RiverScience: Cooks River Ecological Monitoring Program 2011

Prepared by Australian Museum Business Services for Canterbury, Marrickville and Rockdale Councils on behalf of the Cooks River Alliance

Final Report

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Executive Summary

The Cooks River is a highly impacted river system in south-western Sydney with poor water quality. The ecological health of the river has been monitored since 2005-06 according to the RiverScience protocol. RiverScience is a science-based monitoring program that tracks changes in several ecological indicators at key sites throughout the estuarine sections of the Cooks River.

These indicators include invertebrates such as benthic infauna (e.g. worms which live in the sediment), crabs and encrusting hard surface organisms (e.g. oysters) as well as macrophytes (aquatic plants growing in or near water, such as mangroves and saltmarsh). These groups are used as they are most likely to reflect the health of the ecosystem and are measurable features that provide data on habitats, processes and inputs. Invertebrates are good indicators of ecosystem health as they often occur in high numbers, are relatively sedentary and have shown to be affected by both short-term and long-term disturbances (Bilyard, 1987). Such effects can include changes in the numbers of species, overall biomass, an increase in the numbers of opportunistic or pollution tolerant organisms and overall changes to the functional structure of the community. Macrophytes are also good indicators of ecosystem health as they respond to inputs such as nutrients, light, toxic contaminants, metals, herbicides, turbidity and water level change as well as being simple indicators of clearing and erosion. The invertebrate indicators are surveyed every year and saltmarsh and mangrove surveys every 2-3 years, including in 2011. The results of the monitoring program provide councils within the Cooks River catchment with a description of ecological assemblages and their temporal change. These findings will then be used to guide the on-going management and restoration of the system, providing a benchmark for the success of these actions to date, as well as being useful as an education tool for the local community.

In November and December 2011 Australian Museum Business Services (AMBS) undertook the sixth round of annual RiverScience monitoring. Methodology was replicated from previous surveys with all sampling and identifications, with the qualification that the sorting and identification applied to the macroinvertebrate samples appears more similar to that undertaken during the baseline survey in 2005-06 and the previous 2010 survey rather than to 2007-2009 surveys.

This report presents the results from the 2011 monitoring of the Cooks River. Crab observations and hard surface organism results were compared with those from all previous monitoring years. Benthic invertebrate data was compared with that from the 2005-06 baseline survey and 2010 survey data. Further statistical analyses were conducted on the benthic data from 2005-06, 2010 and 2011; multivariate and univariate analyses were undertaken to detect temporal changes over this time.

Crab abundance has declined at most sites compared to 2010. However, as surveys were conducted in hot, dry conditions not conducive to crab activity, this result is not necessarily indicative of the river's ecological health. The percentage cover of most hard surface colonising organisms was varied amongst sites in 2011. Oyster and barnacle numbers have maintained a significant increase over 2010 and 2011 compared to those found in 2005-06.

Benthic invertebrates have increased in both abundance (number of animals) and taxa richness (number of families) at all sites except Wolli Creek and Beaman Park. Most of these increases were seen in Polychaetes (worms). However, other classes such as Gastropods and Amphipods have also increased since 2005-06 and four new taxa (Oweniidae [Polychaete], Mactridae [Bivalve], Corophiidae [Amphipod] and Gnathiidae [Isopod]) were also recorded this year.

Combining of information from all the recent projects within Cooks River, including the analysis and mapping of sediments, is recommended, as the Cooks River has been subject to pollutants for many years, many of which (such as heavy metals) are held within the sediment of the river. The organization of all data available for the Cooks River will enable firmer conclusions to be drawn on the current health of the system and also provide a stronger baseline for which future monitoring can be compared. This would also assist in identifying reasons behind the relatively poor diversity and abundance of organisms at some sites, provide a more comprehensive understanding of river health, and assist in developing management regimes. In assessing the health of the Cooks River, levels of sediment and water contaminants can be compared with stated ANZECC guidelines, and, secondly the Cooks macrobenthic data can be compared with available data from other estuaries thought to be healthy. The monitoring program will assist in assessing any improvements.

Several other recommendations have been made to improve the immediate health of the Cooks River. These suggested actions will assist in solving recently observed pollutants on a site-specific basis and include, in the short-term: a review of the current program to evaluate the efficacy of its design; perform further statistical analyses with the benthic data from 2005-06, 2010 and 2011 by conducting a vigorous comparison with other biota in other similar estuaries; undertake identification to species level for benthic sampling in future years; fix the location quadrats for the bare space monitoring; and continue or increase measures to reduce gross pollutants in the mangrove and saltmarsh sites. In the medium term it is recommended that the ongoing coordination of monitoring continue amongst the numerous stakeholders, and expand on the current sediment study to include a map of sediment distributions and locate areas within the river that are carrying high levels of pollution (hotspots). Long-term recommendations include the naturalising of the river banks and incorporating data from other long-term projects conducted in the Cooks River.

GLOSSARY

Anthropogenic: Caused or derived by humans and their activities, either deliberately or incidentally.

Benthic: Occurring on the bottom. Organism may crawl, burrow or remain attached to the substrate.

Biological diversity: The number and variety of species in a community.

Ecosystem: An ecological system that includes all the living and non-living components within which they naturally occur.

Habitat: The place in which an organism lives, characterised by physical features or dominant plant type.

Infauna: Animals found in the sediment.

Macroinvertebrate: An invertebrate large enough to be seen without magnification.

Riparian: Of or pertaining to the bank of a river or stream.

Taxa: A grouping within the classification of organisms, such as order, family, genus, species.

Contents

1 Introduction

1.1 Project background

The RiverScience Cooks River Ecological Monitoring Program was established with the aim of monitoring the health of the Cooks River. A set of protocols were originally developed in 2005 and amended in 2007, with monitoring undertaken annually since this time. The monitoring tracks the status of ecosystem health indicators including benthic macroinvertebrates, encrusting hard surface organisms and the presence of crab species. The results of this monitoring are used to guide management directives to improve the health of the Cooks River. The program is administered on behalf of the Cooks River Alliance by representatives from Canterbury, Marrickville and Rockdale Councils.

An interpretation report was also developed in 2007 to provide councils and the broader community with a more accessible interpretation of the program and its aims (AHA Ecology 2007).

1.2 Study area

The Cooks River is located in the inner south of Sydney and runs through heavily urbanised and industrialised suburbs. It begins as a small watercourse near Graf Park in the Bankstown Local Government Area (LGA) and flows 23 km in a generally easterly direction to enter Botany Bay just south of Sydney's Kingsford Smith Airport. The Cooks River catchment is approximately 100 km^2.

Surveys were conducted within estuarine sections of the river and tributaries (including Wolli Creek, Muddy Creek and Alexandra Canal). A variety of different habitats exist within the study area; mangroves were completely removed in the past and have recently returned to many areas, including river banks where there is concrete or steel sheet piling present.

Towards the mouth of the River, there are sandy areas with coarse sediments and in the lower estuary many of the retaining walls are built of rock. Along most of its length the Cooks River is surrounded by parkland and open space, with some foreshore revegetation using native plants and very small pockets of remnant bushland. There are sections of the riverbank which have been naturalized in recent years. The major impacts include urban runoff, dumping of household and trade waste, sewage overflows, industrial discharges, removal of riparian vegetation and littering (Albani 2005; Eco Logical Australia 2010).

Figure 1 shows the Cooks River study area with the locations of sampling sites for benthic invertebrates/crabs and hard substrate photographs.

The site names are:

P1	Cooks River mouth, Kyeemagh	**BC1**	Muddy Creek, Kyeemagh
P2	Muddy Creek, Kyeemagh	**BC2**	Cahill Park, Wolli Creek
P3	Alexandra Canal	**BC3**	Kendrick Park
P4	Tempe Reserve, Marrickville	**BC4**	Waterworth Park, Wolli Creek Mangrove, Undercliffe
P5	Waterworth Park, Undercliffe	**BC6**	Turella Reserve, Undercliffe
P6	Steel Park/Bankside Ave, Undercliffe	**BC7**	Flinders Road, Beaman Park, Earlwood
P7	Beaman Park (rock outcrop)	**BC8**	Tasker Park, Canterbury
P8	Beaman Park (ironwall)	**M1**	Muddy Creek, Kyeemagh
P9	Sugarhouse Rd, Hurlstone Park	**M2**	Flinders Road, Beaman Park, Earlwood
P10	Canterbury Road Mary MacKillop Reserve	**M3**	Waterworth Park, Undercliffe (Wolli Creek)

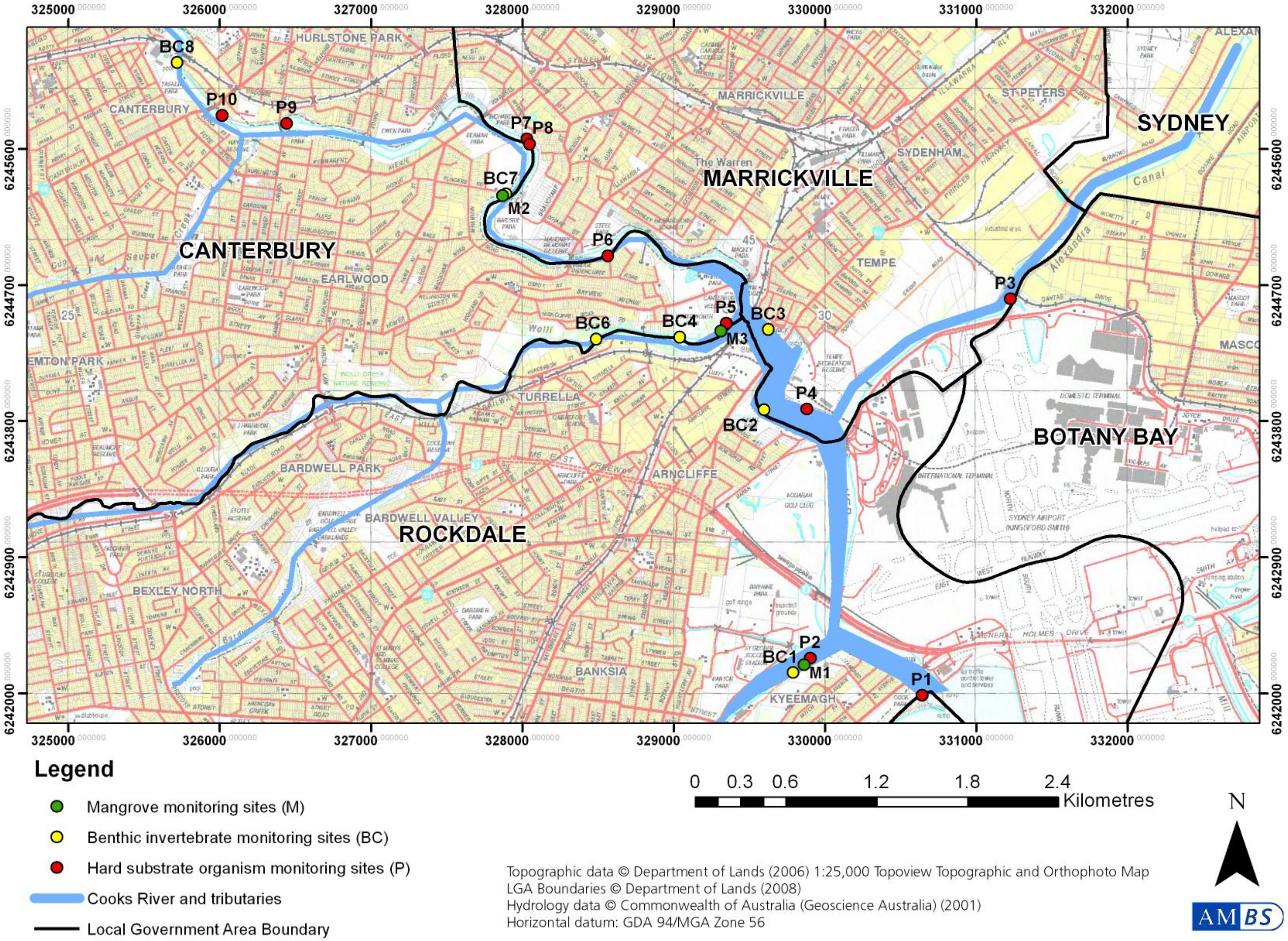

Figure 1: Cooks River study area showing location of sampling sites for benthic invertebrates/crabs and hard substrate photographs.

2 Methods

2.1 Benthic sampling, crab observations and hard substrate organisms

2.1.1 Sampling regime

Sampling was undertaken by Australian Museum Business Services (AMBS) according to the protocols detailed in CERS (2006a) *Cooks River Ecological Monitoring Program – Phase 1: Pilot Study and Monitoring Program Design*. Benthic, crab and hard substrate sampling was undertaken on 9, 10, 11 and 14 November 2011. Saltmarsh and mangrove surveys were undertaken on 16, 19 and 21 December 2011 (see Appendix 1 for dates and sites). Sampling was undertaken at the same sites as those surveyed in Rounds 2-5 (Figure 1). Differences in the location of sites between 2005-06 and 2007 are discussed in Eco Logical Australia (2007).

2.1.2 Benthic invertebrates

Seven sediment cores (10 cm diameter) were taken to 5 cm depth at each of six pre-existing sites along the Cooks River (BC1-BC4, BC7 & BC8). Collected sediment was placed in a plastic bag with a mixture of formalin and biebrich scarlet. Sampling occurred within 2 hours either side of low tide. Cores were taken at the low-water mark along a 2 m stretch of riverbank. Sediment cores were returned to the laboratory and sieved through a 1 mm mesh. Benthic macroinvertebrates were collected and preserved in 70% ethanol. Three samples were randomly chosen for sorting and identification, specimens were identified to family level and numbers tallied on excel spreadsheets. The sorting and identification of all samples were done on a microscope with a magnification range of 60 – 500x. A full listing of data was made with a breakdown according to class and family found within each core at each site. The other four core samples were transferred to ethanol and kept for sorting and identification at a later date if this is required.

The results suggest a difference in the level of sorting and identification of samples undertaken in some previous years and valid comparisons could only be made with the data from 2005-06 and 2010.

2.1.3 Crab observations

Crab abundance was determined in six 0.25 x 0.25 m quadrats at each of seven sites (all benthic monitoring sites plus site BC6). Quadrats were positioned in a semi-circle such that the top quadrats were adjacent to the highest point of the oyster zone. Quadrats were placed approximately 40-50 cm apart with a distance of ~3 m across the base of the semi-circle (Figure 2).

The number of crabs in each quadrat was observed using binoculars from a distance of approximately 10 m. Three observations were taken at 10 minute intervals. The maximum number of crabs observed in each quadrat across the 3 observation intervals was used in data analyses. At the end of the observation time the number of crab burrows in the same quadrats was counted.

All field data were compiled following the completion of surveys and are presented as means across sites. The 2011 results were compared against those from the previous years where possible (Eco Logical Australia 2009a, 2007a and 2007b, CERS 2006b).

2.1.4 Hard substrate organisms

The abundance of encrusting organisms was determined through standardised photographs of hard surfaces at ten sites along the Cooks River (P1 – P10). Hard surfaces included rock walls, mangrove roots, rock outcrops, iron walls and concrete walls. Five photographs of 0.5 x 0.5 m^2 quadrats were taken at each site (as shown in Figure 3). Quadrats were positioned such that the highest edge was along the approximate mid-point of the oyster zone. Photographs were taken along a 5 m stretch of riverbank using a digital camera with a resolution of 12 megapixels. The camera zoom was adjusted so that all sides of the quadrat were just visible. The flash was used.

Using a digital grid, the percentage cover of algae (green turfs), Sydney Rock Oysters, barnacles and bare substrate was determined.

All field data were compiled following the completion of surveys and are presented as averages across sites. The 2011 results were compared against those from the previous years where possible (Eco Logical Australia 2009a, 2007a and 2007b, CERS 2006b).

2.1.5 Statistical Analysis

Univariate analyses

To test for differences in benthic invertebrate abundance, taxa richness (family level), relative abundance and taxa richness for Polychaeta, Mollusca and Crustacea (i.e. the percentage abundance and percentage taxa richness of benthic invertebrates per group) between sites (Muddy Creek [BC1], Cooks River [BC2], Fatima Island [BC3], Wolli Creek [BC4], Beaman Park [BC7] and Campsie [BC8]) along the Cooks River and between years (2006, 2010 and 2011), we used a two factor (site time) fixed effects model Analysis of Variance (ANOVA) (Data Desk 6.1 ®).

Where there was a significant interaction between site and time, results were further analysed using a Scheffe post hoc multiple comparisons test to determine the location of differences among means. Where appropriate, data were transformed to the square root or the arcsine of their square roots before analysis, to improve the homogeneity of variance and to meet assumptions of normality. Alpha = 0.05 (i.e., the Type I error rate) was used to determine the significance of all tests.

Multivariate analyses

To compare temporal changes in benthic assemblages at each site (Muddy Creek, Cooks River, Fatima Island, Wolli Creek, Beaman Park and Campsie) across the years 2006, 2010, and 2011, we used a 1-way PERMANOVA to test for temporal change at each site. These multivariate analyses of the benthic invertebrate assemblage were performed using the PERMANOVA add-on statistical package (Anderson 2001; McArdle & Anderson 2001) within PRIMER (Clarke 1993; Clarke & Gorley 2006). We used the Bray-Curtis measure of dissimilarity with unrestricted permutation of the raw data using 9999 permutations and Type 3 sum of squares. Samples without benthic invertebrates present were removed prior to analysis. Where significant differences in the assemblages were found between years for each site, pairwise post hoc tests were performed with 9999 permutations as described above. Differences between years (2006, 2010, 2011) for each site were also compared using non-metric, multidimensional scaling (Clarke 1993) based on Bray-Curtis dissimilarity. Where there were clear patterns of differences in the benthic invertebrate assemblage between years for each site, dominant invertebrate taxa contributing most to similarities and differences (with a cumulative cut-off of approximately 50%) were identified by SIMPER in PRIMER (Clarke 1993; Clarke & Gorley 2006). The benthic invertebrate assemblage was fourth root transformed prior to analysis to decrease the influence of abundant species.

Figure 2: Crab observation quadrats at Site BC4 (Waterworth Park, Undercliffe).

Figure 3: Positioned quadrat for hard substrate organism photos at Site P1 (Cooks River mouth, Kyeemagh).

2.2 Mangrove and Saltmarsh surveys

Mangrove and saltmarsh surveys were conducted according to the protocols detailed in CERS (2006a) *Cooks River Ecological Monitoring Program – Phase 1: Pilot Study and Monitoring Program Design.* Surveys were conducted on 16, 19 and 21 December 2011 (See Appendix 1 for dates and sites). Surveys were undertaken at the same sites as those undertaken in 2008 including Muddy Creek (M1), Beaman Park (M2). Wolli Creek (M3).

At each site, the density of trees, height, diameter at breast height (DBH), crown foliage diameter (CFD), number of seedlings and stand basal area were compared among sites in randomly selected vegetation quadrats (5 × 5 m). Within each quadrat, tree density (estimated as the total number of trees), tree height (using a clinometer) (NYCSWCD 2010), CFD (using a plum bob) (Brack & Wood 1997) and DBH (NYCSWCD 2010) were measured as averages for each quadrat. The stand basal area was calculated as the sum of the DBH for each quadrat (DECCW 2010). Total seedlings (single stemmed plants < 50 cm in height) and saplings (plants 50 cm -1 m tall with lateral branches not forming the mature canopy) were estimated for each quadrat (Minchinton 2001). For 2011, seedlings were divided into new and old. New seedlings are individuals from the most recent cohort which may either be propagules that have established roots and lifted from the surface or single stemmed plants with an attached cotyledon). Old seedlings represent individuals from prior years before the most recent seed fall (Minchinton 2001). For temporal comparisons all seedlings were combined.

The total area of saltmarsh vegetation was visually assessed for condition and the total area for vegetation type was recorded. Evidence of disturbance including trampling, litter and weed invasion was recorded.

2.2.1 Statistical analyses

Two comparisons were made. First, for 2011, CFD, stand basal area and new and old seedlings were compared between quadrats and sites using a one-way Analysis of Variance (Data Desk 6.1 ®). Significant site differences were estimated using Scheffe post hoc tests. Second, for variables with data from prior years including tree density, height, total seedlings and saplings and DBH, a two-factor (site, time) fixed effects model Analysis of Variance was used (Data Desk 6.1 ®). Where there was a significant interaction between site and time, results were further analysed using Scheffe post hoc multiple comparisons test to determine the location of differences among means. Data for all comparisons were transformed to the log (x+1) to improve the homogeneity of variance and to meet assumptions of normality. Alpha = 0.05 was used to determine the significance of all tests.

Figure 4: Mangrove and Saltmarsh survey site M2, Beaman Park.

3 Results

3.1 Site profiles

Profiles for each site visited along the Cooks River are presented in Appendix 1. These contain information about the site location, access, sampling times and dates, habitat type and incidental observations/comments.

3.2 Crab observations

Two species of crabs were present, *Heleocius cordiformis* (Semaphore crab) and *Sesarma erythrodactyla* (Red-fingered marsh crab).

Table 1: Total number of crabs observed during monitoring. Results are not available for sites BC7 and BC8 for the 2005-06 monitoring.

Monitoring Year	Site BC1-BC6	All sites
2011	59	59
2010	102	107
2009	101	115
2008	75	93
2007	75	92
2005-06	57	N/A

The average number of crabs observed per site in 2011 ranged from 0 to 5.8 (Figure 6 and Appendix 3). The maximum number of crabs observed at a site was 35; the total number of crabs observed in 2011 was lower than those found in surveys from 2007 to 2010, with numbers most similar to 2005-06 surveys (Table. 1). Crab and/or burrows were seen at all sites except at the Campsie mangrove site BC8 (Appendix 4).

Crab abundance was substantially lower at BC1 than earlier years but most similar to 2010 numbers. Crab abundance was still higher at sites BC2 and BC4 than earlier surveys but slightly lower than those found in 2010. Crab numbers at BC3 were substantially lower than previous years but most similar to those found in 2005-06. No crabs were seen at BC6 or BC7, which is a decrease compared to those seen in previous years, but most similar to 2010 survey numbers.

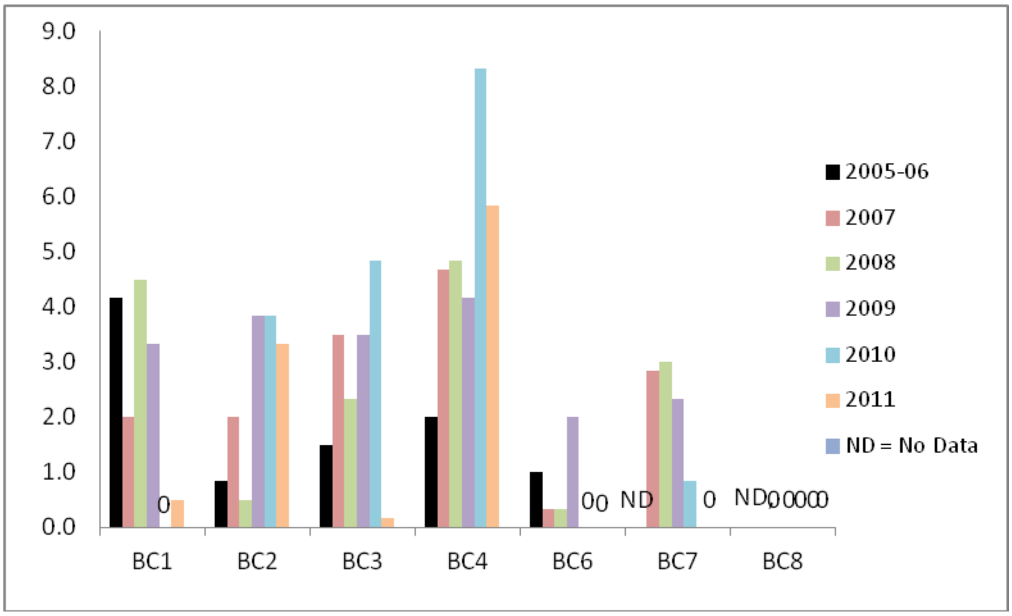

Figure 5: Average crab abundance at sites along the Cooks River from 2005-06 to 2011.

3.3 Hard substrate organisms

Hard substrates along the Cook's River have been colonized by green turf (fine filamentous algae), Sydney Rock Oysters, barnacles and gastropods (snails). Patches within some surfaces remain uncolonised. Patterns in hard substrate cover were correlated with the type of substrate and the distance from the river mouth (Figure 6 and Appendix 5). Sydney Rock Oysters were found on rock surfaces and mangroves close to the river mouth, while barnacles were found predominately on iron walls further upstream. Green algae were found on all substrate types and bare space was found on almost all sites.

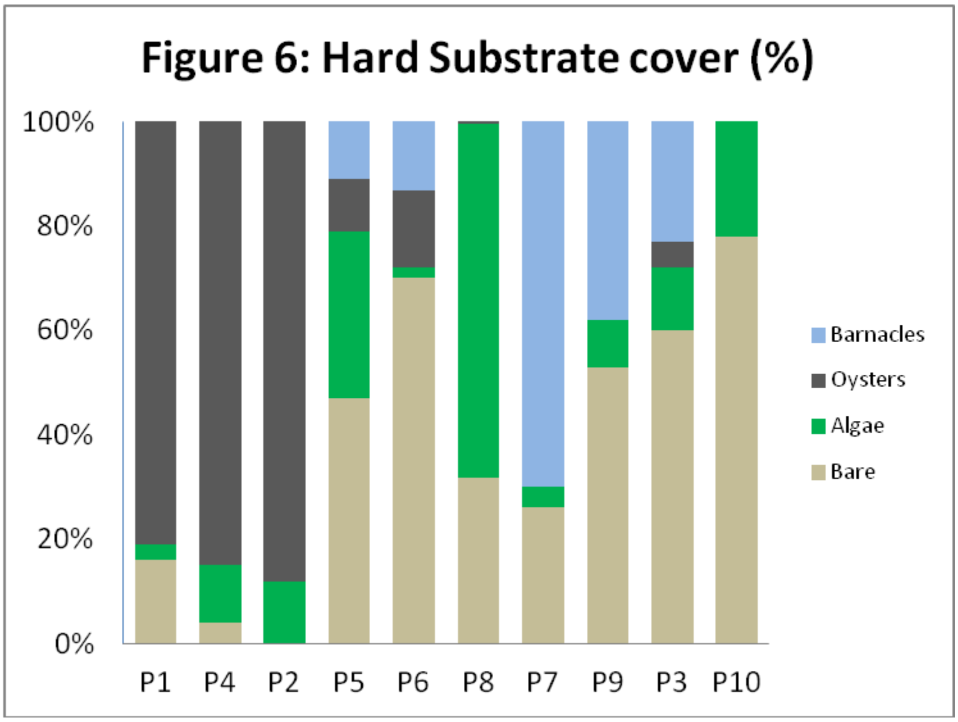

Figure 6: Percentage covers of organisms on hard substrate in the Cooks River in 2011.

Patterns in hard substrate percentage coverage over the 6 years of RiverScience monitoring are shown in Figure 7. All sites have had periods of varying amounts of bare space over the 6 years. All sites have also had some algal growth at least once in the 6 years, this is also highly variable. Four sites (P8, P7, P9 and P3) have had algae present in all years; however, the level of cover has been highly variable over time, ranging from between 2% and 68%. P2 and P10 had significant increases in cover, whilst P6, P7 and P9 had significant decreases in algal cover. Four sites have had no bare space at some stage over the 6 sampling years (P2, P7, P9 and P10).Bare space has increased at 4 sites in 2011; these include P1, P6, P8 and P9. The cover of bare space is highly variable and is often inversely correlated with the amount of algae cover. Notably P10 has had close to 100% bare space in all years except 2007, when it had 0% (algae was 100% during this time).

Sydney Rock Oysters and barnacles are more restricted in their distribution within the river. Rock Oysters were consistently observed at sites P1, P2, and P4, which are sites with mangrove and rock wall substrate. At each of these sites, oyster cover was annually variable, sometimes differing by up to 48% between years (e.g. P1). Oyster cover at site P6 (which was colonised in 2008) has almost doubled since this time. There were changes in oyster coverage in 2011 at most sites within estuarine waters. There was a slight increase in coverage at sites P4 and P2, a slight decrease at P1 and significant decrease at P5. There was no change at P6. There was little or no change at upstream sites (P10, P3, P9, P7, and P8).

Barnacles were consistently found on iron wall sites (P7 and P9) and in Alexandra Canal (P3), where rock oyster coverage was 0% most years. Notable differences found in 2011 compared to previous years include a substantial increase at P5, P7, P9 and P3 and a significant decrease was found at site P8, with 0% coverage for the first time since 2008. Again, total cover was annually variable with a range of up to 40% at site P7. No barnacles were found at the other five other sites; all of these sites have had periods of 0% coverage since surveys began in 2005-06.

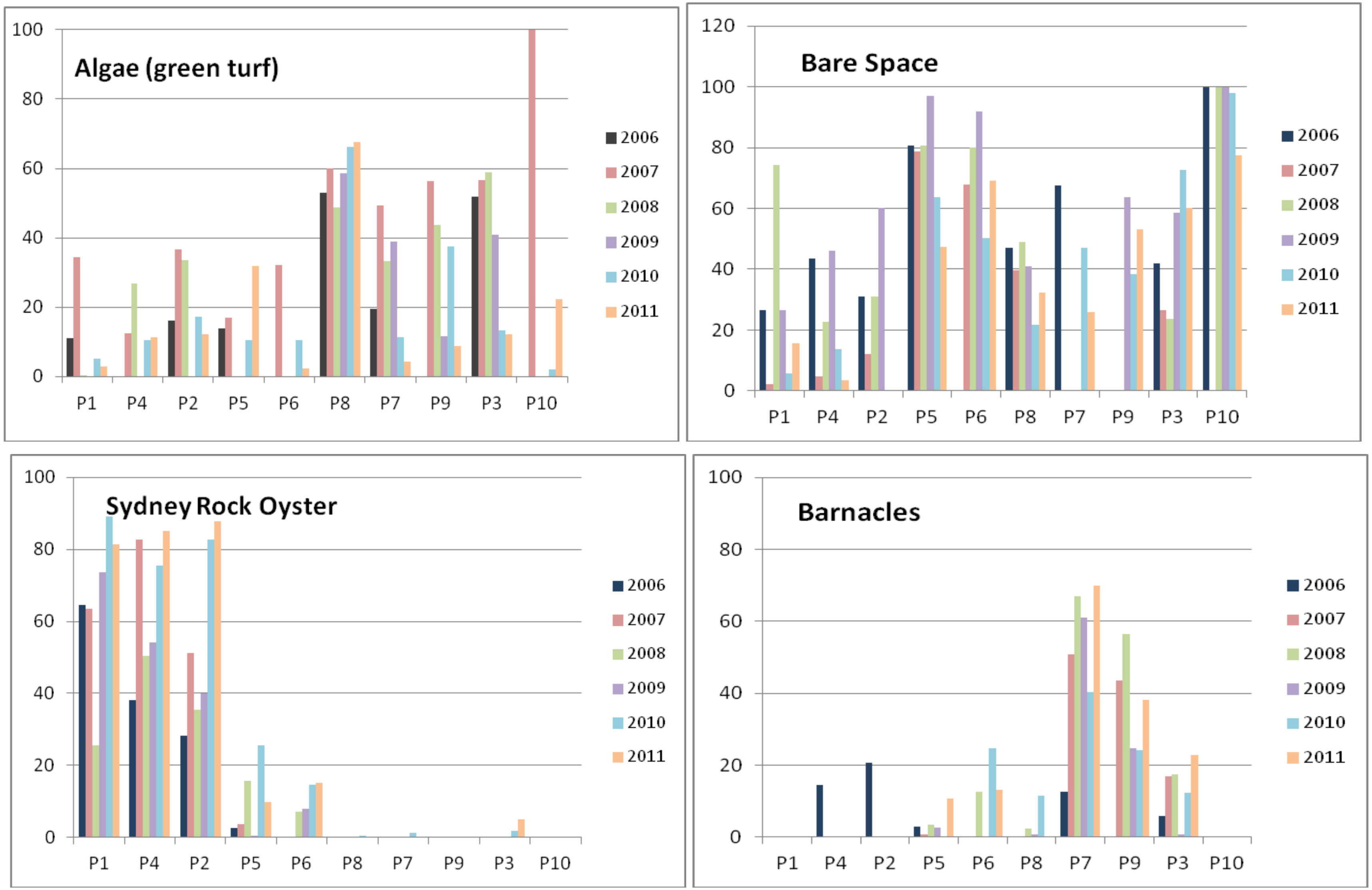

Figure 7: Percentage cover of hard substrate colonisers in the Cooks River 2005-06 to 2011.

3.4 Statistical Analysis – Benthic Invertebrates

3.4.1 Average abundance and taxa richness at family level

The abundance and taxa richness at family level of benthic invertebrates varied with sites and time (Fig. 8; Appendix 2 – Table 1). Benthic invertebrate abundance and taxa richness was significantly lower in 2006 compared to 2010 for all sites except Wolli Creek and Beaman Park. Muddy Creek however had a significant difference in abundance but not taxa richness between years (Fig. 8; Appendix 2 – Table 1; Scheffe post hoc multiple comparisons test on interaction of sites and time). Similarly, with the exception of Beaman Park all sites had a significantly lower abundance and taxa richness in 2006 compared to 2011. Beaman Park had higher taxa richness in 2006 compared to 2011 (Fig. 8; Appendix 2 – Table 1; Scheffe post hoc multiple comparisons test on interaction of sites and time). Benthic invertebrate abundance and taxa richness varied considerably between 2010 and 2011. All sites except the Cooks River and Fatima Island had a lower abundance in 2010 compared to 2011. No significant difference in taxa richness was found between 2010 and 2011 with the exception of Beaman Park, which had higher taxa richness in 2010 compared to 2011, and Campsie, which had lower taxa richness in 2010 compared to 2011 (Fig. 8; Appendix 2 – Table 1; Scheffe post hoc multiple comparisons test on interaction of sites and time).

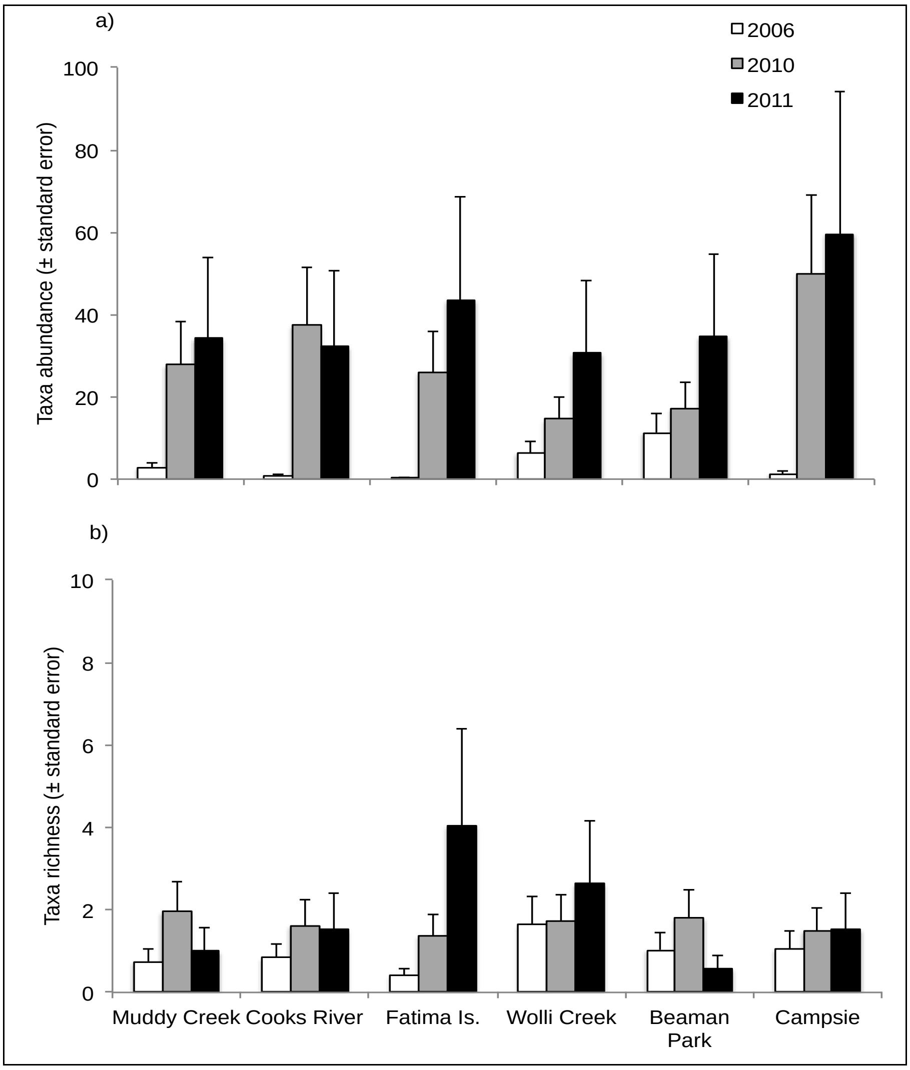

Figure 8. Average benthic taxa abundance (a) and taxa richness (b) ± standard error at sites along the Cooks River from 2006 – 2011. *n* = 6 (2006); *n* = 7 (2010); *n* = 3 (2011).

3.4.2 Relative abundance and taxa richness of Polychaeta, Mollusca and Crustacea

The relative abundance and taxa richness of Polychaeta and Mollusca varied over sites and time but no significant difference was found in, the relative abundance and taxa richness for the interaction of sites and time for Crustacea (Fig. 9, 11; Appendix 2 – Table 2). Polychaeta relative abundance and taxa richness varied between 2006 and 2010 at sites including the Cooks River and Fatima Island whereby the relative abundance and relative taxa richness of Polychaeta were significantly higher in 2010 than 2006 (Fig. 9; Appendix 2 – Tables 2 & 3; Scheffe post hoc multiple comparisons test on interaction of sites and time for Polychaeta). The relative abundance of Polychaeta also varied considerably for the Cooks River and Fatima Island between 2006 and 2011. The relative abundance of Polychaeta was greater in 2006 compared to 2011 for both sites (Fig. 9; Appendix 2 – Tables 2 & 3; Scheffe post hoc multiple comparisons test on interaction of sites and time for each of the major groups). Although a significant interaction between sites and time was found for the relative abundance and relative taxa richness of Mollusca, no significant difference for each site over time was found (Fig.9; Appendix 2 – Tables 2 & 3; Scheffe post hoc multiple comparisons test on interaction of sites and time for Mollusca).

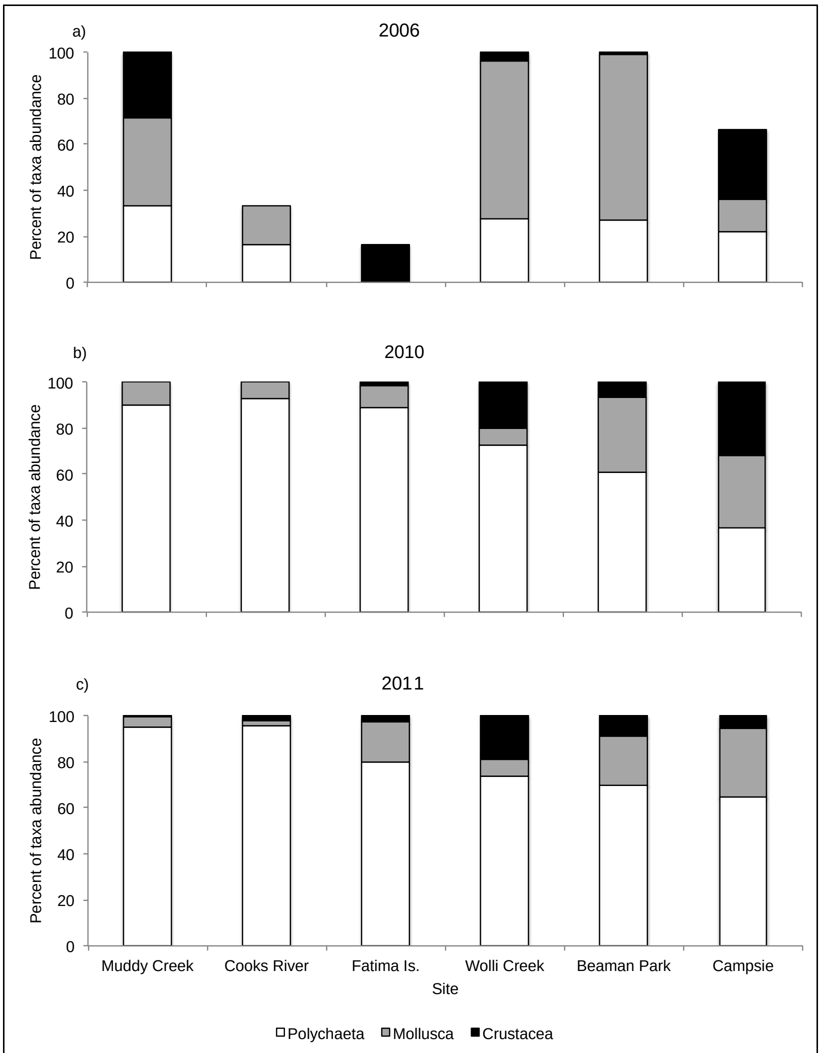

Figure 9: Polychaeta, Mollusca and Crustacea percent abundance at sites along the Cooks River from 2005-06 – 2011. *n* = 6 (2006); *n* = 7 (2010); *n* = 3 (2011).

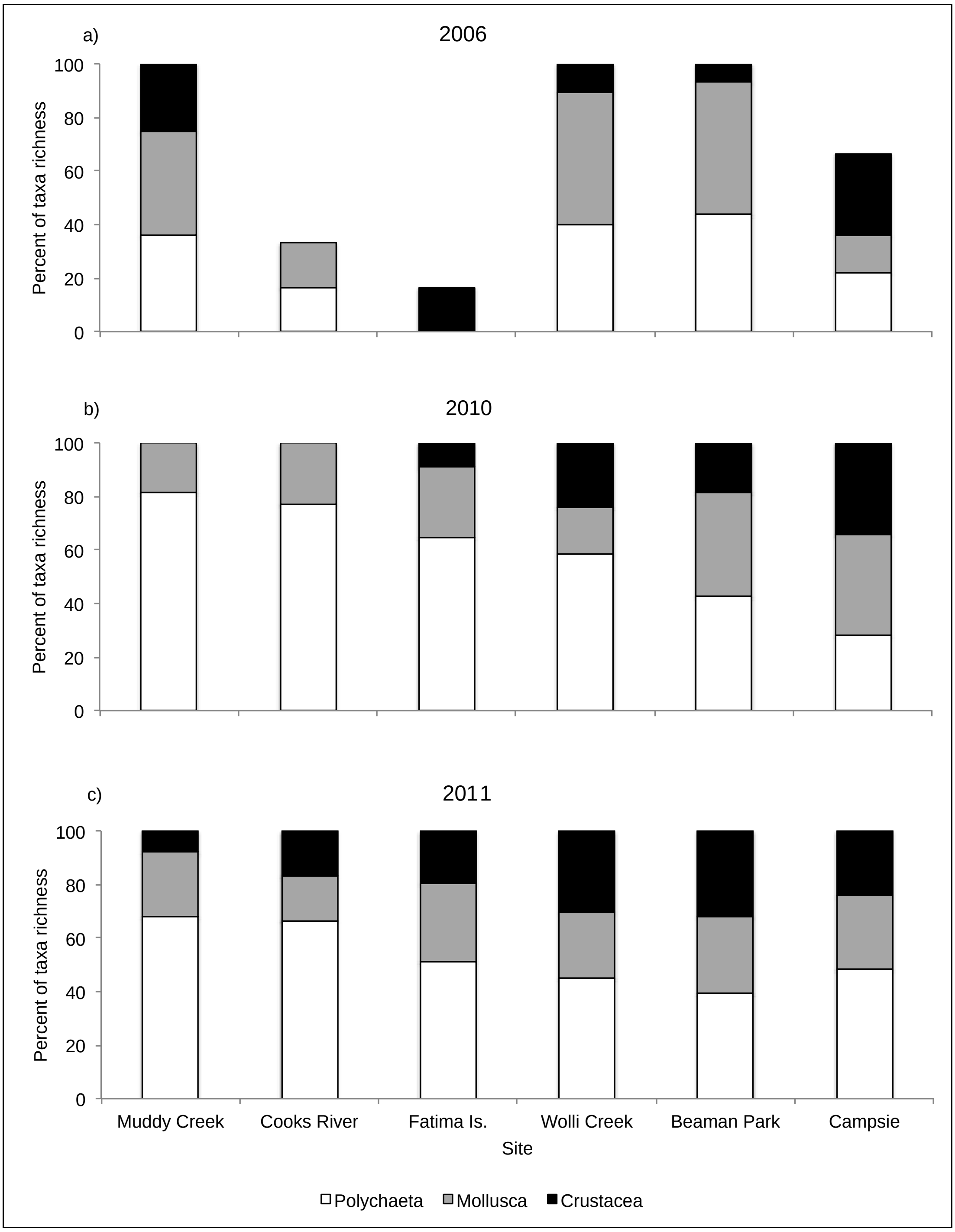

Figure 10: Polychaeta, Mollusca and Crustacea percent taxa richness at sites along the Cooks River from 2006-2011. *n* = 6 (2006); *n* = 7 (2010); *n* = 3 (2011).

3.4.3 Benthic community composition

There were major differences in the benthic invertebrate assemblages for each site over time (Fig. 11). Sites including Muddy Creek, Wolli Creek, Beaman Park and Campsie varied in their benthic invertebrate assemblage between all years (2006, 2010, 2011) (Fig. 11; Table 2). In contrast, Fatima Island only varied in composition between 2010 and 2011 and the Cooks River site varied in composition between 2006 and 2010 in addition to 2010 and 2011 (Fig. 11; Table 2).

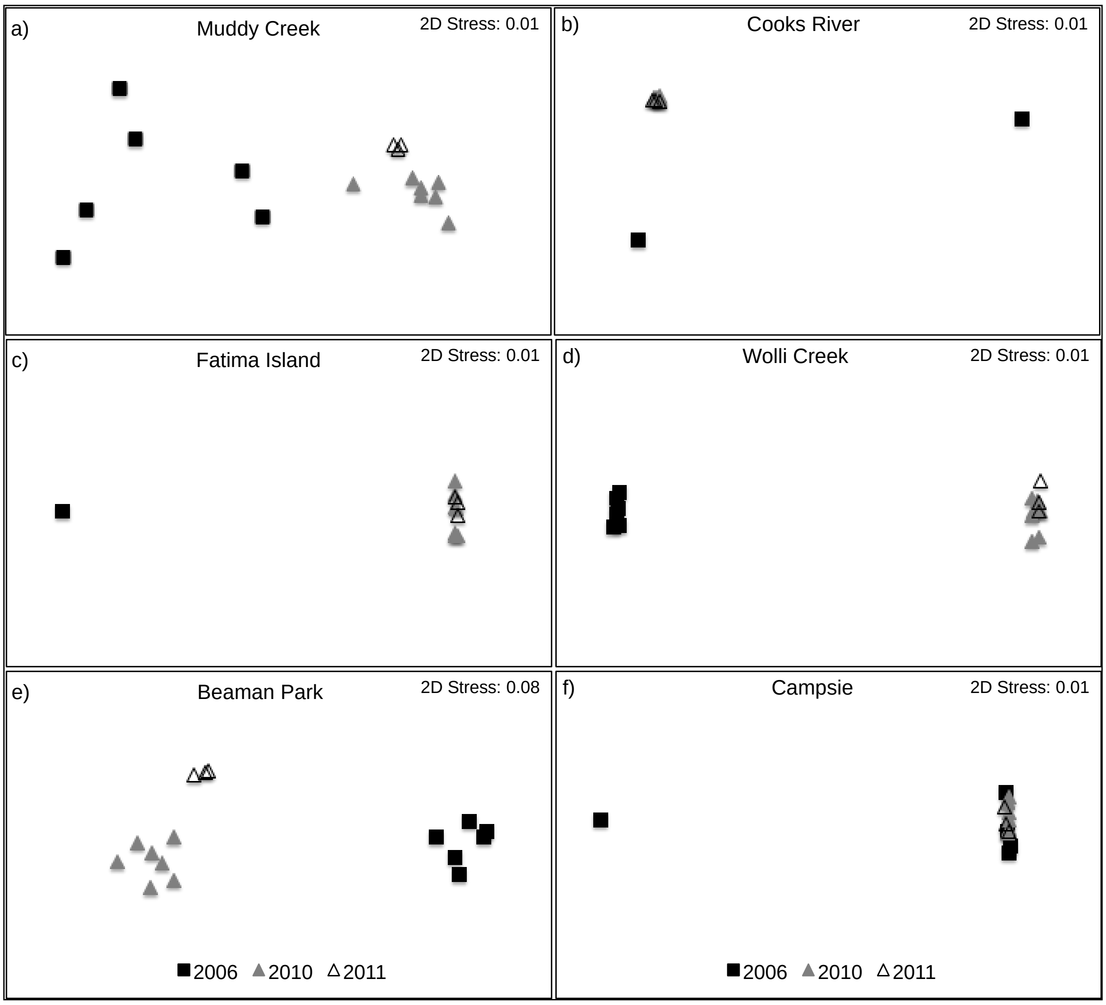

Figure11: Non-metric, multidimensional scaling plot of benthic invertebrate assemblages from replicate samples (one point per core sample) at sites along the Cooks River over time (2006, 2010, and 2011).

Table 2: Results of 1-way PERMANOVAs for year (2006, 2010, 2011) and pairwise comparisons for each site (Muddy Creek, Cooks River, Fatima Island, Wolli Creek, Beaman Park and Campsie) on benthic invertebrate taxa. Data was transformed to the fourth root.

Site	Year		2006-2010		2006 - 2011		2010 - 2011	
	Pseudo - F	P (perm)	t	P (perm)	t	P (perm)	t	P (perm)
BC1 Muddy Creek	6.096	<0.001	2.805	< 0.001	2.022	0.012	2.420	0.008
BC2 Cooks River	6.611	< 0.001	3.314	0.028	1.929	0.102	1.982	0.008
BC3 Fatima Island	7.485	< 0.001	3.253	0.121	3.244	0.247	1.945	0.007
BC4 Wolli Creek	19.747	<0.001	5.404	< 0.001	4.902	0.012	1.844	0.016
BC6 Beaman Park	19.498	<0.001	5.042	< 0.001	4.405	0.011	3.267	0.008
BC8 Campsie	6.744	< 0.001	2.694	0.002	2.106	0.0	3.663	0.010

Significant differences in the benthic invertebrate assemblage at Muddy Creek, Cooks River and Campsie occurred between 2006 and 2010 with the composition dissimilarity for each site being 90% or greater (Appendix 2 - Table 4). At Muddy Creek differences between 2006 and 2010 were driven predominately by two families of polychaetes: Nephtyidae and Sabellidae that were dominant in 2010 and contributed to a high site similarity (59.2%).

In 2006 the similarity of the assemblage was low at Muddy Creek (14.26 %) and was made up with a mix of polychaetes, molluscs and crustaceans (Appendix 2 - Tables 4 and 5). Differences in the benthic invertebrate assemblage between 2006 and 2010 at the Cooks River site were also predominately driven by polychaetes: Capitellidae, Nereididae and Spionidae which made up nearly 50% of the cumulative cut-off. These families were virtually absent at the Cooks River site in 2006 with Capitellidae and Nereididae being dominant at this site in 2010 (Appendix 2 - Tables 4 and 5).

In contrast, between 2006 and 2010, differences in the benthic invertebrate assemblages at Campsie were driven largely by oligochaetes and insects that were dominant in 2010 compared to 2006. In 2006 this site was dominated by one family of crustaceans (the Sphaeromatidae) that made up over 78% of the benthic invertebrate composition (Appendix 2 - Tables 4 and 5).

High site dissimilarity was also evident between 2006 and 2011, particularly at Muddy Creek and Campsie, with an average dissimilarity for each site being greater than 90%. At Muddy Creek dissimilarity between 2006 and 2011 was primarily due to three families of polychaetes: Capitellidae, Spionidae and Sabellidae and one family of molluscs: Nassariidae, which were all virtually absent in 2006 (Appendix 2 - Tables 4 and 5).

In 2006 Muddy Creek was dominated with a mix of molluscs, polychaetes and crustaceans causing low site similarity compared to 2011, which had high site similarity (85.44 %) and was dominated by polychaetes (Appendix 2 - Tables 4, 5). In contrast, at Campsie, dissimilarity in the assemblages between 2006 and 2011 was due to a large mix of oligochaetes, polychaetes, molluscs and insects (Appendix 2 - Table 4). High site similarity at Campsie was evident in 2011 and made up of a large mix of benthic invertebrates, whereas crustaceans from the family Sphaeromatidae dominated the assemblage in 2006 (Appendix 2 - Table 5).

Differences in the benthic invertebrate assemblages between 2010 and 2011 for each site was lower than prior year comparisons and ranged from 31% to 60% (Appendix 2 - Table 4). At Beaman Park differences between years were made up of a large mix of polychaetes, molluscs and crustaceans. Mixed polychaete families dominated the assemblages for both years with minor densities of oligochaetes. Molluscs from the family Galeommatidae occurred in 2011 (Appendix 2 - Table 5).

Campsie had the largest site dissimilarity between 2010 and 2011 (nearly 61%).This was due to a mix of three polychaete families (Sabellidae, Nereididae and Spionidae), two families of molluscs (Hydrobiidae and Galeommatidae), and oligochaetes (Appendix 2 - Table 4). Most of these differences were due to a mix group of benthic invertebrates occurring in 2011, whereas in 2010 the site was made up predominantly with oligochaetes and insects (Appendix 2 - Table 5).

The Cooks River site had the lowest site dissimilarity for all years compared (nearly 32%) that occurred between 2010 and 2011. High similarities in the benthic assemblages for each of these years were also apparent (Appendix 2 - Tables 4 and 5). In 2010 two families of polychaetes (Nereididae and Capitellidae), and one family of molluscs (Nassariidae) contributed to over 60% of the cumulative cut-off of the assemblage. The polychaetes Nereididae and Capitellidae were also dominant in 2011 but with the addition of the polychaete family: Spionidae (Appendix 2 - Table 5).

3.5 Mangrove and Saltmarsh

Grey mangrove *(Avicennia marina)* (Forssk.) Vierh was the only species of mangrove present within the survey sites.

The average crown foliage diameter (CFD) in 2011 varied between sites along the Cooks River (Fig. 12, Table 3). Post hoc comparisons using Scheffe's procedure revealed that Muddy Creek had on average a greater CFD than Beaman Park and Wolli Creek (Fig. 13, *P* = 0.012 for Beaman Park; *P* = 0.012 for Muddy Creek), which were similar in their CFD's (Fig 13, *P* = 0.957).

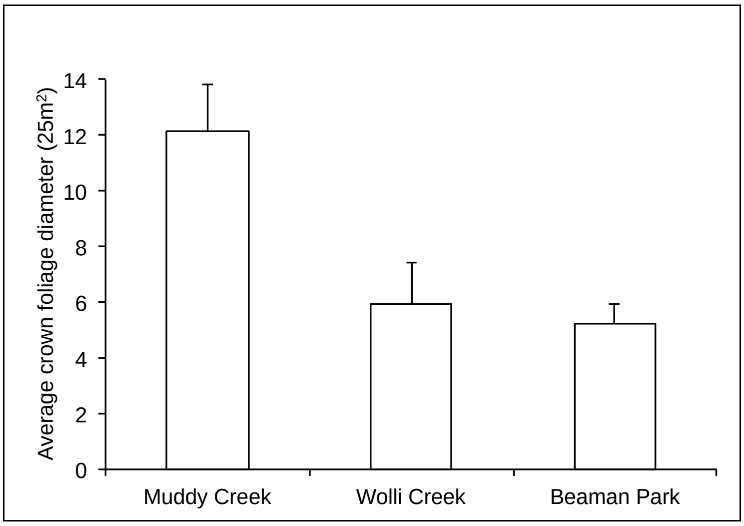

Figure 12: Average crown foliage diameter (± standard error) of mature mangrove trees in 2011.

In 2011 new seedlings were abundant, but with few established old seedlings (Fig. 13). Wolli Creek had the greatest density of new seedlings compared to all other sites, but there was high variability within sites and these differences in new or old seedlings among sites were not significant (Fig. 13, Table 3). Only one sapling was present in the sampling surveys at Wolli Creek and so no analysis was conducted.

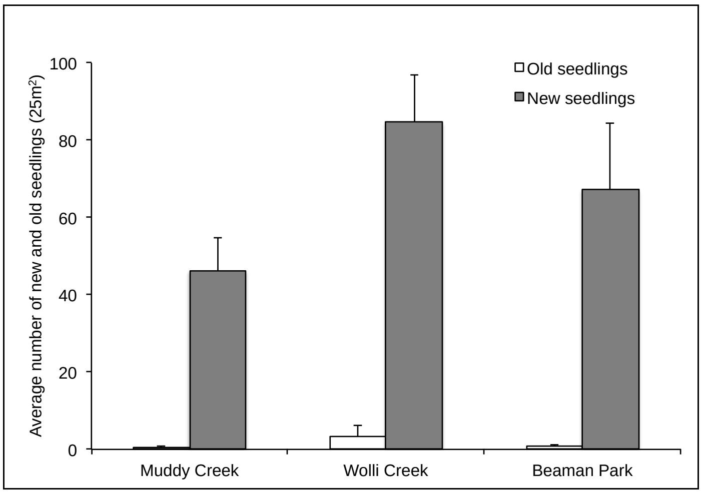

Figure13: Average number of old and new seedlings (± standard error) per $25m^2$ in mature mangrove stands in 2011.

The basal area, representing the sum of the diameter at breast height (DBH) for all mangrove trees in each stand or quadrat, did not vary across sites in the Cooks River (Fig. 14, Table 3).

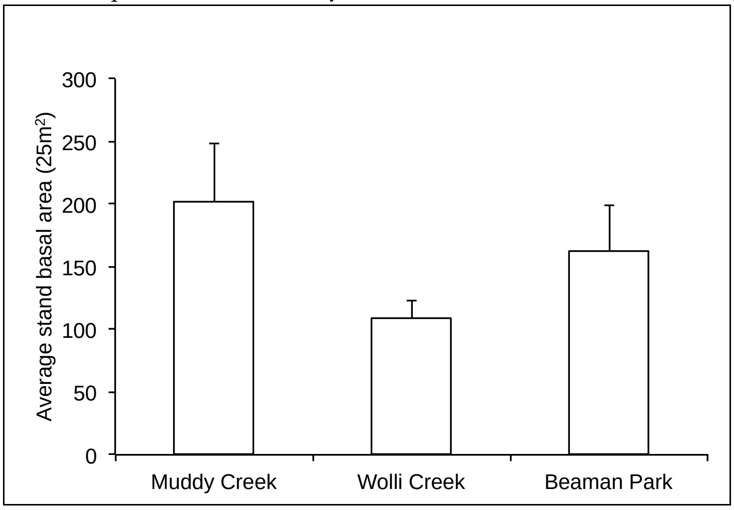

Figure14: Average stand basal area (± standard error) per 25m^2 of mature mangrove trees 2011.

There was no significant interaction between space and time for the overall density of trees (Fig. 15, Table 4). However, differences in tree density for all years surveyed was found among sites, with Beaman Park having greater densities of trees than all other sites (Fig. 15, Table 4; Scheffe post hoc comparisons test on sites, P <0.001 for Beaman Park, P <0.001 for Muddy Creek). Tree density was also significantly greater at Wolli Creek than Muddy Creek (Fig. 16, Table 4; Scheffe post hoc comparisons test on sites, P = 0.019). For all sites surveyed, tree density was lower in 2011 than initial surveys conducted in 2005 (Fig. 15, Table 4; Scheffe post hoc comparisons test on sites, P = 0.026).

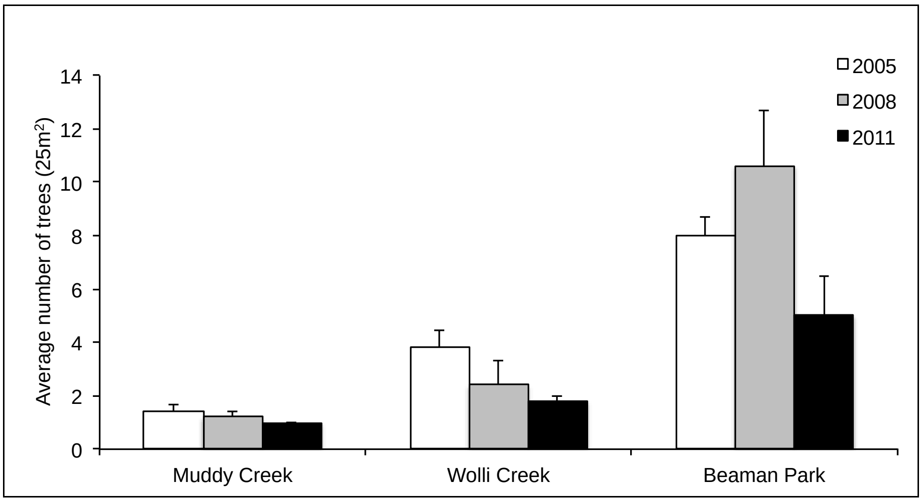

Figure15: Average density (± standard error) of mature mangrove trees over time.

Tree height varied among sites and over time (Fig. 16, Table 3). Although there was a trend towards an increase in mangrove heights for both Wolli Creek and Beaman Park over time, average height only significantly increased from 2008 to 2011 at Wolli Creek (Fig. 15; Scheffe post hoc multiple comparisons test on interaction of sites and time, P = 0.003). In 2008 Wolli Creek had significantly shorter trees compared to Beaman Park and Muddy Creek (Fig. 16; Scheffe post hoc multiple comparisons test on interaction of sites and time, P = 0.003 for Beaman Park, P <0.001 for Muddy Creek). The average mangrove height at Muddy Creek declined considerably from 2008 to 2011, although this trend was not significant (Fig. 16, Scheffe post hoc multiple comparisons test on interaction of sites and time, P = 0.586).

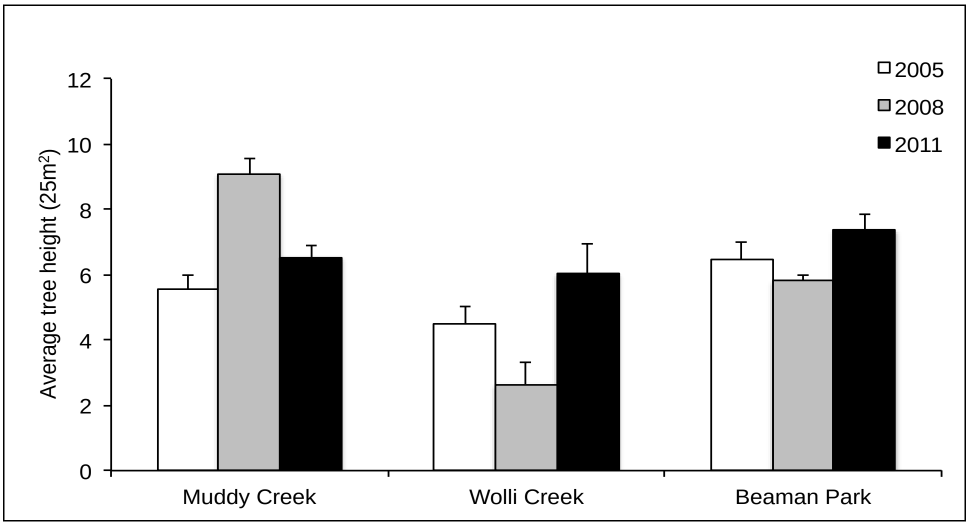

Figure16: Average height (± standard error) of mature mangrove trees over time.

The total number of seedlings varied across sites and over time (Fig. 17, Table 3). In 2005 the number of seedlings at Wolli Creek were more than three times greater than seedling numbers at all other sites and for all other times surveyed (Fig. 17; Scheffe post hoc multiple comparisons test on interaction of sites and time, *P* <0.001, for all interactions of sites and time with Muddy Creek 2005). The number of seedlings increased steadily from 2005 to 2011 at Muddy Creek and Beaman Park (Fig. 17; Scheffe post hoc multiple comparisons test on interaction of sites and time, *P* <0.001 for Beaman Park, *P* <0.001 for Muddy Creek). In 2011 the number of seedlings were similar across all sites (Fig. 17; Scheffe post hoc multiple comparisons test on interaction of sites and time, *P* >0.05).

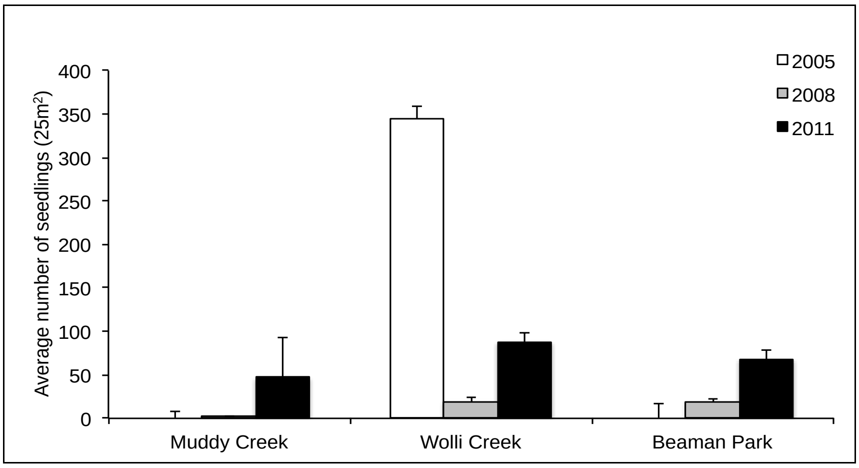

Figure17. Average number of old and new seedlings (± standard error) per 25m^2 in mature mangrove stands over time.

A non-significant trend towards an increase in the diameter at breast height (DBH) from 2005 to 2011 for each site was apparent but no interaction between site and time was found (Fig. 18, Table 4). Significant differences however between sites were found. The mean DBH at Muddy Creek was greater than Beaman Park and Wolli Creek (Fig. 18; Scheffe post hoc comparison of sites, Beaman Park *P* <0.001; Wolli Creek

P <0.001). Overall the DBH increased from 2005 to 2011 (Fig. 18; Scheffe post hoc comparison of sites, *P* <0.001).

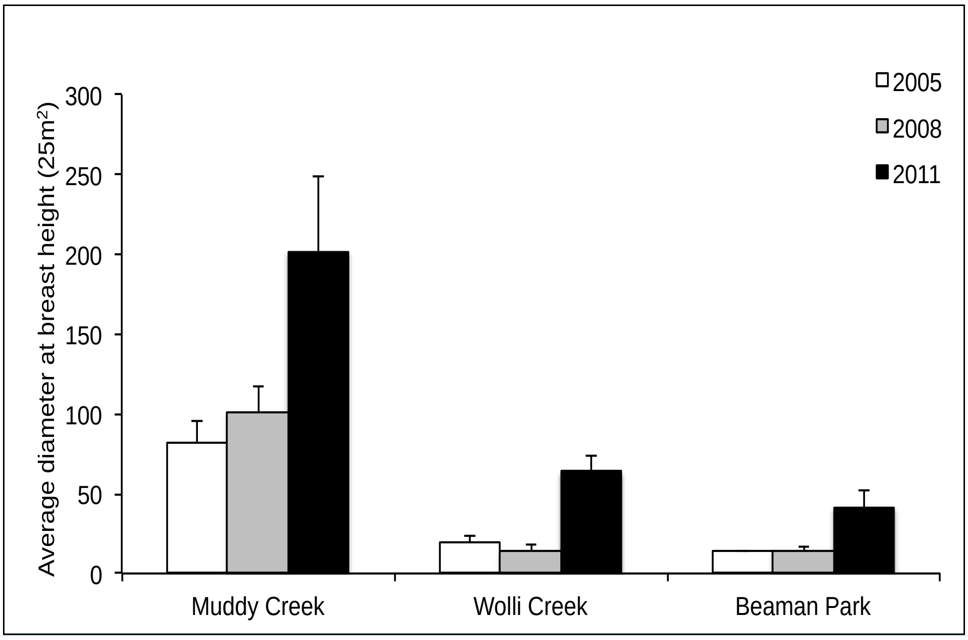

Figure18: Average diameter at breast height (DBH) (± standard error) of mature mangrove trees over time.

Table 3: Results of a one-way analysis of variance for the effect of site (Muddy Creek, Wolli Creek, Beaman Park; *df* = 2, 12) on crown foliage diameter, new and old seedlings, and stand basal area. For all variables, data were transformed to log (*x*+1).

Variable for 2011 only	4 - Site	
	F	*P*
Crown foliage diameter	8.132	<0.001
New seedlings	1.970	0.182
Old seedlings	0.219	0.806
Stand basal area	1.846	0.200

Table 4: Results of two-factor, analysis of variance for the effect of site (Muddy Creek, Wolli Creek, Beaman Park; df = 2, 36), time (2005, 2008, 2011; df = 2, 36) and their interaction (df = 4, 36) for tree density, tree height, total seedlings and saplings, and diameter at breast height. For all variables, data were transformed to log (x+1).

Variable	4 - Site		5 - Time		6 – Site x Time	
	F	P	*F*	*P*	*F*	*P*
Tree density	43.932	<0.001	4.255	0.022	1.763	0.158
Tree height	13.789	<0.001	2.702	0.081	5.656	0.001
Seedlings	168.580	<0.001	105.760	<0.001	82.327	<0.001
Diameter at breast height	43.014	<0.001	17.870	<0.001	1.730	0.1647

3.6 Litter and weeds

The presence of litter in mangrove communities at Beaman Park was extensive, with on average greater than 80 pieces recorded per quadrat. Litter included a variety of plastic, glass and paper products including drinking straws, cigarette packets, takeaway coffee cups, chip packets, glass bottles, shoes, cardboard, paper, aluminium cans, gauze and plastic bags. Wolli Creek had the least amount of rubbish while Muddy Creek had on average 14 pieces per quadrat.

The presence of naturalised exotic species establishing self-sustaining populations in the natural environment (DAFF 2011) and plants declared noxious or 'invasive' and recognised as problem species in New South Wales (under the Noxious Weeds Act 1993 - Groves *et al.* 2005; AWS 2006) were prevalent at Wolli Creek and Muddy Creek and are listed in Table 5.

Table 5: Exotic plant species including naturalised species and those declared noxious present at Wolli Creek, Muddy Creek and Beaman Park in December 2011.

	4 - Declaration	
	Naturalised	Noxious
Wolli Creek		
Solanum nigrum	✓	
Stenotaphrum secundatum	✓	
Foeniculum vulgare	✓	
Senna pendula var. *glabrata*	✓	✓
Asparagus aethiopicus	✓	✓
Muddy Creek		
Parietaria judaica	✓	✓
Anredera cordifolia	✓	✓
Lantana camara	✓	✓
Ehrharta species	✓	
Bidens pilosa	✓	
Cestrum parqui	✓	✓
Ricinus communis.	✓	✓
Beaman Park (N/A)		

No saltmarsh plant communities were found at Muddy Creek or Beaman Park. Four species of saltmarsh species were found along a 170 × 1 m strip at Wolli Creek (33.92704°S, 151.15337°E). The total area for saltmarsh plants including *Sarcocornia quinqueflora* (Bunge ex Ung.-Sternb.) A.J.Scott, *Suaeda australis* (R.Br.) Moq, *Phragmites australis* (Cav.) Trin. ex Steud and *Juncus kraussii* Hochst. along this strip was recorded with *P. australis* recording highest density (Fig. 19). Twelve *S. australis* seedlings (<50 cm tall) were also found within this saltmarsh strip.

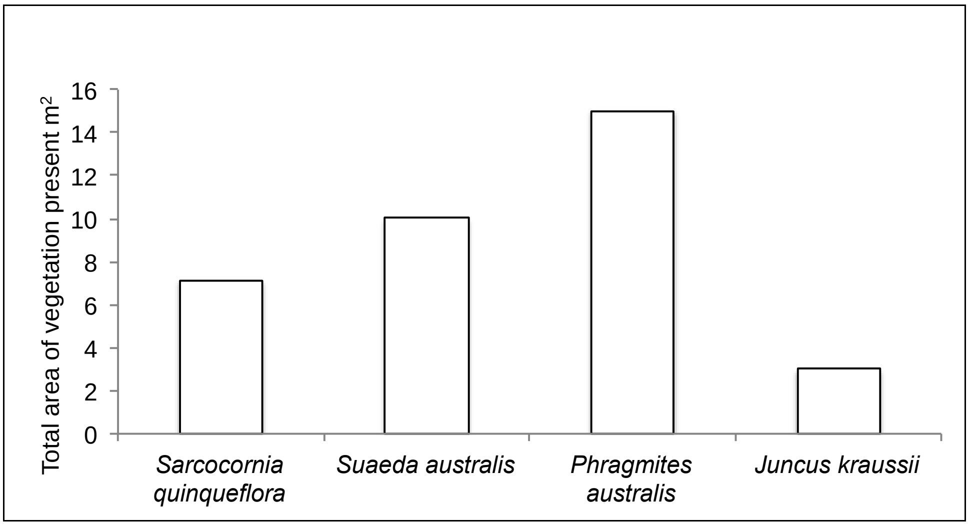

Figure19: Area (m^2) and type of saltmarsh vegetation present at Wolli Creek

4 Discussion

4.1 2011 Monitoring program outcomes

4.1.1 Benthic invertebrates

The diversity and abundance of benthic invertebrates in the Cooks River in 2011 has continued to increase compared to 2005-06 and 2010 at all sites except BC1, which had a slightly higher family richness in 2010. The 2011 data cannot be compared to the 2007, 2008 and 2009 results as a different method was used for sorting and identification of samples. Therefore, only survey results from 2011 may be compared with survey results from 2005 – 06 and 2010. The weather conditions prior to and during the 2011 surveys were hot and dry, with minimum rainfall recorded for the month of November (www.bom.gov.au). In contrast, weather conditions prior to the 2010 surveys were the wettest since 2007. Major weather events such as floods and droughts are known to effect the physiochemical composition of estuaries and hence changes in the benthic community (Jones 1990).

When compared with 2010 and 2005-06 data, both the abundance and diversity of benthic invertebrates in the Cooks River has increased slightly; these increases were found in the abundance of polychaetes (worms) at all sites and the abundance of amphipods (small crustacea) and gastropods (snails) at most sites. Polychaetes are the least sensitive of the major macrobenthic classes to anthropogenic perturbations and, under stressed conditions, tend to increase in abundance and number relative to the more sensitive classes such as the crustacea and mollusca (Stark 1988). Common families of polychaetes found in both polluted and unpolluted waterways were found. These include Capitellidae and Nephtyidae which were the dominant families at most sites and indicate a polluted waterway, whilst there was also an increase in the families Hesionidae and Oweniidae which are more commonly found in unpolluted bays (Stark 1988). This may indicate an improvement in the health of the waterway. As in previous years the most diverse range of families were found at site BC4 (Wolli Creek Mangroves) and there was an increase in diversity at BC7 (Beaman Park). Particularly, the abundance of amphipoda has increased at these sites. Four new families were also found in the 2011 survey; these include a Polychaete (Oweniidae), Bivalve (Mactridae), Amphipoda (Corophiidae) and an Isopod (Gnathiidae) (Appendix 2).

4.1.2 Water Quality (Cooks River Valley Association [CRVA])

Water quality tests during 2010-11 indicated generally poor conditions, with low dissolved oxygen, high available phosphate, high *E. coli* levels (CRVA 2010-11), with frequent occurrences of test results outside ANZECC guidelines. A major pollution incident occurred in Cup and Saucer Creek (between BC8 and BC7) which yielded an extremely high level of *E. coli*, this same site was also reported as having consistent poor water quality. Other results from the 2010-11 report (AMBS 2010-11) include:

- A median pH generally within the guideline range;
- Median turbidity at all sites except for one; and
- Median levels of available phosphate above the guideline.

Due to a lack of records of river health prior to impacts and the fact that there may be more useful parameters for water quality testing in estuarine systems, such as turbidity and chlorophyll a, it is not possible to draw a direct cause and effect relationship between these events and the results of 2011 surveys.

4.1.3 Crabs

Crab abundance was low in comparison to previous years; numbers were most similar to those found in 2005-06 surveys. Significant decreases were found at Fatima Island, Wolli Creek, Brackish Saltmarsh and Beaman Park (BC3, BC4, BC6 and BC7). However, a high number of burrows were found at all sites except BC8; this is an indication that crabs are present at all sites except BC8. It must also be noted that the surveys were conducted in hot, dry conditions during the hottest part of the day; these results should not be taken as an indication of a decrease in river health. Future surveys should be timed so that they are conducted during a time period where low tide occurs either early morning or late afternoon when crabs are most active.

It is also important to note the limitations of the sampling method (Mazumder & Saintilan 2003). The visual census measured is biased towards those species apparent on the surface and active at least diurnally at low tide and weather conditions such as hot, sunny or cooler overcast days will influence the behaviour of crabs (A. Murray, pers. comm.). Therefore the crab fauna may be more diverse than indicated by this survey.

4.1.4 Hard surface organisms

The diversity of taxa found on hard surfaces is typical of the severity of anthropogenic impacts experienced by the Cooks River. Impacted locations generally have lower species diversity than relatively clean sites. For example, Besley (1995) found 10 taxa within impacted sites in the Sydney region and 17 taxa in relatively clean sites in the same study. Previous studies suggest that intertidal rock assemblages are more suitable than individual taxa to determine the health of anthropogenic disturbed estuarine locations (Coutenay et al 2005).

The results of the 2011 survey are consistent with those from the previous 6 years' monitoring results. On a year-to-year basis there is a high degree of variability in the percentage cover of colonising organisms. Some of the variability, particularly for green algae, is likely to be a consequence of changing environmental conditions. For example, filamentous green algae are highly ephemeral and respond quickly to favourable environmental conditions, but will also desiccate very quickly in dry conditions.

Some variability can also be explained by the monitoring protocol. Firstly, the measure of cover is a relative proportion for each group, adding up to a total of 100%. Furthermore, colonisation of hard surfaces is naturally variable both in space and time. While photographs are taken at the same sites every year, the exact position of the quadrats differs slightly, which will add to the variability of results. This sampling artefact could be removed with the use of fixed location quadrats.

The percentage cover of most hard surface colonising organisms was above average at most sites in 2011 compared to other years. The bare space has decreased at all sites, with an increase in the colonisation of oysters at the sites close to river mouth (e.g. P1, P4, P2 and P5). A slight increase in barnacle cover was evident at the sites further upstream (e.g. P8, P9 and P3). There was a significant decrease in algae cover at all sites except P8; it is highly likely that this is a result of the hot, dry weather conditions that were present during surveying.

4.1.5 Mangroves and saltmarsh

Saltmarsh and mangroves are the main estuarine vegetation communities within foreshore areas of the Cooks River. The densities and distributions of this vegetation have changed through reclamation for agriculture and urbanisation and through changes to the banks and flows of the Cooks River (AHA Ecology 2007). These areas are important for the production of invertebrates, algae and fish; retention, recovery and removal of excess nutrients and pollution; and flood control and storm protection (Ecological 2010).

No significant differences in the mangrove and saltmarsh populations were found in the 2011 surveys, although there is a trend towards an increase in mangrove heights for both Wolli Creek and Beaman Park and the number of seedlings found at Beaman Park and Muddy Creek are also increasing over time.

Although mangrove communities along the Cooks River appear to be in a healthy condition, naturalized exotic species were found to be present at Wolli Creek and Muddy Creek. These could potentially become a problem for the mangrove and saltmarsh community if not managed effectively,

Mangroves can also potentially encroach into saltmarsh habitat. The only saltmarsh community is found at Wolli Creek, which is the same area where mangroves have shown an increase in new seedlings and height, both of which are indicative of improving mangrove health. It is important to monitor this population and manage it appropriately to ensure that this population does not encroach into the saltmarsh community. Therefore the restricted distribution of saltmarsh should be managed as a priority.

4.2 Ecological health of the Cooks River

The Cooks River catchment is one of the major catchments in the Sydney region, largely incorporating residential housing, commercial and industrial development, and sewage transfer systems. In wet weather, urban stormwater carries contaminants from a range of industrial and domestic sources including chemicals contained in gardening products and vehicle exhaust particulate matter (Coutenay et al 2005). Sediments are sometimes considered to be the ultimate sink for all classes of pollutants and these can persist long after the original source of contamination is eliminated (Reynoldson 1987). Further indications of the degraded nature of Cooks River include gross pollutants such as litter, shopping trolleys and other visible pollutants, particularly throughout mangrove areas. Oily leachate is seeping from sediments at several sites in the upper estuary and the river bank is eroding in several areas.

Gaps in the knowledge of the Cooks River have included physio-chemical aspects of the system such as sediment and water quality. Sediments are also known as physico-chemical drains and are extremely important in understanding river health as they act as sinks for pollutants (A. Jones, pers. comm.). Sediments exhibit electrical properties, particularly fine sediments, which cause many pollutants to be absorbed through the surface of fine sediments and become concentrated. An assessment of these sediments within Cooks River has recently been completed by the University of NSW (Albani 2011). Further indication of river health, through existing current standards (Simpson et al 2005), which assess estuarine systems in a similar manner to the ANZECC water quality guidelines, were also given in this report. The report found high levels of contamination along the river and describes the Cooks River as both a source and sink for pollution, the study found all of the sites to contain muds and sands typical of estuarine environments, as well as evidence of human contamination of the sediments including gravels, plastics and metals. These pollutants have settled in the river from a variety of sources including; industrial waste, possibly the most threatening to marine life is laden with toxic petroleum by-products and heavy metals; commercial waste, washed down with the storm water, often carries the kind of gross pollutants normally associated with shopping malls, such as plastic bottles, bags, and paper waste.; storm water also carries waste from impervious surfaces, such as roofs and roads; while rain washing the dust off roads transports numerous metallic compounds and other contaminants, which until recently included leaded petrol(Albani 2011). Albani's 2011 report outlines the sources and extent of pollutants found within the Cook's River.

All of the monitoring projects conducted within the Cooks River are of benefit, and assist in gaining an understanding of the health of the river and long-term monitoring can indicate any changes. It is, however, difficult to make any firm conclusions from these results without having an understanding of and making comparisons with the other components of the river system. Combining all the results from these projects would fill gaps in current knowledge of the Cooks River and assist in making firmer conclusions from survey results.

5 Recommendations

5.1 Improving the health of the Cooks River

5.1.1 Short Term (1-2 years)

Given that *RiverScience: Cooks River Ecological Monitoring Program* has been running for 5 years, it is recommended that the program be reviewed over the next year to assess and evaluate the efficacy of its design. It is also recommended that the following be considered in this review:

- **Further statistical analysis** - univariate and multivariate analyses were conducted on the benthic data from 2005-06, 2010 and 2011 surveys, for the first time since the surveys began. Further analyses could also be conducted with this data to test the overall health of the biota through a vigorous comparison with other biota in other estuaries with similar salinities and sediment types.
- **Further benthic invertebrate sampling:** – it will be important to monitor the range of classes found at all sites in future as the presence of a broad range of classes is indicative of a healthy ecosystem. Future assessments should consider as a goal an increase in the abundance not only of the class Amphipoda but also of polychaete families Hesionidae and Oweniidae at all sites. This would indicate a restoration of some elements of macrobenthic community assemblage within the Cooks River as they are more sensitive families more common in unpolluted waters (A. Jones, *pers. comm.*). Ideally these families could be further identified to species level to give a more accurate indication of species richness and allow for conclusions to be drawn on the health of the Cooks River via indicator species present (Bilyard 1987).
- **Fixed location quadrats for bare space monitoring:** - fixed location quadrats for the bare space monitoring would assist in making more accurate assumptions in any changes over time.
- **Macrophyte health:** – some sites, such as Beaman Park and Muddy Creek where Mangrove and Saltmarsh were surveyed, still capture noticeable levels of rubbish and ways to reduce these gross pollutants needs to continue and even increase. Further surveys to identify and monitor existing fragments of saltmarsh vegetation in the Cooks River and Wolli Creek estuary should be a priority, as should reconstructed saltmarsh as this provides habitat and feeding ground for terrestrial and aquatic species

5.1.2 Medium Term (2+ years)

- **Ongoing coordination of monitoring**: the Cooks River runs through six LGAs and receives stormwater runoff and groundwater from portions of 13 LGAs. Numerous state agencies and major landholders also impact upon or have an interest in the Cooks River. To this end, it is important to bring together the results of stakeholder projects and programs, to inform future works and management regimes. It is recommended in the future for this program to be conducted by the Cooks River Alliance.
- **Mapping of sediment distributions:** - this would locate areas within the river that are carrying pollution, known as hotspots; this has also been completed for nearby estuaries in Port Jackson (Professor Gavin Birch, Sydney University) and the Hawkesbury (Sydney Water) and could be done as an extension to the already completed sediment study conducted by UNSW (Albani 2011). This knowledge could also be combined with the details of survey sites for the water quality and RiverScience surveys, allowing a deeper understanding of the current state of the Cooks River, in a broad, ecosystem context and also on a site-by-site basis. This

information could further assist with providing the basis of an alternative biota design and guiding the most appropriate management regimes.

- **Studies on the hydrology of the river**: a conceptual model of hydro-dynamic flows within the river would provide information on how contaminants move through the estuary and be useful in determining the most appropriate practices and/or rehabilitation. For example, an option for locations with heavily contaminated sediments would be to cap these with clean sediments (such has been done in Homebush Bay). However, the success of this measure would be determined by the hydrology of the river.

5.1.3 Ongoing

- **Naturalising the river banks:** the sites with the highest invertebrate diversity and best saltmarsh and mangrove health have the most natural river banks. Naturalisation can greatly improve the river bank habitat for native birds and animals; wetlands are also established as part of this process and these have a positive role in improving the river's ecology and health by treating stormwater runoff from streets and industrial areas before it enters the river
- **Integrating monitoring projects**: – monitoring through water quality testing is currently occurring on the Cooks River through the Botany Bay Water Quality Improvement Program buoys, the Cooks River Valley Association (CRVA) Streamwatch program and through the grant-funded Community River Health Monitoring through the Georges River Combined Councils Committee. It would be beneficial for this data to be integrated to assist in identifying reasons behind the relatively poor diversity and abundance of organisms at some sites, provide a deeper understanding of river health and assist in developing management regimes.
- **Water quality monitoring and assessment:** monitoring and assessment of estuary sites and freshwater inputs to assist with the identification of problem waterways and tributaries contributing the most pollution and continue with targeted implementation of Water Sensitive Urban Design (WSUD).

References

AHA Ecology (2007). Cooks River Ecological Monitoring Program RiverScience Interpretation Project. Report prepared for the RiverScience Steering Committee, 24 pp.

Albani, A (2005). *Cooks River Survey*. Sydney, UNSW. (available at http://www.canterbury.nsw.gov.au/www/html/223-cooks-river-survey.asp)

Albani, A (2011) Cooks River – *Environmental Assessment, Part 2: Cores.* Report prepared for Rockdale City Council. UNSW Global Pty Ltd. 45pp

Anderson MJ (2001) A new method for non-parametric multivariate analysis of variance. Austral Ecology 26:32-46

AWS (2006) The Australian Weeds Strategy - A national strategy for weed management in Australia. Natural Resource Management Ministerial Council, Australian Government Department of the Environment and Water Resources, Canberra ACT. www.weeds.gov.au/publications/strategies/pubs/weed-strategy.pdf Accessed July 2011

Besley, C. (1995). *Interpretive Report: Biological indicators pilot study intertidal rock platform assemblages*. Sydney, Australian Water Technologies EnSight.

Bilyard, G.R. (1987). The value of benthic infauna in marine pollution monitoring studies. Marine Pollution Bulletin 18: 581-585

Brack C.L & Wood G.B (1997) Quantifying the tree crown. Australian National University, Canberra Australia. Viewed Dec, 2011 http://fennerschool-associated.anu.edu.au/mensuration/BrackandWood1998/CROWN.HTM#diameter

CERS (2006a). *Cooks River Ecological Monitoring Program – Phase I: Pilot Study and Monitoring Program Design*. Report prepared for the RiverScience Committee. 126pp.

CERS (2006b). *Cooks River Ecological Monitoring Program – Phase II: Vegetation Mapping and Benchmark Data for Macrophyte and Invertebrate Indicators*. Report prepared for the RiverScience Committee. 151pp.

Clarke KR, Gorley RN (2006) Primer v6: In: PRIMER-E: Plymouth, UK

Clarke KR (1993) Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology 18:117-143

Coutenay, Glenn Christopher, Gladstone, William & Schreider, Maria (2005) Assessing the response of estuarine intertidal assemblages to urbanised catchment discharge. *Environmental Monitoring and Assessment* **107**: 375-398

Cooks River Catchment Management Committee (1999) *Cooks River Catchment Management Strategy*. Sydney, Cooks River Catchment Management Committee.

2008-09 Annual Streamwatch Report. Published by Cooks River Valley Association (CRVA).

2009-10. Annual Streamwatch Report. Published by Cooks River Valley Association (CRVA)

2010-11 Annual Streamwatch Report. Published by Cooks River Valley Association (CRVA).

Deeley, D.M. & Paling, E.I (1999) Assessing the ecological health of estuaries in Australia. Urban Subprogram No. 10.

DAFF (2011) Sleeper Weeds. Department of Agriculture Fisheries and Forestry (2011). http://www.daff.gov.au/brs/land/weeds/sleeper Viewed July, 2011

DECCW (2010) Techniques for measuring stand basal area. Private native forestry code of practice guideline No. 5. Department of Environment, Climate Change and Water. Sydney Australia. Viewed Dec, 2011. http://www.environment.nsw.gov.au/resources/vegetation/10175basalstandarea.pdf

Eco Logical Australia (2010) *RiverScience Ecological Monitoring Program (Cooks River) Round 4 Monitoring*, Report prepared for the RiverScience Steering Committee, 36pp.

Eco Logical Australia (2009a) *RiverScience Ecological Monitoring Program (Cooks River) Round 3 Monitoring*, Report prepared for the RiverScience Steering Committee, 30pp.

Eco Logical Australia (2009b) *Cooks River Estuarine Vegetation Management Plan*, Report prepared for the Cooks River Foreshores Working Group, 71pp.

Eco Logical Australia (2007a) *RiverScience Ecological Monitoring Program (Cooks River) Round 2 Monitoring December 2007*, Report prepared for the RiverScience Steering Committee, 25pp.

Eco Logical Australia (2007b) *RiverScience Ecological Monitoring Program (Cooks River) Comparison of Hard Substrate Organism Photographs (2005/06 – 2007)*, Report prepared for the RiverScience Steering Committee, 8pp.

Eco-Logical Australia (2010) Estuarine Vegetation Management Plan Report prepared for City of Canterbury, Marrickville and Rockdale Councils on behalf of the Cooks River Foreshores Working Group

Gómez Gesteira, J.L., Dauvin, J.C. (2000). Amphipods are good bio-indicators of the impact of oil spills on soft-bottom macrobenthic communities. *Marine Pollution Bulletin* **40:** 1017–1027.

Groves RH, Boden R, Lonsdale WM (2005) Jumping the garden fence: invasive garden plants in Australia and their environmental and agricultural impacts. CSIRO report prepared for WWF-Australia. WWF-Australia, Sydney.

Jones, A.R (1990) Zoobenthic variability associated with a flood and drought in the Hawkesbury Estuary New South Wales: Some consequences for environmental monitoring. *Environmental Monitoring and Assessment* **14***: 185-195*

Lindegarth M & Hoskin M (2001) Patterns of distribution of macro-fauna in different types of estuarine, soft sediment habitats adjacent to urban and non-urban areas. *Estuarine, Coastal and Shelf Science* **52:** 237-247.

Mazumder, D. & Saintilan, N. (2003). A comparison of sampling techniques in the assessment of burrowing crab abundance in saltmarsh and mangrove environments. *Wetlands (Australia)* **21**: 1-15.

McArdle BH & Anderson MJ (2001) Fitting multivariate models to community data: a comment on distance-based redundancy analysis. Ecology 82:290-297

Miller, Wendy & Boulton, Andrew J. (2005) Managing and rehabilitating ecosystem processes in regional urban streams in Australia. *Hydrbiologia* **552**: 121-133

Minchinton T.E (2001) Canopy and substratum heterogeneity influence recruitment of the mangrove *Avicennia marina*. *Journal of Ecology* **89**: 999-902.

NYCSWCD (2010) Forestry Measurements. New York City Soil and Water Conservation District. Viewed Dec, 2011 http://www.nycswcd.net/files/Forestry%20Measurements.pdf

Reynoldson, Trefor, B. (1987) Interactions between sediment contaminants and benthic organisms. *Hydrobiologia* **149**: 53-66

Simpson, Stuart, L., Batley, Graeme, E., Chariton, Anthony, A., Stauber, Jenny, L., King, Catherine, K., Chapman, John, C., Hyne, Ross, V., Gale, Sharyn, A. & Roach, Anthony, C. (2005) Handbook for Sediment Quality Assessment. Environmental Trust, CSIRO.

Stark JS (1998) Heavy metal pollution and macrobenthic assemblages in soft sediments in two Sydney estuaries, Australia. *Marine and Freshwater Research* **49:** 533-540.

Ward T, Butler E & Hill B 1998 Environmental indicators for national state of the environment reporting – Estuaries and the Sea, Australia: State of the Environment (Environmental Indicator Reports). Department of the Environment, Canberra

Wildsmith M.D, Rose T.H, Potter I.C., Warwick R.M, & Clarke, K.R. (2010) Benthic macroinvertebrates as indicators of environmental deterioration in a large microtidal estuary. *Marine Pollution Bulletin* In press.

Wildsmith M.D, Rose T.H, Potter I.C., Warwick R.M, Clarke, K.R. & Valesinsi, F.J (2009) Changes in the benthic macroinvertebrate fauna of a large microtidal estuary following extreme modifications aimed at reducing eutrophication. *Marine Pollution Bulletin* **58:** 1250–1262

Appendix 1: Site Profiles

Note: Co-ordinates are presented as decimal degrees (GDA1994 MGA Zone 56) and as Easting and Northing.

Benthic and Crab Monitoring Sites

Site	Coordinates	Access Notes	Sample Date	Habitat Type	Comments
BC1 Muddy Creek (Rockdale LGA)	Benthic samples: 33.9475°S, 151.1581°E 6242137.912, 329788.8405 Crab observations: 33.9474°S, 151.1581°E 6242150.384, 329793.0958	Foot access via bike path within Kyeemagh Boatramp Reserve	11/11/11, 15:30	Fringing mangrove, thick Sydney oyster bed at low water mark	Birds using site, including Silver Eye, Australian White Ibis, Indian Myna.
BC2 Cooks River (Cahill Park, Rockdale LGA)	Benthic samples: 33.9318°S, 151.1564°E 6243875.599, 329597.7361 Crab observations: 33.9318°S, 151.1564°E 6243871.433, 329601.8417	Foot access from Cahill Park. Site adjacent to storm-water outfall.	11/11/11, 13:40	Sand spit.	Shorebirds using site, including Silver Gull, Reef Egret, Pied Cormorant.
BC3 Fatima Is (Marrickville LGA)	Benthic samples: 33.927°S, 151.1568°E 6244407.015, 329627.3245 Crab observations: 33.927°S, 151.1568°E 6244404.593, 329625.5306	Foot access from Kendrick Park. Sampled sandy beach mouthward of mangroves.	10/11/11, 16:30	Sandy beach.	Birds using site, including Pied Cormorant, Australian White Ibis, Silver gulls. Severe bank erosion – Artificial Rock wall not stable
BC4 Wolli Creek Mangrove (Canterbury LGA)	Benthic samples: 33.9274°S, 151.1505°E 6244356.39, 329041.6128 Crab observations: 33.9274°S, 151.1505°E 6244357.392, 329050.7109	Foot access via Waterworth Park.	10/11/11, 13:35	Rock outcrop adjacent to mangroves.	Very little litter present. Pacific Black Ducks present.
BC6 Brackish Saltmarsh (Canterbury LGA) CRAB	Crab observations: 33.9274°S, 151.1445°E 6244344.796, 328488.9872	Foot access along track beginning at end of Jackson St. Observations at fringe	10/11/11, 15:15	Saltmarsh on edge of mangrove forest.	Very little litter present. Little Black Cormorants present. Bank drops off steeply with

Site	Coordinates	Access Notes	Sample Date	Habitat Type	Comments
OBSERVATIONS ONLY ON SALTMARSH EDGE		of saltmarsh on mouth-ward side of fence.			erosion increasing from previous years.
BC7 Beaman Park (Canterbury LGA)	Benthic samples: 33.9189°S, 151.1381°E 6245278.515, 327880.7334 Crab observations: 33.9187°S, 151.1382°E 6245302.426, 327893.3076	Foot access via Beaman Park. Site just mouthward of footbridge.	09/11/11, 15:45	Mangrove.	Large amount of litter. Starling and Feral Pigeon observed. Mud anoxic, black and smelly. Leachate seeping into creek from within mud.
BC8 Campsie (Canterbury LGA)	Benthic samples: 33.9106°S, 151.1149°E 6246158.822, 325724.302 Crab observations: 33.9105°S, 151.1149°E 6246171.491, 325717.5105	Foot access via Tasker Park. Site just mouthward of footbridge.	09/11/11, 12:30	Mangrove.	Moderate amount of litter. Silver Gulls present. Mud anoxic, black and smelly. Leachate seeping into creek from within mud.

Hard Substrate (Photographic) Monitoring Sites

Site	Coordinates	Access Notes	Sample Date, Time, Conditions	Habitat Type	Comments
P1 Cooks River Mouth (Rockdale LGA)	Photographs: 33.949°S, 151.1673°E 6241988.141, 330643.0904	Foot access via O'Dea Ave. Opposite air traffic control tower.	14/11/11, 16:45	Rock wall. Base of wall submerged at low tide.	Little litter present. Popular fishing spot. Silver Gulls observed.
P2 Muddy Creek (Rockdale LGA)	Photographs: 33.9466°S, 151.1593°E 6242234.316, 329902.1564	Foot access via bike path within Kyeemagh Boatramp Reserve	11/11/11, 16:45	Rock wall. Base of wall submerged at low tide.	Birds observed include Australian White Ibis and Indian Myna.
P3 Alexander Canal (Airport, Marrickville LGA)	Photographs: 33.9255°S, 151.1741°E 6244608.668, 331225.2133	Foot access off Airport Drive. Downstream of storm-water outfall.	14/11/11, 15:45	Concrete retainer. Base of wall submerged at low tide.	Moderate amount of litter present. No shorebirds observed. Directly under airport take-off and landing flight path.
P4 Tempe Reserve (Marrickville LGA)	Photographs: 33.9318°S, 151.1594°E 6243880.414, 329878.3806	Foot access from Tempe Recreation Reserve	11/11/11, 14:50	Rock wall. Exposed sand flat at base of wall with few, small mangroves.	Silver Gulls observed.
P5 Wolli Creek Mouth (Canterbury LGA)	Photographs: 33.9266°S, 151.1538°E 6244449.223, 329346.6013	Foot access via Waterworth Park. Between velodrome and Wolli Creek Station	10/11/11, 14:10	Rock outcrop. Exposed mud flat at base of wall with few, small mangroves.	Small amount of litter. Pacific Black Ducks observed.
P6 Steel Park (Canterbury LGA)	Photographs: 33.9225°S, 151.1454°E 6244893.382, 328563.7776	Foot access via bike path opposite Steel Park.	10/11/11, 13:05	Rock outcrop within mangroves.	Large amount of litter, close to homes. Adjacent to bike-path and close to dog off leash area. Silver Gulls observed.
P7 Beaman Park (Marrickville Golf Course Ironwall, Marrickville LGA)	Photographs: 33.9154°S, 151.1398°E 6245665.799, 328029.0321	Foot access via Marrickville Golf Course (Riverside Crescent)	09/11/11, 15:00	Ironwall with mud flat at base.	Moderate amount of litter. No shorebirds observed. Adjacent to golf course. Fully inundated at high tide.

Site	Coordinates	Access Notes	Sample Date, Time, Conditions	Habitat Type	Comments
P8 Beaman Park (Marrickville Golf Course Rock Outcrop, Marrickville LGA)	Photographs: 33.9157ºS, 151.1400ºE 6245633.709, 328047.9558	Adjacent to site P7.	09/11/11, 14:30	Isolated and very small rock outcrop within mangroves.	100+ pieces of litter per 10m bank – accumulated within mangrove roots. No shorebirds observed. Adjacent to golf course.
P9 Old Sugar Works (Canterbury LGA)	Photographs: 33.9142ºS, 151.1226ºE 6245768.989, 326440.8737	Foot access via Sutton Reserve (Church St).	09/11/11, 14:00	Ironwall with mud flat at base.	Moderate amount of litter. Popular fishing spot. Oily slick on water's surface. Adjacent boat harbor anoxic pool of water and mud, emitting sulphurous-smelling gas. No Shorebirds observed.
P10 Campsie (Canterbury Rd, Canterbury LGA)	Photographs: 33.9137ºS, 151.1180ºE 6245823.258, 326014.4158	Food access via bike-path from Close St.	09/11/11, 13:30	Concrete retainer (dry at low tide) with mud flat at base.	Adjacent to mangroves with moderate accumulations of litter. No Shorebirds observed Underneath Canterbury Rd (high traffic volume).

Benthic and Crab Monitoring Sites

Site	Coordinates	Access Notes	Sample Date	Habitat Type	Comments
M1 Muddy Creek (Rockdale LGA)	33.9474°S, 151.1583°E	Foot access via bike path within Kyeemagh Boatramp Reserve	16/12/11, 17:30	Mangroves	Lot of litter & rubbish
M2 Beaman Park	33.9187°S, 151.1382°E	Foot access via Beaman Park. Site just mouthward of footbridge.	19/12/11, 10:30	Mangroves	Lot of litter & rubbish
M3 Wolli Creek	33.9274°S, 151.1533°E	Foot access via Waterworth Park. Between velodrome and Wolli Creek Station	21/12/11, 11:30	Saltmarsh and Mangroves	

Mangrove and saltmarsh vegetation surveys were conducted in December of 2005, 2008 and 2011 at three sites in the Cooks River: Muddy Creek (), Wolli Creek (33.9274°S, 151.1533°E) and Beaman Park (33.9187°S, 151.1382°E).

Appendix 2: Statistical Analysis – Benthic Invertebrates

Average abundance and taxa richness at family level

Table 1: Results of two-factor, analysis of variance and Scheffe post hoc multiple comparison tests for the effect of site (Muddy Creek, Cooks River, Fatima Island, Wolli Creek, Beaman Park and Campsie; *df* = 5, 78), time (2006, 2010, 2011; *df* = 2, 78) and their interaction (*df* = 10, 78) for benthic taxa abundance and richness. For all variables, data were transformed to the square root.

Variable	Site		Time		Site x Time	
	F	P	*F*	*P*	*F*	*P*
Abundance	58.747	<0.001	443.440	<0.001	40.640	<0.001
Richness	15.438	<0.001	237.200	<0.001	9.385	<0.001
Scheffe post hoc tests	2005-06--2010		2006-2011		2010 - 2011	
	Abundance	Richness	Abundance	Richness	Abundance	Richness
BC 1 - Muddy Creek	2006<2010 **	ns	2006 < 2010 ***	2006 < 2010 **	2006 < 2010 ***	ns
BC 2 Cooks River	2006 < 2010 ***	2006 < 2010 ***	2006 < 2010 ***	2006 < 2010 ***	ns	ns
BC 3 Fatima Island	2006 < 2010 ***	2006 < 2010 ***	2006 < 2010 ***	2006 < 2010 ***	ns	ns
BC 4 Wolli Creek	ns	ns	2006 < 2010 ***	2006 < 2010 **	2006 < 2010 *	ns
BC 6 Beaman Park	ns	ns	2006 < 2010 ***	2006 < 2010 ***	2006 < 2010 ***	2006 < 2010 *
BC 8 Campsie	2006 < 2010 ***	2006 < 2010 ***	2006 < 2010 ***	2006 < 2010 ***	2006 < 2010 ***	2006 < 2010 ***

ns = not significant, *<0.05, **<0.01, ***<0.001.

Relative abundance and taxa richness of Polychaeta, Mollusca and Crustacea

Table 2: Results of two-factor, analysis of variance for the effect of site (Muddy Creek, Cooks River, Fatima Island, Wolli Creek, Beaman Park and Campsie; *df* = 5, 78), time (2006, 2010, 2011; *df* = 2, 78) and their interaction (*df* = 10, 78) on the percentage abundance and taxa richness of Polychaeta, Mollusca and Crustacea. For all variables, data were transformed to the arcsine of their square root.

Variable	Site		Time		Site x Time	
	F	P	F	P	F	P
Abundance		ns				
-Polychaeta	2.952	**0.017**	48.895	**< 0.001**	2.484	**0.012**
- Mollusca	3.966	**0.003**	2.552	0.084	3.488	**<0.001**
- Crustacea	2.318	0.051	0.034	0.967	1.252	0.269
Taxa richness	ns	ns				
- Polychaeta	2.472	**0.039**	20.561	**<0.001**	2.876	**0.004**
- Mollusca	1.727	0.138	0.595	0.554	2.431	**0.014**
- Crustacea	2.332	0.050	1.999	0.142	0.831	0.601

Table 3: Results of Scheffe post hoc multiple comparison tests for the interaction effect of site (Muddy Creek, Cooks River, Fatima Island, Wolli Creek, Beaman Park and Campsie) and time (2006, 2010, and 2011) for Polychaeta and Mollusca percent taxa abundance and richness. For all variables, data were transformed to the square root.

Scheffe post hoc tests	2005-06--2010		2006-2011		2010 - 2011	
	Abundance	Richness	Abundance	Richness	Abundance	Richness
Polychaeta		ns				
- BC1 Muddy Creek	ns	ns	ns	ns	ns	ns
- BC2 Cooks River	2006 < 2010 **	2006 < 2010*	2006 < 2011*	ns	ns	ns
-- BC3 Fatima Island	2006 < 2010 ***	2006 < 2010 **	2006 < 2011*	ns	ns	ns
- BC 4 Wolli Creek	ns	ns	ns	ns	ns	ns
- BC 6 Beaman Park	ns	ns	ns	ns	ns	ns
- BC 8 Campsie	ns	ns	ns	ns	ns	ns
Mollusca						
- BC1 Muddy Creek	ns	ns	ns	ns	ns	ns
- BC 2Cooks River	ns	ns	ns	ns	ns	ns
--BC 3 Fatima Island	ns	ns	ns	ns	ns	ns
- BC 4 Wolli Creek	ns	ns	ns	ns	ns	ns
- BC 6 Beaman Park	ns	ns	ns	ns	ns	ns
- BC 8 Campsie	ns	ns	ns	ns	ns	ns

ns = not significant, *<0.05; **<0.01; ***<0.001.

Benthic community composition

Table 4: Benthic invertebrate taxa with average dissimilarities between years (2006, 2010, and 2011) for each site (Muddy Creek, Cooks River, Fatima Island, Wolli Creek, Beaman Park and Campsie) based on Bray-Curtis similarity on fourth-root transformed data. Taxa are listed in ascending order according to their percent contribution and cumulative contribution to respective dissimilarity between years for each site.

SIMPER	2005-06--2010			2006-2011				2010 - 2011			
	Dissimilarity	Contrib. (%)	Cum... (%)		Dissimilarity	Contrib. (%)	Cum... (%)		Dissimilarity	Contrib. (%)	Cum... (%)
BC1 - Muddy Creek	97.92				94.92				53.57		
Nephtyidae (P)		19.33	19.33	Capitellidae (P)		19.74	19.74	Spionidae (P)		18.98	18.98
Sabellidae (P)		17.83	37.76	Spionidae (P)		15.34	35.07	Capitellidae (P)		16.93	35.92
Capitellidae (P)		12.15	49.92	Nassariidae (M)		9.14	44.22	Galeommatidae (M)		10.44	46.36
Nassariidae (M)		7.51	57.43	Sabellidae (P)		9.03	53.25	Nephtyidae (P)		10.39	56.75
BC2 - Cooks River	92.80				ns				31.95		
Capitellidae (P)		18.26	18.26					Paracalliopiidae (C)		8.49	8.49
Nereididae (P)		16.77	35.03					Sabellidae (P)		8.48	16.97
Spionidae (P)		12.52	47.56					Nassariidae (M)		8.29	25.26
Nassariidae (M)		12.35	59.90					Nereididae (P)		7.85	33.11
								Galeommatidae (M)		7.08	40.19
								Spionidae (P)		7.07	47.26
								Oligochaeta		6.88	54.14
BC3 –Fatima Island	ns				ns				46.55		
								Sabellidae (P)		12.39	12.39
								Oligochaeta		11.36	23.75
								Nassariidae (M)		9.94	33.68
								Amphibolidae (M)		6.47	40.15
								Nereididae (P)		6.09	46.24
								Spionidae (P)		5.64	51.88
BC4 - Wolli Creek	76.53				72.57				57.02		

SIMPER	2005-06--2010			2006-2011				2010 - 2011			
	Dissimilarity	Contrib. (%)	Cum... (%)		Dissimilarity	Contrib. (%)	Cum... (%)		Dissimilarity	Contrib. (%)	Cum... (%)
Nephtyidae (P)		15.73	15.73	Sabellidae (P)		13.01	13.01	Sabellidae (P)		17.25	17.25
Neoleptonidae (M)		15.61	31.35	Melitidae (C)		9.67	22.67	Spionidae (P)		10.60	27.85
Melitidae (C)		12.19	43.53	Neoleptonidae (M)		9.30	31.97	Galeommatidae (M)		7.92	35.76
Oligochaeta		8.12	51.65	Nephtyidae (P)		8.89	40.86	Copepoda		6.00	41.76
				Galeommatidae (M)		6.56	47.42	Melitidae (C)		5.97	47.73
				Oligochaeta		6.42	53.84	Amphibolidae (M)		5.44	53.17
<u>BC6 – Beaman Park</u>	76.53				72.57				57.02		
Neoleptonidae (M)		18.04	18.04	Sabellidae (P)		10.66	10.66	Sabellidae (P)		11.86	11.86
Nephtyidae (P)		12.89	30.93	Neoleptonidae (M)		9.98	20.65	Capitellidae (P)		10.05	21.91
Mytilidae (M)		10.49	41.43	Galeommatidae (M)		8.95	29.60	Mytilidae (M)		7.00	28.91
Oligochaeta		9.59	51.02	Oligochaeta		7.63	37.23	Galeommatidae (M)		6.82	35.73
				Capitellidae (P)		7.39	44.62	Corophiidae (C)		6.78	42.51
				Nephtyidae (P)		7.23	51.85	Hydrobiidae (M)		6.55	49.06
								Copepoda		6.31	55.36
<u>BC8 - Campsie</u>	90.00				95.04				60.83		
Oligochaeta		27.09	27.09	Oligochaeta		15.48	15.48	Sabellidae (P)		10.23	10.23
Insecta		26.79	53.88	Nereididae (P)		9.56	25.04	Nereididae (P)		9.07	19.30
				Sabellidae (P)		8.29	33.33	Spionidae (P)		8.45	27.76
				Galeommatidae (M)		7.98	41.31	Hydrobiidae (M)		8.12	35.88
				Hydrobiidae (M)		7.05	48.37	Galeommatidae (M)		7.38	43.26
				Insecta		6.89	55.25	Oligochaeta		6.83	50.09

ns = not significant (from pairwise comparisons between year for each site).

P = Polychaeta; M = Mollusca; C = Crustacea

Table 5: Benthic invertebrate taxa with average similarities within years (2006, 2010, and 2011) for each site (Muddy Creek, Cooks River, Fatima Island, Wolli Creek, Beaman Park and Campsie) based on Bray-Curtis similarity on fourth-root transformed data. Taxa are listed in ascending order according to their percent contribution and cumulative contribution to respective similarity between years for each site.

SIMPER	2005-06			2010				2011			
	Similarity	Contrib. (%)	Cum... (%)		Similarity	Contrib. (%)	Cum... (%)		Similarity	Contrib. (%)	Cum... (%)
BC1 - Muddy Creek	14.26				59.20				85.44		
Laternulidae (M)		23.37	23.37	Nephtyidae (P)		33.00	33.00	Capitellidae (P)		24.95	24.95
Nereididae (P)		22.76	46.13	Sabellidae (P)		32.26	65.26	Spionidae (P)		18.26	43.22
Cirolanidae (C)		22.36	68.49					Nereididae (P)		11.22	54.44
BC2 – Cooks River	All similarities for 2006 were zero				78.47				70.33		
				Nereididae (P)		25.55	25.55	Capitellidae (P)		23.56	23.56
				Capitellidae (P)		22.27	47.82	Spionidae (P)		17.87	41.44
				Nassariidae (M)		14.78	62.60	Nereididae (P)		17.41	58.85
BC3 –Fatima Island	Less than two samples				64.32				64.35		
				Nephtyidae (P)		32.37	32.37	Nephtyidae (P)		25.63	25.63
				Nereididae (P)		19.11	51.48	Sabellidae (P)		18.94	44.57
								Amphibolidae (M)		18.58	63.14
BC4 - Wolli Creek	69.03				69.17				71.62		
Neoleptonidae (M)		42.90	42.90	Nephtyidae (P)		24.64	24.64	Sabellidae (P)		16.09	16.09
Nereididae (P)		34.31	77.21	Nereididae (P)		22.12	46.76	Nereididae (P)		14.83	30.92
				Melitidae (C)		15.39	62.15	Melitidae (C)		11.82	42.74
								Nephtyidae (P)		11.62	54.36
BC6 – Beaman Park	67.34				65.22				81.07		
Neoleptonidae (M)		44.82	44.82	Nephtyidae (P)		24.28	24.28	Sabellidae (P)		11.50	11.50

SIMPER	2005-06 Similarity	Contrib. (%)	Cum... (%)		2010 Similarity	Contrib. (%)	Cum... (%)		2011 Similarity	Contrib. (%)	Cum... (%)
Nereididae (P)		33.85	78.66	Nereididae (P)		19.77	44.04	Nereididae (P)		10.08	21.58
				Oligochaeta		18.83	62.87	Capitellidae (P)		9.73	31.31
								Galeommatidae (M)		9.73	41.04
								Oligochaeta		9.04	50.08
BC8 - Campsie	18.67				65.84				85.45		
Sphaeromatidae (C)		78.57	78.57	Oligochaeta		42.86	42.86	Oligochaeta		19.18	19.18
				Insecta		39.19	82.05	Nereididae (P)		10.75	29.93
								Galeommatidae (M)		9.24	39.17
								Sabellidae (P)		8.98	48.15
								Hydrobiidae (M)		8.10	56.25

P = Polychaeta; M = Mollusca; C = Crustacea

Appendix 3: Benthic Data

Site Total

Family (no. of individuals)	Sites					
Polychaeta	BC1	BC2	BC3	BC4	BC7	BC8
Nereididae	12	39	12	67	71	189
Syllidae	1	0	0	0	0	6
Spionidae	110	59	3	6	7	49
Capetillidae	277	187	15	13	73	3
Orbiniidae	0	0	0	0	0	0
Sabellidae	13	37	94	148	143	112
Phyllodocidae	0	0	0	0	0	0
Lumbrineridae	0	0	0	0	0	0
Hesionidae	2	0	0	0	0	0
Nephtyidae	3	25	145	30	33	2
Oweniidae (New Family)	0	1	1	0	0	0
Gastropoda						
Hydrobiidae	0	0	0	0	22	55
Amphibolidae	0	0	53	12	7	0
Nassariidae	13	8	6	0	0	0
SubCl. Opistobranchia	0	0	0	1	0	0
Bivalvia						
Mytilidae	0	0	0	0	0	0
Galeommatidae	6	0	3	10	71	90
Psammobiidae	0	0	0	0	0	0
Tellinidae	0	1	0	1	1	0
Mactridae (New Family)	0	1	0	0	0	0
Unknown	0	0	0	0	2	16
Amphipoda						
Aoridae	0	0	2	1	7	0
Dexaminidae	0	0	0	1	0	0
Paracalliopiidae	2	3	0	0	0	0
Melitidae	0	0	4	52	5	3
Corophiidae (New Family)	0	2	3	1	15	3
Decapoda						
Ocypodididae	0	0	0	0	0	0
Grapsidae	0	0	1	1	0	0
Isopoda						
Sphaeromatidae	0	0	0	1	4	14
Gnathiidae (New Family)	0	0	0	1	0	0
Oligochaeta	3	3	2	8	52	>1700
Mysidacea	0	0	1	0	0	0
Podocopida	0	0	0	0	2	23

Appendix 4: Crab Observation Data

(Site Average using maximums)

	2011	2010	2009	2008	2007	2005-06
Site	Crabs	Crabs	Crabs	Crabs	Crabs	Crabs
BC1	0.5	0.0	3.3	4.5	2.0	4.2
BC2	3.3	3.8	3.8	0.5	2.0	0.8
BC3	0.2	4.8	3.5	2.3	3.5	1.5
BC4	5.8	8.3	4.2	4.8	4.7	2.0
BC6	0.0	0.0	2.0	0.3	0.3	1.0
BC7	0.0	0.8	2.3	3.0	2.8	ND
BC8	0.0	0.0	0.0	0.0	0.0	ND

Total Number of burrows

	2011
Site	No. of Burrows
BC1	27
BC2	28
BC3	9
BC4	40
BC6	38
BC7	19
BC8	0

Appendix 5: Hard Substrate Data

(Site Averages)

Site	Habitat	Species % Cover			
		Algae (green turf)	Sydney Rock Oyster	Barnacles	Bare Substrate
P1	Rock wall	3	81	0	16
P4	Rock wall	11	85	0	4
P2	Mangrove	12	88	0	0
P5	Mangrove	32	10	11	47
P6	Rock outcrop	2	15	13	69
P8	Rock outcrop	68	0	0	32
P7	Iron wall	4	0	70	26
P9	Iron wall	9	0	38	53
P3	Concrete wall	12	5	23	60
P10	Concrete wall	22	0	0	78