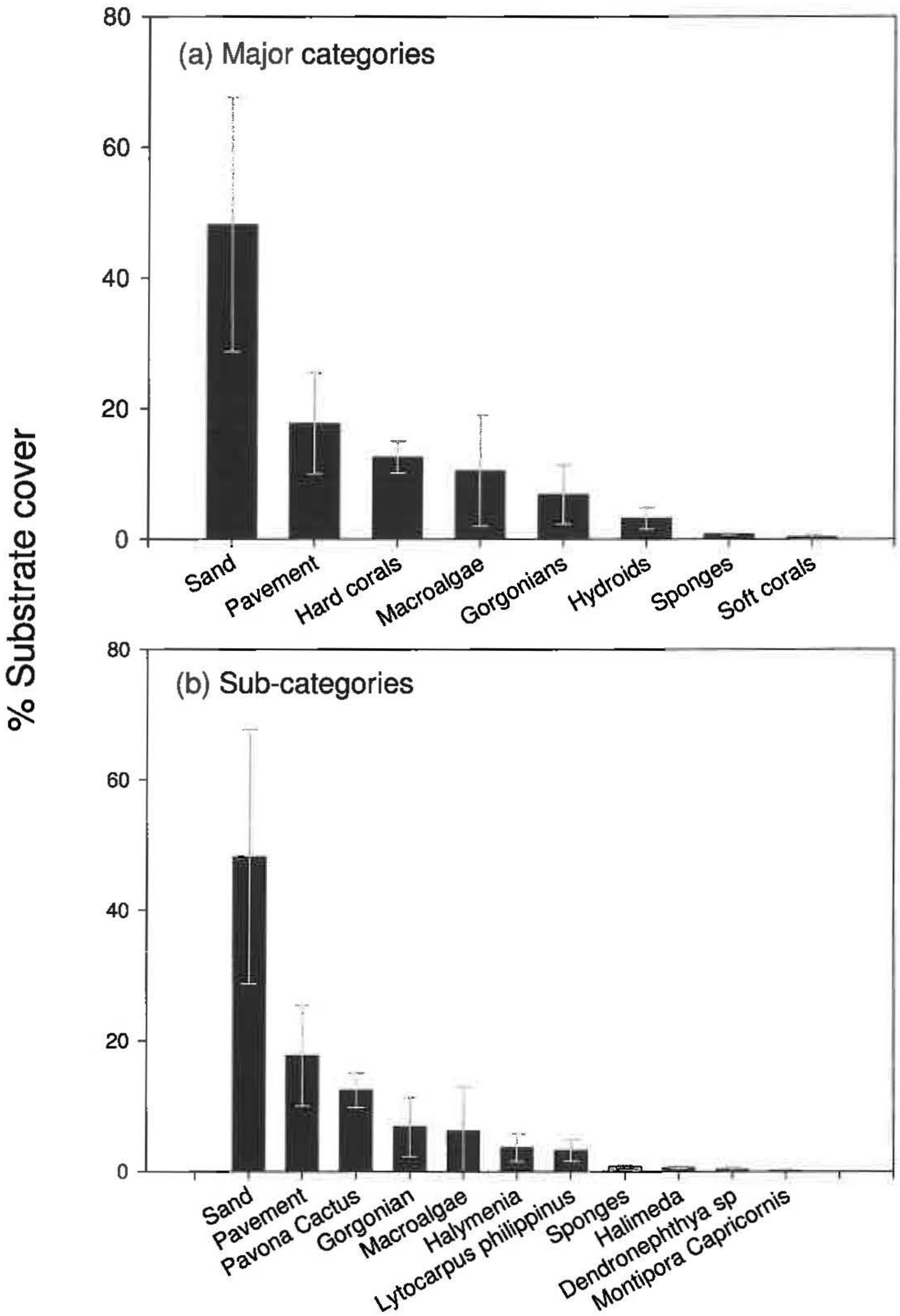

Figure 23. Percent (a) major and (b) sub-category substrate cover at Bluff Rock during the pre-dredge sampling period. Mean (±se), $n = 3$.

4.0 Conclusions and recommendations

Water quality and sediment physical and chemical parameters were significantly affected following the dredge event at the Rosslyn Bay Marina in September 2006. Furthermore, macrobenthic community assemblages were affected at dredge and adjacent dredge locations, however, there were no significant changes in macrobenthic assemblages at the reference location, suggesting that the dredge event was most likely the cause of a shift in biodiversity and not natural or seasonal disturbance. Sediment metal levels were significantly lower following post-dredge sampling, possibly due to metal resuspension into the water column and transportation to adjacent spoil grounds, however, metals in resident oyster tissues from dredge affected areas showed elevated levels for particular metals following post-dredge sampling, possibly due to resuspended, particulate and/or dissolved metals originating from sediments being ingested by the oysters.

The general paradigm on benthic organism recovery following a significant disturbance is a complex one. The consensus on macrobenthic recovery following a disturbance is that communities tend to recover at a much faster rate in environments that are periodically exposed to constant disturbances or reside in high energy environments. These environments include shallow coastal systems inhabited by opportunistic organisms that are relatively mobile surface scavengers. Recovery rates following a disturbance in more stable environments such as deeper estuaries and coastal systems are usually significantly longer, as species richness is greater with deeper burrowing organisms with high levels or bioturbation.

It is therefore suggested that a follow-up investigation be commissioned to improve our understanding on how a disturbance such as a dredge event affects the ecosystem and determine the driving mechanisms of recovery for future management practices. It is recommended that a similar investigation be undertaken one year after the dredge event at Rosslyn Bay to determine if (a) (i) water quality, and (ii) sediment physico chemical parameters are restored to pre-dredge conditions, (b) macrobenthic community assemblages have recolonised to a similar pre-dredge community level, and (c) levels of metals in sediments and oysters have changed since the dredge events at all locations.

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Appendix I

Crustaceans

Amphipoda sp. 42

Haplostylus cf queenslandensis

Tanaidacae sp. 2

Cerapus sp. 2

Platyischnopidae Platyischnopus

Urohaustarius halei


Alpheus pacifica


Amphipoda sp. 44


Cyclaspis sp. 1


Mysidiacea sp. 1


Caprellidae sp. 2


Eurydice minya


Copepoda sp. 2


Corophiidae sp. 4


Corophiidae sp. 5


Cerapus sp. 2


Diogenes guttatus


Dulichella appendiculata


Leucothoe sp. 1


Waldeckia sp. 1


Megalopa sp. 1


Maera sp. 1

Halicreions sp. 1

Ogyrides delli

Ostracoda sp. 2

Paranthurida sp. 1

Leptochela sydniensis

Birubius wallisae

Tanaidacae sp. 11

Appendix II

Polychaetes


Isolda pulchella


Amphinomidae sp. 4


Scyphoproctus sp.


Cirratulidae sp. 2

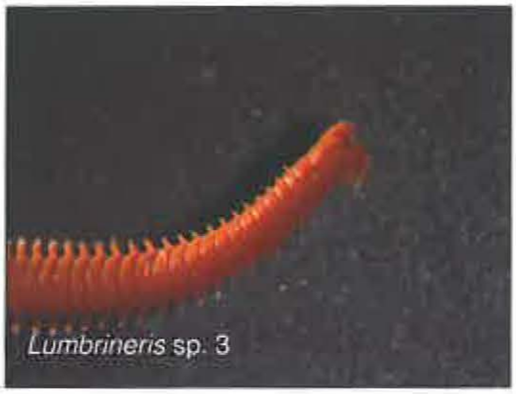

Eunice vittata


Marphysa bifurcata


Flabelligeridae sp. 4


Glycera sp. 1


Lumbrineris sp. 2


Lumbrineris sp. 3


Lumbrineris sp. 4


Maldanidae sp. 1


Nephtys sp. 1


Australonereis sp. 1


Orseis sp. 1


Diopatra dentata

Nothria sp. 1

Onuphis eremita

Orbiniidae sp

Haploscolopos sp. 1

Paraonidae sp. 6

Pectinaria papillosa

Phyllodocidae sp. 9

Poecilochaetus sp.1


Polynoidae sp. 4


Sabellidae sp. 8


Leanira sp. 1


Spionidae sp. 9


Syllidae sp. 9


Pista typha


Streblosoma sp. 1


Trichobranchidae sp. 1

Appendix III

Bivalves


Tellina sp. 7


Bivalvia sp. 79


Cuspidaridae sp. 1


Bivalvia sp. 42


Corbula tunicata


Anodontia omissa


Anodontia sp. 1


Mactra sp. 2


Mactra sp. 1


Paphies cf. *elongata*


Nuclana (scaededa) crassa


Nuculana novaeguiensis


Gari anomula


Azorinus sp. 2


Pharella wardi


Strigilla sp. 1


Tellina serricostata


Tellina sp. 3


Veneridae sp. 3


Antigona lamellaris


Paphia exarata


Placamen tiara

Appendix IV

Gastropods

Appendix V

Miscellaneous