Port Curtis Macrobenthic Monitoring Programme

Gladstone Port Authority

October, 1999

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Central Queensland University
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1. Executive summary

The Gladstone Port Authority (GPA) commissioned the consultants WBM Oceanics, Australia, in 1993, to design a long term macrobenthic monitoring programme for Port Curtis to quantitatively assess whether current or future anthropogenic activities significantly impact macrobenthic fauna and the Port Curtis ecosystem. This programme was agreed by GPA and Queensland Environmental Protection Agency (EPA) to be the core of the marine environmental monitoring programme for Port Curtis. Since November 1995, GPA has sponsored macrobenthic sampling at 16 Stations across Port Curtis. Southern Pacific Petroleum Development (SPPD) supported additional sampling sites south of Friend Point and near the mouth of Flying Fox. Sampling occurred twice a year (April and November) and involved determination of macrobenthic species diversity, equitability and abundance, as well as sediment composition and organic matter content.

215, 950 individuals from 654 macrobenthic species were collected and sorted. Of these species, gastropods (marine snails) were most common with 237 species recorded, followed by polychaetes (marine worms) with 129 species, crustaceans (prawns, crabs etc) with 103 species, bivalves (shellfish) with 97 species and other assorted taxa with 88 species.

Stations 1 and 2, near Auckland Point, were low in species richness, diversity, abundance and equitability. Station 6 in contrast had high species richness, diversity and equitability. Station 11 at Curtis Island was relatively diverse, while Station 12 had very high abundance (low equitability). Station 14 and 16, at Grahams Creek were low in diversity and equitability.

Analysing the data by site, Site 2 (Clinton Coal Wharf) had high diversity and equitability, and Site 3 (Curtis Island) had high species richness and abundance. Of the SPPD stations, Station 22 in particular and Site 6 as a whole had low diversity compared to other stations in Port Curtis. High abundance of a few species at Station 22 caused diversity and equitability indices to be lowered.

Multivariate statistical analysis suggests that the macrobenthic community of Port Curtis is a mosaic of patches within which each community remains relatively similar over time. Multivariate analysis techniques provide a valuable tool for monitoring future changes in benthos, which may be associated with environmental change.

Several species of gastropods are common across all stations in Port Curtis. These species may become important as indicators of anthropogenic effects or environmental change.

Sediment type and organic matter are known to be closely related to macrobenthic community composition. Sediment varied greatly between stations and ranged from mud, to muddy sand and to sand with coarse granules. Preliminary observations suggest changes in species composition with sediment variation. Further sampling and analysis are required to further elucidate these relationships.

At this stage, there is no evidence of macrobenthic community degradation at sites, with changes in diversity between sites probably attributable to sediment composition. Any change to community composition over time as a result of environmental stress will be detected by multivariate statistical techniques and refined sampling design.

2. Introduction

Macrobenthic communities, both those living on the sediment or burrowing into it, directly interact with biological, physical and chemical components of the marine environment especially the sediment. Macrobenthic invertebrate communities are sensitive to environmental stress, including pollution, and can potentially detect gross and possibly subtle changes in the aquatic environment (Hartley, 1982; Steimle, 1990; Hammer, 1990). Scientific evidence of impacts in the marine macrobenthic community relies upon detection of statistically significant community changes in sentinel/disturbed areas, which do not occur in reference/undisturbed areas.

GPA determined, in consultation with EPA and the consultants WBM Oceanics, that macrobenthic communities will serve as the primary indicators for the long term monitoring of Gladstone Harbour (WBM, 1993). GPA together with the EPA conducted the Curtis Coast Study (QDEH, 1994), which encompassed Port Curtis and the Curtis Coast. This provides a baseline inventory of land and marine resources. During the period of this study GPA commissioned the consultants WBM Oceanics, Australia, to design a long term benthic monitoring programme for Port Curtis (WBM, 1993). A sampling design was mutually determined by GPA and WBM. This utilised power analysis techniques to predict an appropriate level of replication of sampling necessary to achieve the primary objective of such a monitoring programme, namely **"to quantitatively assess whether current or future anthropogenic activities significantly impact benthic fauna and the Port Curtis ecosystem"**. WBM Oceanics Australia have undertaken short term macrobenthic studies within Port Curtis for GPA and the Queensland Department of Environment, (WBM, 1990, 1991).

GPA in 1995 invited Central Queensland University (CQU), through its developing Centre for Environmental Management (CEM), to instigate long term marine environmental programmes for Port Curtis involving initially macrobenthos and later seagrass and mangroves programmes. The macrobenthic programme, in terms of design and implementation, explicitly follows the programme developed by GPA and WBM in 1993.

The WBM/GPA sampling design regime allowed for future expansion if required. SPPD supported an additional area south of Friend Point before the Narrows (Stations 17 - 20) from November 1995 and an area near the mouth of Flying Fox Creek from April 1997 (Stations 21 - 24). This report analyses data for sampling periods up to and including April 1998. Subsequent samples are yet to be processed.

3. Methodology

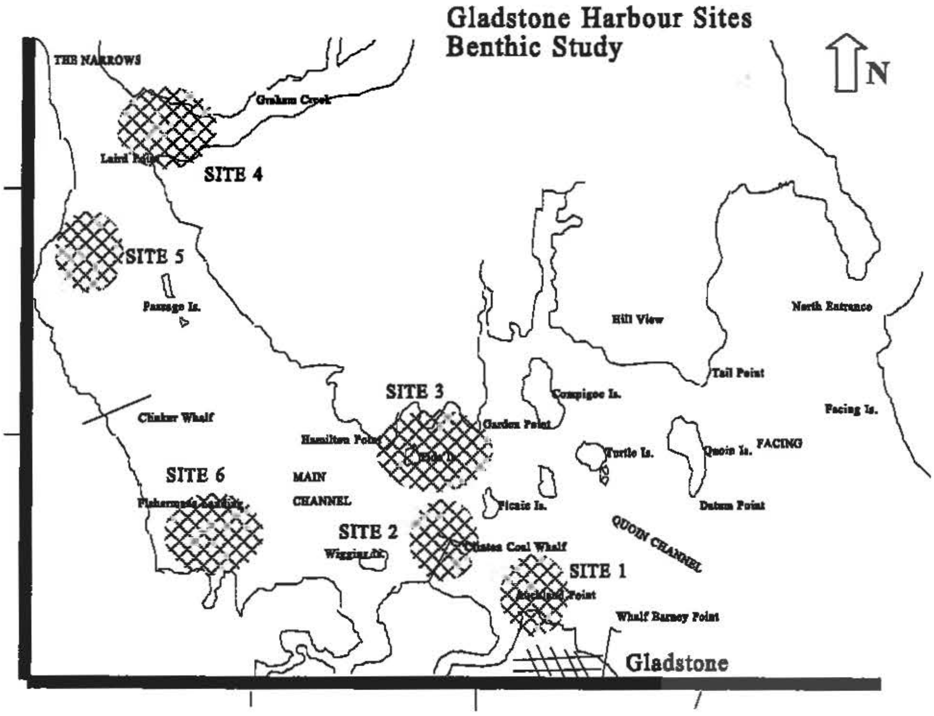
3.1 Sampling design

The Port Curtis Macrobenthic Monitoring Programme is a stratified sampling design using two environmental types, sentinel/disturbed sites and reference/undisturbed sites. Sentinel sites are located in the vicinity of Auckland Point Wharf and Clinton Coal Wharf. Reference sites are located adjacent to Curtis Island and at Graham Creek in the Narrows. Within each site, 4 stations were selected giving a pooled data set of 8 stations in sentinel sites and 8 stations in reference sites. Two additional sentinel sites (8 stations) have been located at Friend Point and adjacent to Flying Fox Creek making a total of 24 stations (16 sentinel and 8 reference).

Table 1. Macrobenthic sampling sites in Port Curtis.

Site Number	*Site Name*	*Station Numbers*	*Type*
1	Auckland Point & Wharf	1, 2, 3, 4	Sentinel
2	Clinton Coal Wharf	5, 6, 7, 8	Sentinel
3	Curtis Island	9, 10, 11, 12	Reference
4	Graham Creek	13, 14, 15, 16	Reference
5	Friend Point	17, 18, 19, 20	Sentinel
6	Fisherman's Landing /Flying Fox	21, 22, 23, 24	Sentinel

Figure 1. Macrobenthic sampling sites in Port Curtis.



3.2 Replication

Statistical power analysis indicated that replication of 10 samples per station effectively detected (with a power of >80%) changes of approximately 14% in benthic parameters, between each of the initial 4 sites (Sites 1-4), and between sentinel sites (Sites 1 and 2) and reference sites (Sites 3 and 4) (WBM, 1993).

3.3 Sampling frequency

Sampling occurs twice per year, in late dry season (November) and in late wet season (April). Sampling periods are periods of expected maximum and minimum benthic populations for Port Curtis.

3.4 Field collection

Samples were collected from a chartered vessel (MV RUYS) using a 0.018m^3 van Veen grab in November 1995, April 1996, November 1996, April 1997, November 1997, April 1998, November 1998 and April 1999. A small portion of sediment was collected from each sample and retained for particle size analysis. Samples were sieved through 1mm sieves and preserved in 5% formalin/seawater for at least 72 hours. Samples were later changed into 70% ethanol to which glycerol was added and stored for future sorting.

3.5 Laboratory sorting and classification

Samples were sorted using dissection microscopes and the abundance noted. The benthic fauna was identified to family level, separated and preserved for further identification as required. Line drawings were prepared for all fauna identified. Specimens were retained in a reference collection and will ultimately be sent to museums for formal identification and registration as voucher specimens. This process will require funding in the future.

3.6 Statistical analysis

Macrobenthic data were analysed to assess whether there were any spatial differences among sites or evident temporal trends. Statistical analysis of data was undertaken using both univariate and multivariate methods.

3.6.1 Univariate analysis

Two univariate indices were chosen to represent macrobenthic fauna assemblages at each station in each time period. The Shannon-Weiner index of diversity is dependent upon the number of species present, their relative proportions and the total sample size. Equitability is the ratio of observed diversity to that of a completely equal species frequency distribution (range 0-1). Equitability close to 1 indicates well distributed abundance across species, while low equitability reflects skewness. High species richness increases species diversity, and a more even or equitable distribution among species also increases diversity.

3.6.2 Multivariate analysis

A multidimensional scaling (MDS) analysis and one way analysis of similarity (ANOSIM) of abundance data for the 30 most common species was used to examine temporal trends in community structure.

A two way analysis of variance (ANOVA) was also undertaken on the Shannon-Weiner diversity indices calculated from all species found at each site versus time, using stations within each site as replicates. Considering the nature of the sampling, a two way Model II ANOVA was performed (sites and times were treated as random factors). A repeated measures ANOVA was not used since successive samples are not from exactly the same place within each site.

3.7 Sediment sampling

3.7.1 Air dry moisture content

Sediment samples were obtained using a van Veen grab from each benthic site in November 1995 to April 1999. Prior to the analysis of particle size distribution and organic matter content, the moisture content of air dry soil was determined to correct for the extra mass of water present in air dried samples (Bruce and Rayment, 1982). An approximate 100g sample of air dried sediment from each benthic site was weighed and placed in an oven at 105°C until constant mass was achieved as determined through subsequent weighing. Air dry moisture content was taken as the water remaining in the air dry sample expressed as a percentage of the oven dry sample mass (AS1289. B1.1, 1977).

3.7.2 Particle size analysis

Approximately 100 g of air dried sediment was ground with a mortar and pestle so as to retain discreet particles. The resultant sample was weighed and then sieved through an agitated stack of Endecott test sieves with apertures of 2mm, 1mm, 500μm, 250μm, 125μm and 63μm respectively. After dry sieving (the dry sieving process is only applicable for coarse sediment, sediment with a mixture of very coarse and fine particles may undergo both dry and wet sieving), the sediment fractions remaining on the sieves were then wet with sodium hexametaphosphate dispersing solution. This was allowed to stand for approximately one day. The resultant slurry was then hand washed through the sieve stack until the wash water was clear and the remaining material air dried at 40°C until constant mass was reached. Each fraction's mass was calculated as a percentage of the total samples mass and corrected for air dry moisture content. The fraction less than 63μm was calculated as the difference between the sum of the fractions greater than 63μm and the total mass of the sample (AS 1289. C6.1, 1977).

3.7.3 Total combustible matter (estimate of organic matter content)

Approximately 100 grams of sediment from each site was ground, placed in a crucible with a lid, and oven dried at 105°C until constant mass was reached. Mass was recorded and the samples placed in an ashing furnace to be combusted for one hour at a temperature of 850°C (AS 3580.

10.1, 1991). Samples were then removed and replaced in the drying oven at 105°C to cool before further weighing. The difference in mass between initial and final weighing was expressed as a percentage of the initial mass and used as an estimate of the percentage organic matter.

4. Results

4.1 Statistical analysis of benthos

Univariate analysis

215, 950 individuals from macrobenthic 654 species were collected and sorted. Of these species, gastropods (marine snails) were most common with 237 species recorded, followed by polychaetes (marine worms) with 129 species, crustaceans (crabs, prawns etc) with 103 species, bivalves (shellfish) with 97 species and other assorted taxa with 88 species.

Macrobenthic fauna abundance and diversity have been analysed from both station and site perspectives. Diversity and equitability indices, as well as species richness and abundance for all stations and sites are presented in Tables 2-9 (GPA stations and sites are highlighted). Means and standard deviations of diversity and equitability indices, species richness and abundance over time for stations (Table 10), sites (Table 11) are presented. Means and standard deviations of the above parameters were also determined for each sampling period to assess temporal changes occurred (Table 12).

Stations 1 and 2, near Auckland Point, were low in species richness, diversity, abundance and equitability. Station 6 in contrast had high species richness, diversity and equitability. Station 11 at Curtis Island was relatively diverse, while Station 12 had very high abundance (low equitability). Station 14 and 16, at Grahams Creek were low in diversity and equitability.

Analysing the data by site, Site 2 (Clinton Coal Wharf) had high diversity and equitability, and Site 3 (Curtis Island) had high species richness and abundance. Of the SPPD stations, Station 22 in particular and Site 6 as a whole had low diversity compared to other stations in Port Curtis. High abundance of a few species at Station 22 caused diversity and equitability indices to be lowered.

Table 2. Station diversity

	Site 1				Site 2				Site 3				Site 4				Site 5				Site 6			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Nov-95	2.93	3.29	2.97	3.54	3.33	3.44	3.78	3.83	4.14	3.30	3.73	2.91	3.14	2.96	3.31	2.91	2.63	2.66	3.47	3.00				
Apr-96	2.79	2.83	2.68	3.18	3.38	3.76	3.68	3.06	3.00	3.44	3.52	3.24	3.17	2.68	3.15	3.05	2.90	2.87	3.33	3.25				
Nov-96	2.81	2.20	3.48	3.17	3.70	3.74	3.73	3.14	3.57	2.59	3.70	3.47	3.18	2.80	3.26	2.81	2.91	2.72	3.55	3.33				
Apr-97	2.76	2.33	3.29	3.34	3.20	3.78	3.62	3.20	3.11	3.44	3.60	3.13	3.05	2.69	3.06	2.73	2.91	2.88	3.14	2.99	3.02	1.48	2.57	2.64
Nov-97	2.96	3.33	3.26	3.06	3.52	3.78	2.77	3.24	2.94	3.73	3.56	2.26	3.39	2.92	3.36	3.32	3.04	2.89	3.55	3.20	2.96	1.53	2.80	2.95
Apr-98	3.18	2.09	3.07	2.65	3.49	3.62	1.47	3.25	3.24	2.53	3.73	3.17	3.69	2.90	3.42	3.50	2.79	2.83	2.75	2.78	2.67	1.08	2.64	2.84

Table 3. Station equitability

	Site 1				Site 2				Site 3				Site 4				Site 5				Site 6			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Nov-95	0.67	0.77	0.75	0.81	0.73	0.71	0.81	0.83	0.84	0.69	0.78	0.59	0.67	0.70	0.73	0.66	0.58	0.59	0.71	0.68				
Apr-96	0.77	0.72	0.72	0.75	0.72	0.76	0.85	0.67	0.62	0.76	0.69	0.65	0.79	0.64	0.73	0.67	0.67	0.64	0.73	0.73				
Nov-96	0.69	0.54	0.82	0.76	0.81	0.81	0.82	0.79	0.73	0.60	0.76	0.70	0.72	0.66	0.73	0.70	0.69	0.66	0.75	0.72				
Apr-97	0.68	0.64	0.79	0.82	0.78	0.86	0.85	0.84	0.78	0.79	0.77	0.65	0.67	0.68	0.69	0.62	0.65	0.69	0.70	0.73	0.81	0.35	0.67	0.68
Nov-97	0.81	0.76	0.78	0.75	0.76	0.87	0.77	0.80	0.68	0.78	0.73	0.46	0.71	0.65	0.72	0.73	0.69	0.67	0.75	0.71	0.74	0.36	0.77	0.72
Apr-98	0.85	0.58	0.79	0.79	0.82	0.88	0.51	0.83	0.74	0.63	0.82	0.66	0.80	0.72	0.77	0.78	0.65	0.67	0.70	0.77	0.75	0.29	0.78	0.77

Table 4. Station species richness

	Site 1				Site 2				Site 3				Site 4				Site 5				Site 6			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Nov-95	80	73	53	78	96	127	104	99	141	105	116	140	108	70	93	84	91	90	137	84				
Apr-96	37	50	42	71	110	140	76	98	126	119	170	147	57	64	74	94	75	86	97	87				
Nov-96	59	59	71	66	99	101	97	53	133	95	131	142	81	72	87	57	68	61	114	105				
Apr-97	59	38	65	59	52	81	70	45	54	76	104	121	97	53	83	83	87	67	90	59	41	70	46	50
Nov-97	39	80	66	60	100	76	37	56	73	76	131	131	120	92	108	95	82	74	113	91	53	73	39	61
Apr-98	42	36	49	29	72	61	18	50	80	55	92	119	100	57	86	87	75	69	51	37	44	35	30	41

Table 5. Station abundance

	Site 1				Site 2				Site 3				Site 4				Site 5				Site 6			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Nov-95	1155	657	416	300	897	2772	575	557	1061	761	1069	7857	4101	728	1930	2114	3839	9094	2595	1248				
Apr-96	234	465	175	443	1975	2243	380	816	2156	2940	10830	6751	462	844	1903	4226	5170	4575	2427	1162				
Nov-96	733	1261	312	462	714	849	690	301	1453	1451	1579	5486	1413	722	870	617	2366	2612	1290	1708				
Apr-97	460	307	355	274	700	354	370	145	504	915	1669	3668	1469	500	2378	3662	3001	2821	1737	840	280	4037	722	1476
Nov-97	223	1287	364	509	1293	395	145	220	912	812	1804	8923	1816	1495	1999	1274	1988	2450	2059	1021	483	3028	374	782
Apr-98	117	656	239	129	536	217	131	224	896	571	983	4773	1213	667	1053	789	2269	2161	1111	312	358	6722	267	464

Table 6. Site diversity

	1	2	3	4	5	6
Nov-95	3.75	3.97	3.52	3.4	3.12	
Apr-96	3.72	3.8	3.63	3.33	3.31	
Nov-96	3.34	3.93	3.74	3.30	3.41	
Apr-97	3.54	3.78	3.47	3.16	3.24	2.47
Nov-97	3.81	3.95	2.88	3.52	3.48	2.49
Apr-98	3.22	3.83	3.58	3.79	2.97	1.54

Table 8. Site species richness

	1	2	3	4	5	6
Nov-95	180	215	249	187	199	
Apr-96	132	205	260	134	165	
Nov-96	150	158	227	123	161	
Apr-97	126	128	171	151	138	109
Nov-97	145	148	209	186	164	124
Apr-98	102	124	188	154	116	76

Table 7. Site equitability

	1	2	3	4	5	6
Nov-95	0.72	0.74	0.64	0.65	0.59	
Apr-96	0.76	0.71	0.65	0.68	0.65	
Nov-96	0.67	0.78	0.69	0.69	0.67	
Apr-97	0.73	0.78	0.68	0.63	0.66	0.53
Nov-97	0.77	0.79	0.54	0.67	0.68	0.52
Apr-98	0.7	0.79	0.68	0.75	0.62	0.36

Table 9. Site abundance

	1	2	3	4	5	6
Nov-95	2528	4801	10748	8873	16746	
Apr-96	1317	5414	22677	7435	13334	
Nov-96	2768	2554	9969	3622	7976	
Apr-97	1396	1569	6756	8009	8399	6515
Nov-97	2383	2043	2043	6584	7518	4667
Apr-98	1141	1108	7223	3722	5853	7811

Table 10. Mean and standard deviation of diversity and equitability indices, species ricnhness and abundance for stations (grouped sampling events).

		Site 1				Site 2				Site 3			
		1	2	3	4	5	6	7	8	9	10	11	12
Diversity	Mean	2.91	2.68	3.13	3.16	3.44	3.69	3.18	3.29	3.33	3.17	3.64	3.03
	S.D.	0.16	0.55	0.28	0.30	0.17	0.13	0.92	0.28	0.45	0.49	0.09	0.42
Equitability	Mean	0.75	0.67	0.78	0.78	0.77	0.82	0.77	0.79	0.73	0.71	0.76	0.62
	S.D.	0.08	0.10	0.04	0.03	0.04	0.07	0.13	0.06	0.08	0.08	0.04	0.09
Richness	Mean	52.7	56.0	57.7	60.5	88.2	97.7	67.0	66.8	101.2	87.7	124.0	133.3
	S.D.	16.57	18.08	11.34	16.98	21.75	30.8	33.6	24.8	36.6	23.1	27.21	11.57
Abundance	Mean	487	772	310	353	1019	1138	382	377	1164	1242	2989	6243
	S.D.	394	410	89	144	535	1094	224	258	574	883	3856	1970

		Site 4				Site 5				Site 6			
		13	14	15	16	17	18	19	20	21	22	23	24
Diversity	Mean	3.27	2.83	3.26	3.05	2.86	2.81	3.30	3.09	2.88	1.36	2.67	2.81
	S.D.	0.23	0.12	0.13	0.30	0.14	0.10	0.31	0.20	0.19	0.25	0.12	0.16
Equitability	Mean	0.73	0.68	0.73	0.69	0.66	0.65	0.72	0.72	0.77	0.33	0.74	0.72
	S.D.	0.06	0.03	0.03	0.06	0.04	0.04	0.02	0.03	0.04	0.04	0.06	0.05
Richness	Mean	93.8	68.0	88.5	83.3	79.7	74.5	100.3	77.2	46.0	59.3	38.3	50.7
	S.D.	22.16	13.84	11.40	13.84	8.57	11.33	29.13	24.71	6.24	21.13	8.02	10.02
Abundance	Mean	1746	826	1689	2114	3106	3952	1870	1049	374	4596	454	907
	S.D.	1239	346	592	1520	1209	2660	600	464	102	1909	238	518

Table 11. Mean and standard deviation of diversity and equitability indices, species ricnhness and abundance for sites (grouped sampling events).

		1	2	3	4	5	6
Diversity	Mean	3.563	3.877	3.47	3.417	3.255	2.167
	S.D.	0.24	0.083	0.304	0.218	0.188	0.543
Equitability	Mean	0.725	0.765	0.647	0.678	0.645	0.47
	S.D.	0.037	0.033	0.056	0.041	0.034	0.095
Richness	Mean	139.2	163	217.3	155.8	157.2	103
	S.D.	26.17	38.64	34.62	26.32	28.05	24.56
Abundance	Mean	1922	2915	9903	6374	9971	6331
	S.D.	713.9	1776	6968	2222	4163	1580

Table 12. Mean and standard deviation of diversity and equitability indices,species ricnhness and abundance for sampling events (grouped stations).

	Diversity		Equitability		Richness		Abundance	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
N-95	3.26	0.41	0.715	0.078	98.5	24.2	2186	2422
A-96	3.15	0.31	0.714	0.058	91.0	35.8	2509	2693
N-96	3.19	0.44	0.723	0.073	87.6	27.4	1344	1160
A-97	3.00	0.48	0.716	0.107	68.8	21.2	1360	1241
N-97	3.10	0.48	0.715	0.107	80.3	27.4	1486	1768
A-98	2.89	0.65	0.723	0.128	59.0	25.5	1119	1562

Multivariate analyses

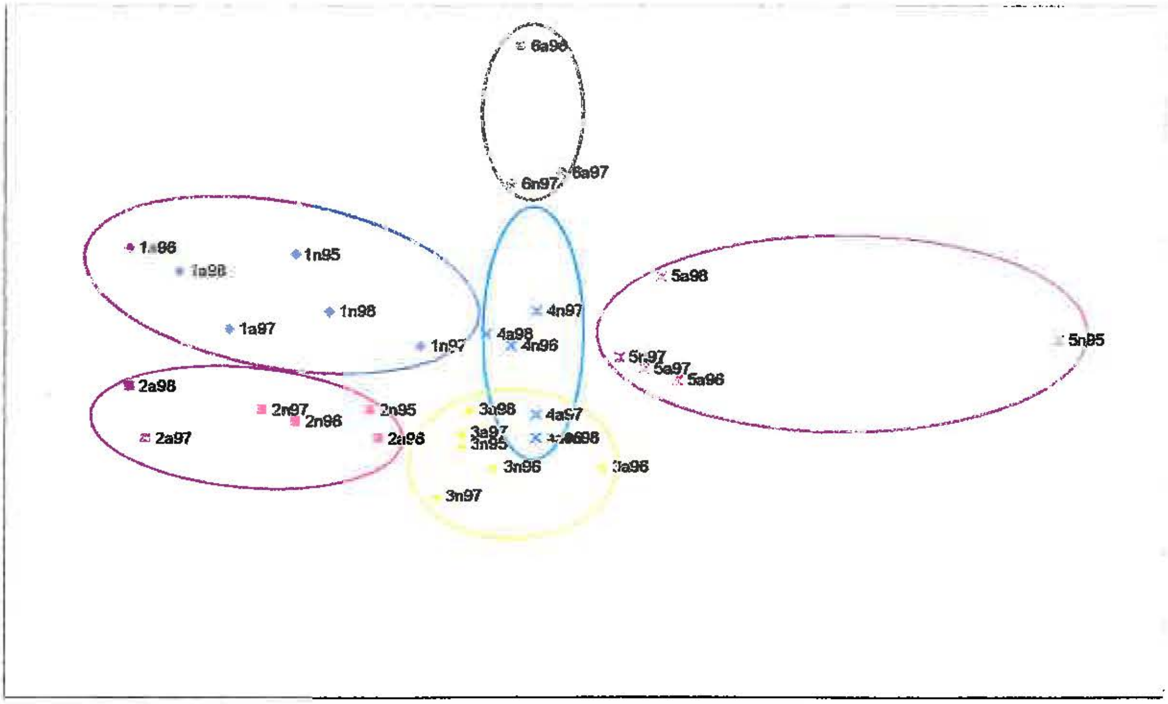
The MDS showed that there was no significant difference in community composition within sites over time ($p > 0.05$) but there were persistent and significant differences in community composition among sites ($p < 0.05$). This pattern is evident in Figure 2 which expresses the relationships among sites over time within a 2 dimensional space. Data are coded as a 4 character alphanumeric string where the first number is the site, the second the sampling month (April or November) and the last two numbers indicate the year. Interestingly the data do not appear very "noisy" - the set of data for each site remains relatively clustered over time.

The results suggest that within Port Curtis year to year variability is not significant but location is. The harbour could perhaps be viewed as a persistent mosaic of different communities. Consequently, gross changes in species composition (e.g. caused by some environmental perturbation, including seasonal freshwater flow) would show as the departure of a site from within the boundary of the region occupied by previous samples (ellipse in Figure 2) taken at that site, which would result in a significant effect of time.

By inspection of Figure 2 it can be seen that data for samples taken on several occasions at the same site are within a relatively tight cluster. Different sites occupy different parts of the space, which is consistent with differences among sites.

The ANOVA of species diversity also showed a significant difference amongst sites ($p < 0.05$) but no effect of time ($p > 0.05$) and no interaction ($p > 0.05$) between these factors. This means that diversity differs among sites but does not differ significantly over time, which is consistent with the MDS analysis reported above. The sites are different to each other, but variation within each site is insignificant over time. Again, therefore, any environmental perturbation that grossly affects community composition is likely to result in a change in diversity at the affected site that would be detected as an effect of time and perhaps a significant interaction between site and time.

Figure 2. MDS analysis of the macrobenthic data for Port Curtis, November 1995 to April 1996. Different sites are shown in different colours.
Stress = 0.10



4.2 Common and Rare Species

The macrobenthic communities encountered in Port Curtis consist of a relatively small number of species with high abundance and a large number of species with very low abundance. Three gastropod species (marine snails) were found to have very high abundance (greater than 10, 000 individuals).

While no species was found at every station in every sampling period, 11 species were found at every station in at least one sampling period. These comprise 10 gastropods (marine snails) and one formaniferan (a single celled animal secreting a calcium carbonate shell).

Species that were common to all stations were also generally abundant. These species are therefore assumed to be tolerant of a variety of sediment types and probably of different

4.3 Sediment characteristics

Particle size distribution was analysed for each sampling station and each sampling period (for both GPA and SPPD sites). A mean and standard deviation was calculated for each station over all sampling periods, and from this, a description given (Table 13). Sediment varied greatly between stations and ranged from mud, to muddy sand and to sand with coarse granules.

Table 14 shows the change in particle distribution for each station over time. Several stations exhibit large changes in particle size distribution over time.

Station 1, in Site 1, was moved in April 1998 due to land reclamation for a container wharf and 'hard stand area' at that site. Therefore soil and benthic samples from prior to April 1998 cannot be compared to those after this date. Sediment samples from Station 7 were not taken in April 1998 due to high rock content (consistent with previous particle size distribution). Stations 18 and 21 appeared to have greatly reduced silt and clay content. Station 19 had a large increase in silt and clay content in April 1998 possibly accounting for reduced diversity, species richness and abundance (Tables 2-5). Particle size distribution also varied at Stations 5, 6, 10, 12 and 16. Future monitoring will elucidate if significant change has occurred.

4.4 Sediment and benthos

Analysis of benthic assemblages with sediment type has not yet been completed. However, general observations suggest that different species composition occurs at stations with different sediment types (for example, gastropods from the family Collumbellidae occur more frequently in sandy sediments). Some species occur at several stations within Port Curtis irrespective of sediment composition. Further analysis of this data may elucidate trends between diversity, equitability, and species composition with sediment type in the harbour.

Table 13. Mean particle size distribution (%) and organic matter content (%) for macrobenthic stations in Port Curtis between November 1995 and April 1998. Dominant particle size for each station is in bold.

Station		Silt/Clay <63um	V.fine sand 63um	Fine sand 125um	Medium sand 250um	Coarse sand 500um	V. coarse sand 1um	Granules 2um	Organic Content	Description
1	Mean	**54.44**	15.47	9.70	8.88	6.12	1.04	1.86	7.72	Sandy mud
	S.D.	**29.03**	9.43	7.65	14.02	13.76	2.19	4.43	2.69	
2	Mean	**84.23**	8.50	2.30	0.57	0.22	0.16	0.24	9.71	Primarily mud
	S.D.	**4.47**	2.11	1.73	0.44	0.28	0.18	0.33	2.63	
3	Mean	0.30	0.49	2.58	13.52	15.01	10.98	**56.62**	5.21	Sandy with granules
	S.D.	0.20	0.44	2.27	6.98	6.05	6.03	**15.38**	1.34	
4	Mean	0.34	0.42	2.06	9.09	7.26	12.27	**68.12**	4.36	Sandy with granules
	S.D.	0.15	0.10	0.53	2.63	1.99	13.48	**15.74**	0.97	
5	Mean	16.73	5.96	11.93	**23.52**	8.42	6.75	22.46	7.23	Sandy with granules
	S.D.	13.24	3.41	3.76	**4.67**	3.38	2.08	18.90	1.95	
6	Mean	5.27	2.13	5.59	15.52	10.77	11.49	**48.56**	5.59	Sandy with granules
	S.D.	11.53	2.10	2.99	4.07	3.54	3.99	**14.57**	2.75	
7	Mean	0.51	0.87	2.40	12.17	12.92	8.38	**62.17**	6.02	Sandy with granules
	S.D.	0.18	0.59	1.50	7.21	6.18	4.77	**20.24**	0.77	
8	Mean	0.46	0.63	2.18	14.75	12.63	6.54	**62.36**	5.28	Sandy with granules
	S.D.	0.27	0.27	1.02	7.56	7.81	3.87	**19.26**	1.39	
9	Mean	1.15	1.83	11.96	19.70	9.96	12.16	**42.38**	7.51	Sandy with granules
	S.D.	0.53	0.63	5.04	4.89	2.29	3.26	**6.00**	2.25	
10	Mean	27.55	4.92	19.90	5.16	2.11	4.75	**34.49**	7.95	Muddy sand with granules
	S.D.	24.64	4.04	14.94	5.07	1.62	4.46	**41.23**	2.28	
11	Mean	9.19	4.76	19.13	12.70	9.68	11.66	**31.72**	12.06	Sandy with granules
	S.D.	9.31	1.34	6.41	5.25	5.54	6.50	**1.72**	1.33	
12	Mean	16.58	7.46	10.99	11.53	13.36	14.73	**23.98**	12.84	Muddy sand with granules
	S.D.	18.46	3.91	9.68	6.43	7.94	7.48	**12.56**	2.33	
13	Mean	17.07	2.12	12.19	7.96	7.69	12.36	**39.37**	8.91	Muddy sand with granules
	S.D.	4.43	1.01	3.40	2.68	3.72	4.18	**9.78**	2.57	
14	Mean	**72.85**	8.47	8.28	2.29	1.38	1.39	2.23	11.19	Primarily mud
	S.D.	**9.40**	5.39	3.86	1.23	1.03	1.02	1.74	1.70	
15	Mean	15.45	1.99	13.25	12.64	7.11	12.59	**35.94**	9.69	Muddy sand with granules
	S.D.	7.41	0.96	3.50	7.77	3.31	2.28	**8.35**	1.35	
16	Mean	22.76	2.62	10.74	13.19	7.25	9.94	**31.82**	9.60	Muddy sand with granules
	S.D.	23.02	1.04	2.65	13.82	4.34	5.45	**19.84**	2.11	
17	Mean	**63.91**	13.26	8.29	1.97	1.16	3.41	5.57	10.37	Sandy mud
	S.D.	**4.08**	4.30	1.85	0.41	0.43	4.14	2.77	0.87	
18	Mean	**51.57**	12.99	13.23	10.33	3.47	1.73	4.57	10.66	Sandy mud
	S.D.	**19.75**	5.15	0.64	17.93	6.35	1.29	1.81	2.04	
19	Mean	**36.54**	5.57	12.12	13.07	8.56	10.40	11.80	10.48	Muddy sand
	S.D.	**21.90**	4.19	8.11	7.53	6.32	6.77	7.66	1.83	
20	Mean	**50.64**	6.93	18.47	4.23	2.67	4.05	4.40	8.39	Sandy mud
	S.D.	**14.84**	5.26	7.64	3.01	1.99	3.89	2.69	3.31	
21	Mean	**60.92**	18.00	11.02	5.10	1.60	0.65	0.94	7.06	Sandy mud
	S.D.	**28.85**	2.39	13.77	8.24	2.65	1.00	1.51	1.56	
22	Mean	6.11	3.56	10.31	**32.33**	26.74	10.34	9.74	5.46	Sandy
	S.D.	8.29	2.59	4.94	**10.76**	13.80	1.17	9.97	2.25	
23	Mean	**61.78**	21.88	7.89	1.42	0.41	0.51	4.60	8.59	Sandy Mud
	S.D.	**10.38**	6.05	3.03	0.54	0.16	0.15	2.79	1.73	
24	Mean	**18.46**	11.98	15.10	16.30	14.18	10.55	12.77	5.40	Muddy sand
	S.D.	**4.31**	4.37	1.59	2.75	2.65	4.92	0.83	0.73	

4.5 Organic matter

Organic matter content is presented for each station (GPA and SPPD) over sampling periods (Table 14) and also as an average for each station within sites (Table 13). Organic matter was very variable over time and between stations with no clear trends present at this early stage.

Further statistical analysis will elucidate patterns between species composition and organic matter. Since silt and organic matter are thought to be closely related, benthic fauna found in silty areas would probably reflect species that prefer high organic loads.

5. Conclusions

215, 950 individuals from 654 macrobenthic species were collected and sorted. Of these species, gastropods (marine snails) were most common with 237 species recorded, followed by polychaetes (marine worms) with 129 species, crustaceans (prawns, crabs etc) with 103 species, bivalves (shellfish) with 97 species and other assorted taxa with 88 species.

The macrobenthic communities encountered in Port Curtis consist of a relatively small number of species with high abundance and a large number of species with very low abundance. 11 species were found at every station in at least one sampling period. Species that were common to all stations were also generally abundant.

Multivariate statistical analysis suggests that the macrobenthic community of Port Curtis is a mosaic of different patches within which each community remains relatively similar over time. Multivariate analysis techniques provide a valuable tool for monitoring future changes in benthos, which may be associated with environmental change.

Sediment type and organic matter are known to be closely related to macrobenthic community composition. Sediment varied greatly between stations and ranged from mud, to muddy sand and to sand with coarse granules. Preliminary observations suggest changes in species composition with sediment variation. Further sampling and analysis are required to further elucidate these trends.

At this stage, there is no evidence of macrobenthic community degradation at sites, with changes in diversity between sites probably attributable to sediment composition. Any change to community composition over time as a result of environmental stress will be detected by multivariate statistical techniques and refined sampling design.

6. References

Australian Standard AS 1289.B1.1 (1977) *Methods of testing soil for engineering purposes: Determination of the moisture content of a soil - oven drying method (standard method)* Standards Association Australia.

Australian Standard AS 1289.C6.1 (1977) *Methods of testing soil for engineering purposes: Determination of the particle size distribution of a soil - standard method of analysis by sieving.* Standards Association Australia.

Australian Standard AS 3580.10.1 (1991) *Methods for sampling and analysis of ambient air: Method 10.1 Determination of particulates - deposited matter - gravimetric method.* Standards Association Australia.

Bruce, R.C. and Rayment, G.E. (1982) *Analytical methods and interpretations used by the Agricultural Chemistry Branch for soil and land use surveys.* Queensland Department of Primary Industries Bulletin QB820004.

Hammer, D.A. (1990) *Constructed wetlands for wastewater treatment: municipal, industrial and agricultural.* Lewis Publications, Michigan.

Hartley, J.P. (1982) Methods For Monitoring Offshore Macrobenthos. *Marine Pollution Bulletin* **13**:150-154

QDEH (1994) *Curtis Coast Study - Resource Report.* Queensland Department of Environment and Heritage, Rockhampton.

Steimle, R.S. (1990) Benthic Macrofauna and Habitat Monitoring on the Continental Shelf of the Northeastern United States. 1. Biomass. *Technical Report NMFS 86,* US Department of Commerce.

WBM Oceanics Australia (1990) *Impact Assessment Study Reclamation of Land West of Calliope River.* Report prepared for Gladstone Port Authority, WBM Oceanics, Spring Hill. 1-175.

WBM Oceanics Australia (1991) *Fisherman's Landing - Trade Waste Outfall Benthic Monitoring Report 1991-1992.* Report prepared for Queensland Department of Environment and Heritage, WBM Oceanics, Spring Hill. 1-44.

WBM Oceanics Australia (1993) *Proposed Sample Design for Benthic Monitoring Programme of Gladstone Harbour.* Report prepared for Gladstone Port Authority, WBM Oceanics, Spring Hill. 1-21.

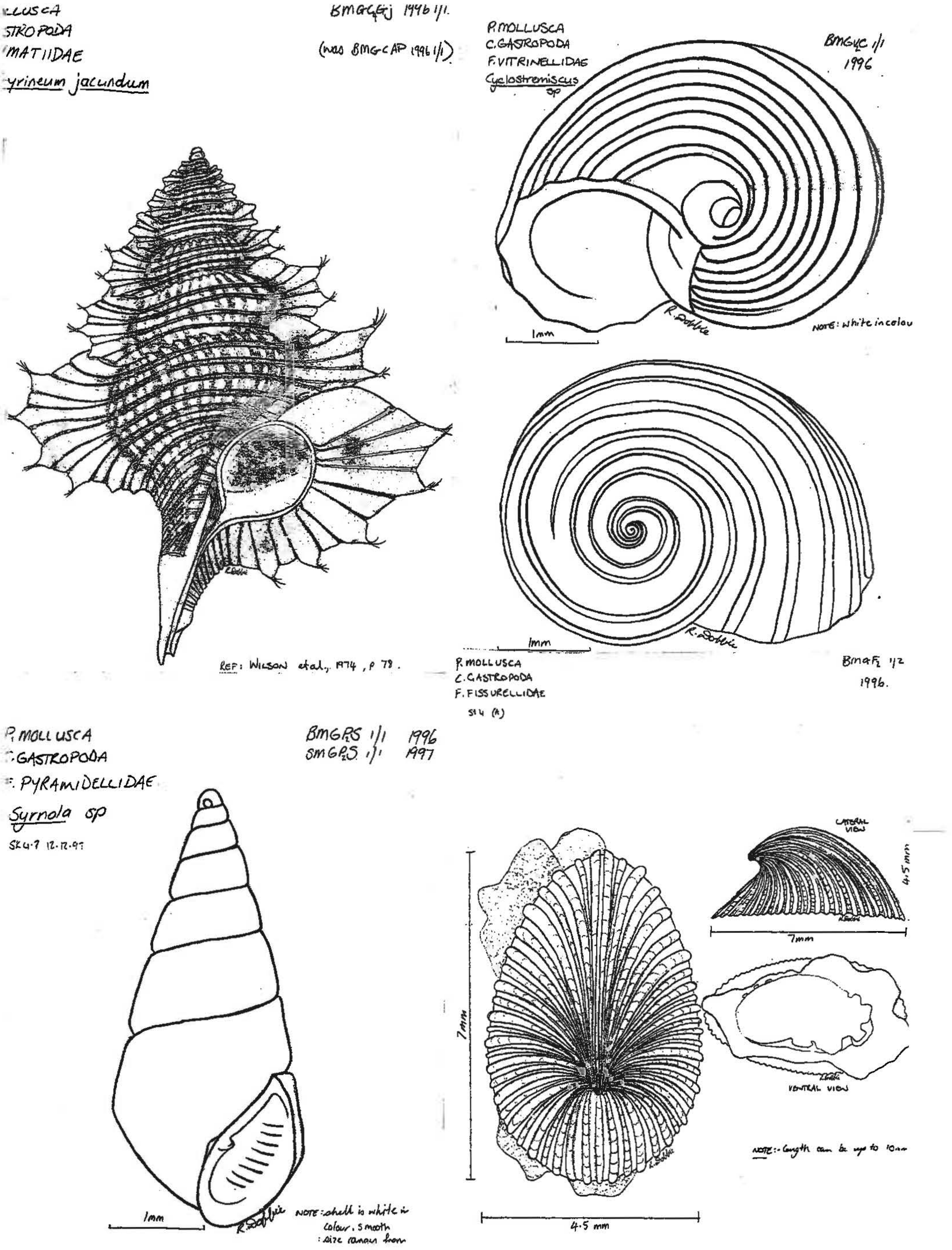
Table 14. Change in particle size distribution and organic content of sediment at each station over time.

Station	Time Period	Silt and Clay <63um	V.fine sand 63um	Fine sand 125um	Medium sand 250um	Coarse sand 500um	V. coarse sand 1um	Granules 2um	Organic Matter
1	Nov-95	74.56	12.53	4.06	1.26	0.36	0.05	0.01	10.02
1	Apr-96	50.66	31.50	11.55	4.27	0.54	0.21	0.06	7.96
1	Nov-96	74.70	14.33	7.06	2.05	0.01	0.08	0.07	9.05
1	Apr-97	51.16	11.77	23.99	8.60	1.62	0.42	0.14	7.49
1	Nov-97	75.29	19.40	3.00	0.25	0.02	0.00	0.00	9.24
1	Apr-98	0.24	3.26	8.54	36.86	34.19	5.50	10.91	2.56
2	Nov-95	81.30	9.22	1.53	0.23	0.02	0.02	0.00	10.32
2	Nov-96	87.59	8.37	1.50	0.35	0.02	0.00	0.00	9.97
2	Apr-97	88.62	6.29	0.99	0.21	0.01	0.06	0.00	9.8
2	Nov-97	78.01	11.67	5.31	0.85	0.58	0.37	0.62	9.69
2	Apr-98	85.65	6.94	2.19	1.20	0.46	0.35	0.59	15.8
3	Nov-95	0.31	0.34	1.83	11.99	12.17	5.94	66.94	3.95
3	Apr-96	0.47	0.50	3.04	8.54	12.48	20.71	53.65	4.55
3	Nov-96	0.25	0.20	0.78	9.03	6.13	4.17	79.10	4.83
3	Apr-97	0.12	0.29	1.16	7.73	18.72	9.48	61.78	6.89
3	Nov-97	0.13	0.22	1.57	20.83	15.89	9.50	51.46	4.14
3	Apr-98	0.56	1.25	6.35	21.46	21.82	11.05	37.14	6.92
4	Apr-96	0.56	0.51	2.42	11.71	9.23	6.85	68.22	5.36
4	Nov-96	0.37	0.38	2.40	10.62	9.21	7.97	68.64	5.43
4	Apr-97	0.21	0.55	1.59	6.44	5.42	4.94	80.24	5.96
4	Nov-97	0.35	0.39	2.50	10.61	7.37	36.28	42.23	3.46
4	Apr-98	0.20	0.29	1.37	6.07	5.09	5.31	81.27	4.6
5	Nov-95	0.62	1.01	6.47	22.40	10.75	6.27	51.75	5.88
5	Apr-96	0.73	1.52	6.30	20.86	12.49	7.54	50.00	5.39
5	Nov-96	30.08	9.84	14.05	16.80	3.57	10.40	14.20	10.66
5	Apr-97	29.40	5.70	11.64	23.67	10.92	4.81	12.07	8.09
5	Nov-97	21.13	7.48	14.89	30.69	9.13	4.98	11.03	6.1
5	Apr-98	18.40	5.26	12.78	25.58	6.01	6.01	24.99	7.27
6	Nov-95	0.89	1.24	3.28	8.77	8.51	17.21	59.16	7.63
6	Apr-96	28.80	6.24	11.13	20.01	4.70	8.61	19.33	9.73
6	Nov-96	0.85	1.05	3.97	13.83	14.15	10.41	55.29	5.25
6	Apr-97	0.44	2.17	6.70	16.60	11.90	9.42	52.13	5.21
6	Nov-97	0.42	1.66	5.03	19.08	12.05	7.56	53.72	3.63
6	Apr-98	0.20	0.42	3.44	14.86	13.32	15.70	51.76	2.07
7	Nov-95	0.30	0.52	1.65	5.81	6.36	3.16	81.50	6.45
7	Apr-96	0.45	0.48	1.29	11.18	11.67	6.26	68.31	5.15
7	Nov-96	0.73	1.02	3.69	18.03	18.55	12.76	44.78	7.09
7	Apr-97	0.66	1.84	4.32	21.01	20.10	14.09	37.00	5.88
7	Nov-97	0.42	0.51	1.04	4.83	7.94	5.63	79.24	5.52
8	Nov-95	0.33	0.70	4.05	18.89	18.05	11.00	46.45	3.67
8	Apr-96	0.97	1.12	1.76	7.12	3.61	2.19	82.84	5.97
8	Nov-96	0.56	0.60	1.88	12.27	8.10	3.50	72.63	7
8	Apr-97	0.22	0.37	1.01	5.41	5.73	3.52	83.12	3.67
8	Nov-97	0.40	0.61	2.45	22.13	22.70	9.21	42.12	6.26
8	Apr-98	0.28	0.41	1.95	22.65	17.56	9.78	47.02	5.12
9	Nov-95	0.37	0.81	3.41	14.95	12.62	16.81	50.50	5.12
9	Nov-96	1.66	2.30	14.20	27.52	9.29	9.54	34.77	10.62
9	Apr-97	1.13	2.20	12.67	18.69	8.74	9.93	45.48	8.87
9	Nov-97	0.99	1.64	16.65	20.77	7.17	10.12	42.03	7.12
9	Apr-98	1.61	2.21	12.88	16.57	12.00	14.39	39.15	5.81

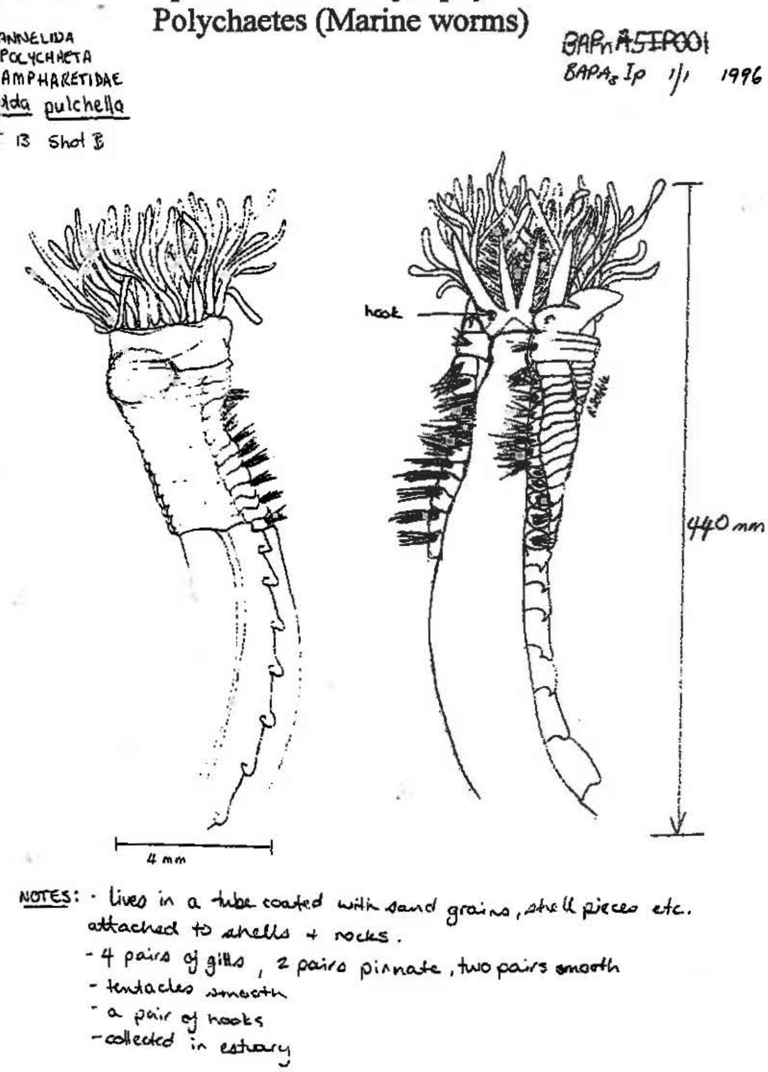
10	Nov-95	0.09	0.08	0.50	1.71	4.41	10.71	82.09	4.03
10	Apr-96	0.33	0.51	1.06	1.48	1.93	2.44	91.39	7.27
10	Nov-96	29.73	4.86	30.16	10.33	1.08	8.58	14.00	10.41
10	Apr-97	51.77	9.95	32.46	3.15	0.33	0.32	0.62	8.39
10	Nov-97	25.13	5.66	26.44	12.81	3.74	6.39	18.77	9.92
10	Apr-98	58.27	8.50	28.79	1.48	1.15	0.10	0.10	7.69
11	Nov-95	2.28	4.95	6.99	12.82	14.85	24.60	31.94	14.05
11	Apr-96	23.99	4.16	19.92	7.45	3.68	9.90	29.56	13.45
11	Nov-96	1.43	4.77	20.15	18.52	10.73	9.02	34.01	11.39
11	Apr-97	13.57	5.80	23.83	9.24	4.60	9.52	32.74	10.94
11	Nov-97	13.11	2.55	24.99	8.59	6.99	10.60	32.22	11.16
11	Apr-98	0.74	6.36	18.92	19.57	17.20	6.33	29.86	11.38
12	Nov-95	48.19	14.22	30.60	2.67	1.18	0.92	0.25	9.01
12	Apr-96	1.28	5.54	7.19	14.16	18.78	18.14	33.46	12.39
12	Nov-96	2.96	3.20	5.65	11.22	18.04	22.58	35.37	15.08
12	Apr-97	23.58	6.77	5.84	6.94	10.19	18.54	26.25	13.82
12	Nov-97	1.99	5.47	8.39	21.47	22.75	14.75	24.57	11.65
12	Apr-98	21.47	9.56	8.27	12.74	9.18	13.45	23.96	15.06
13	Nov-95	18.36	1.87	12.95	8.22	5.46	8.04	43.03	12.28
13	Apr-96	22.79	1.81	8.53	6.28	6.97	6.68	45.71	7.08
13	Nov-96	14.57	3.30	14.09	7.00	3.33	14.98	41.96	10.21
13	Apr-97	20.91	0.94	9.17	5.09	6.84	12.16	43.49	10.88
13	Nov-97	10.93	1.38	10.78	8.33	9.44	15.50	42.45	5.8
13	Apr-98	14.86	3.39	17.59	12.84	14.09	16.80	19.60	7.18
14	Nov-95	68.00	15.78	13.19	0.74	0.09	0.07	0.00	8.63
14	Apr-96	87.52	2.88	3.04	1.00	0.55	0.57	0.91	10.52
14	Nov-96	78.03	3.77	6.16	2.53	1.91	2.22	2.32	12.66
14	Apr-97	75.89	6.58	6.28	2.28	1.23	1.44	1.77	11.63
14	Nov-97	65.22	7.51	12.01	3.40	1.48	2.83	4.61	13.31
14	Apr-98	62.43	14.29	8.98	3.77	3.00	1.20	3.80	10.37
15	Nov-95	1.25	3.69	14.01	19.77	12.56	11.11	36.52	10.83
15	Apr-96	18.52	1.21	9.68	6.49	4.25	13.75	44.67	10.74
15	Nov-96	19.12	1.75	10.86	6.45	4.15	15.74	40.88	8.04
15	Apr-97	13.44	2.52	15.16	24.18	7.65	11.56	24.70	7.91
15	Nov-97	19.63	1.35	10.82	6.16	5.05	13.90	42.08	10.47
15	Apr-98	20.76	1.40	18.95	12.80	9.04	9.46	26.77	10.15
16	Nov-95	19.84	1.78	11.57	9.45	8.48	8.17	39.38	9.22
16	Apr-96	17.02	1.75	8.72	8.12	9.00	15.62	38.37	10.97
16	Nov-96	69.00	4.60	14.28	2.99	1.75	1.78	2.83	10.71
16	Apr-97	10.16	2.50	8.45	8.92	5.07	14.15	50.05	8.94
16	Nov-97	9.88	2.43	8.22	8.68	4.94	13.77	48.70	11.85
16	Apr-98	10.68	2.64	13.23	40.99	14.27	6.14	11.57	5.93
17	Nov-95	68.90	12.71	7.50	2.20	1.18	1.63	3.36	9.76
17	Apr-96	64.49	13.36	8.60	2.48	1.67	1.87	5.19	10.63
17	Nov-96	65.98	14.15	7.12	1.84	1.28	1.42	5.94	11.04
17	Apr-97	59.64	20.87	9.38	2.23	1.41	1.65	1.72	9.45
17	Nov-97	58.36	9.87	5.96	1.75	1.03	11.86	8.39	9.72
17	Apr-98	66.10	8.60	11.20	1.34	0.41	2.06	8.81	11.64
18	Nov-95	65.1	14.8	12.2	2.8	0.6	0.8	1.2	8.76
18	Apr-96	61.1	15.1	12.8	2.9	0.9	1.0	3.9	9.39
18	Nov-96	58.8	15.5	13.9	3.1	0.8	1.2	5.4	9.77
18	Apr-97	57.6	15.0	13.6	3.2	1.0	1.2	6.3	14.51
18	Nov-97	55.0	15.1	13.5	3.1	1.1	4.3	5.4	10.76
18	Apr-98	11.9	2.5	13.4	46.9	16.4	1.9	5.2	10.79

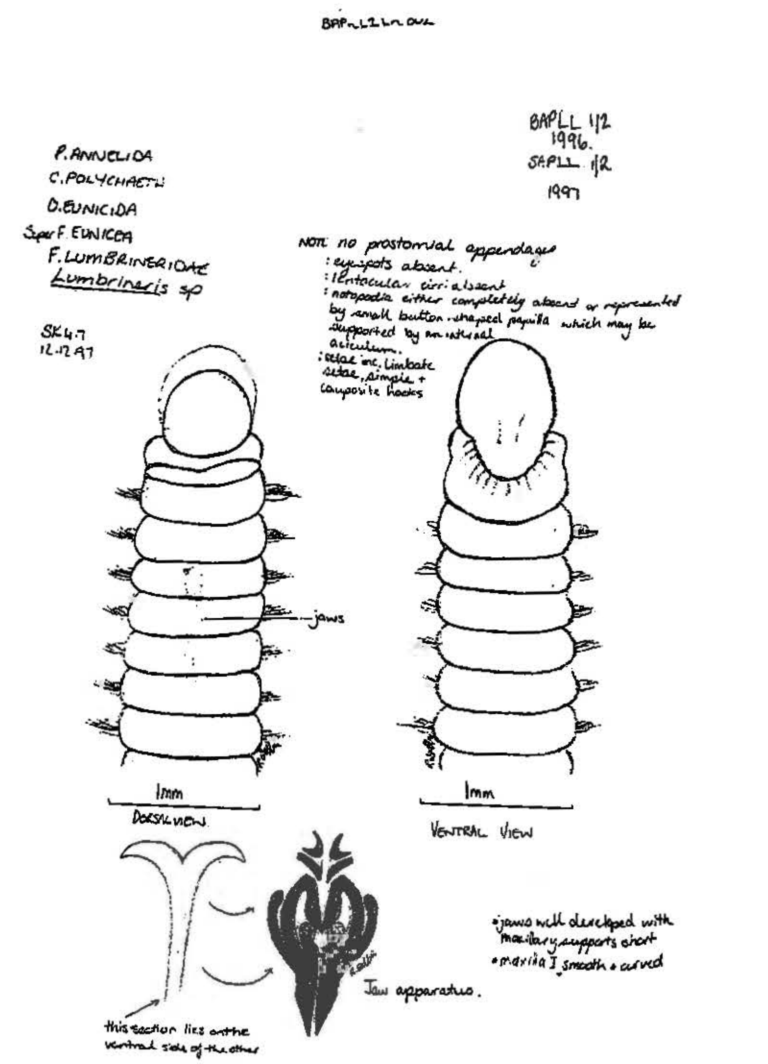
19	Nov-95	24.6	2.4	27.4	18.1	3.7	9.6	12.7	10.62
19	Apr-96	26.4	2.9	9.4	12.2	16.0	11.2	20.4	10.03
19	Nov-96	31.8	2.7	10.1	13.6	15.5	13.4	10.6	8.63
19	Apr-97	22.6	5.1	10.7	11.9	8.2	20.7	19.6	11.56
19	Nov-97	33.3	6.9	12.2	22.4	8.0	7.3	7.5	13.39
19	Apr-98	80.5	13.4	3.0	0.1	0.0	0.2	0.0	8.63
20	Apr-96	51.9	4.2	24.9	3.3	2.0	2.3	7.6	10.04
20	Nov-96	49.6	4.4	25.4	8.3	3.0	3.3	3.0	10.62
20	Apr-97	58.8	8.6	24.8	1.7	0.9	0.9	2.2	9.27
20	Nov-97	60.6	3.2	16.1	1.2	1.0	10.5	4.5	8.41
20	Apr-98	61.0	16.9	11.4	3.4	2.8	0.5	1.4	10.15
21	Apr-97	77.39	16.47	3.45	0.20	0.06	0.05	0.00	8.66
21	Nov-97	77.76	16.78	2.70	0.48	0.08	0.09	0.15	6.99
21	Apr-98	27.61	20.76	26.91	14.61	4.66	1.80	2.68	5.54
22	Apr-97	2.35	5.23	12.87	31.88	29.46	11.43	5.46	6.3
22	Nov-97	15.61	4.87	13.44	21.80	11.79	10.49	21.14	7.17
22	Apr-98	0.36	0.58	4.62	43.30	38.98	9.11	2.63	2.92
23	Apr-97	50.08	28.39	10.93	1.64	0.51	0.65	6.38	7.67
23	Nov-97	69.87	20.82	4.88	0.81	0.23	0.52	1.39	7.51
23	Apr-98	65.39	16.44	7.87	1.81	0.49	0.34	6.03	10.58
24	Apr-97	17.53	8.16	14.00	15.48	15.87	15.38	13.21	4.66
24	Nov-97	14.70	11.02	14.37	19.36	15.54	10.71	13.28	6.11
24	Apr-98	23.16	16.75	16.93	14.05	11.13	5.56	11.82	5.44

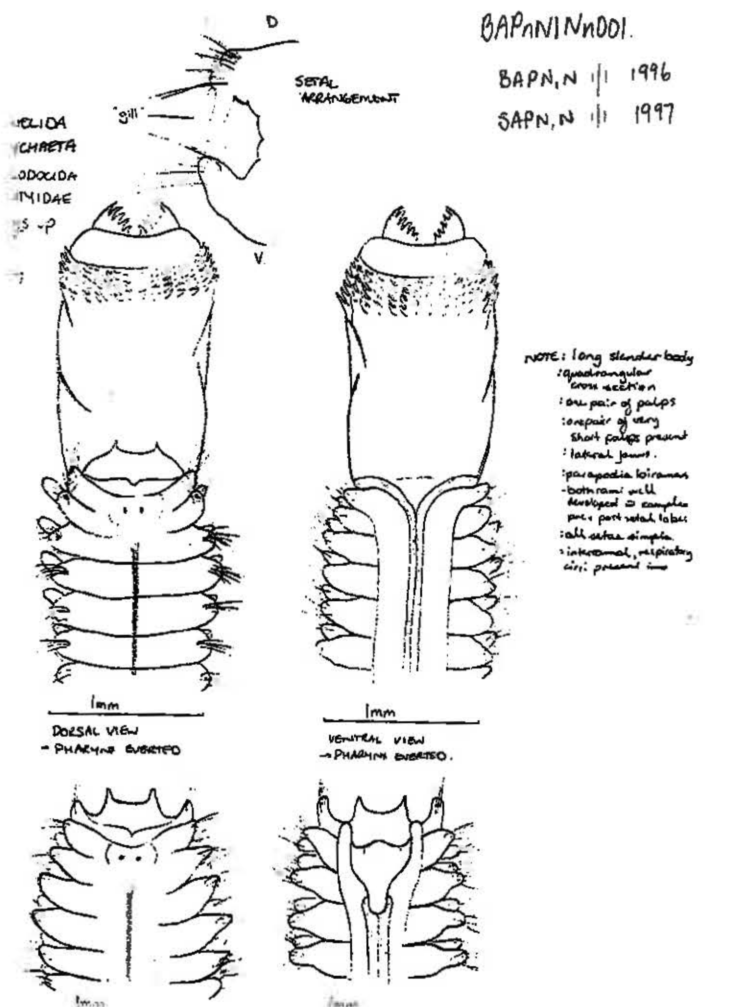
gure 3a: Species from 4 major phyla of macrobenthic invertebrates - Gastropods (Marine snails)

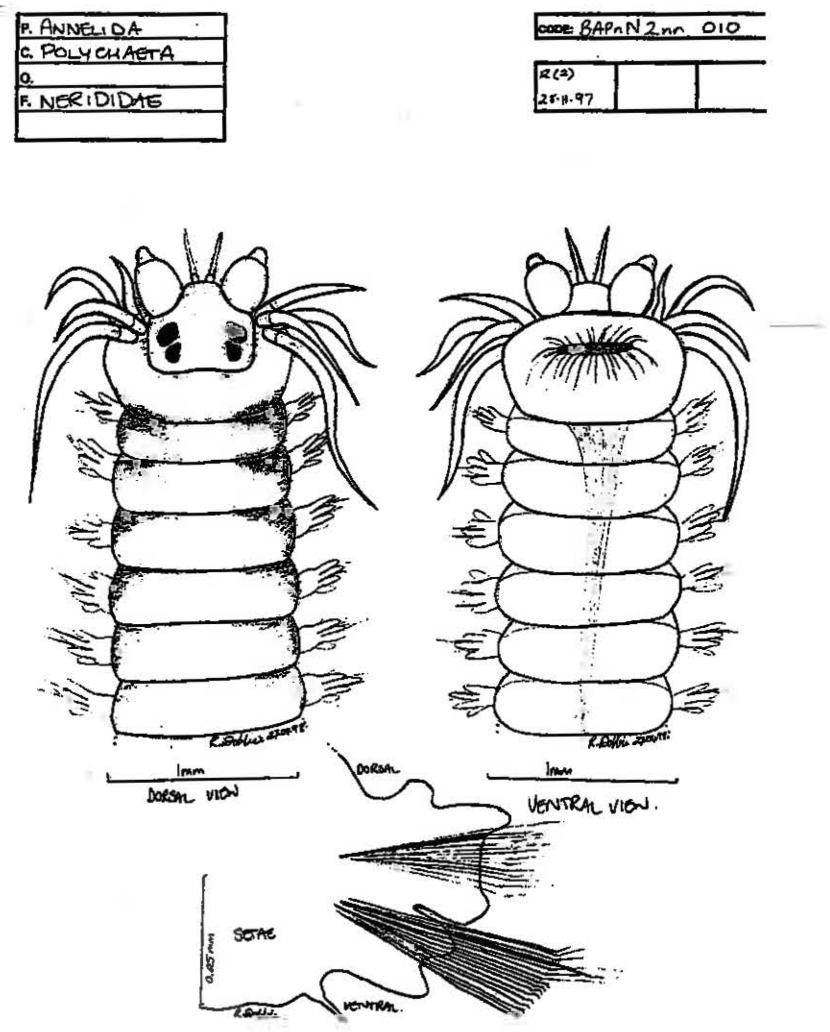


ure 3b: Species from 4 major phyla of macrobenthic invertebrates - Polychaetes (Marine worms)





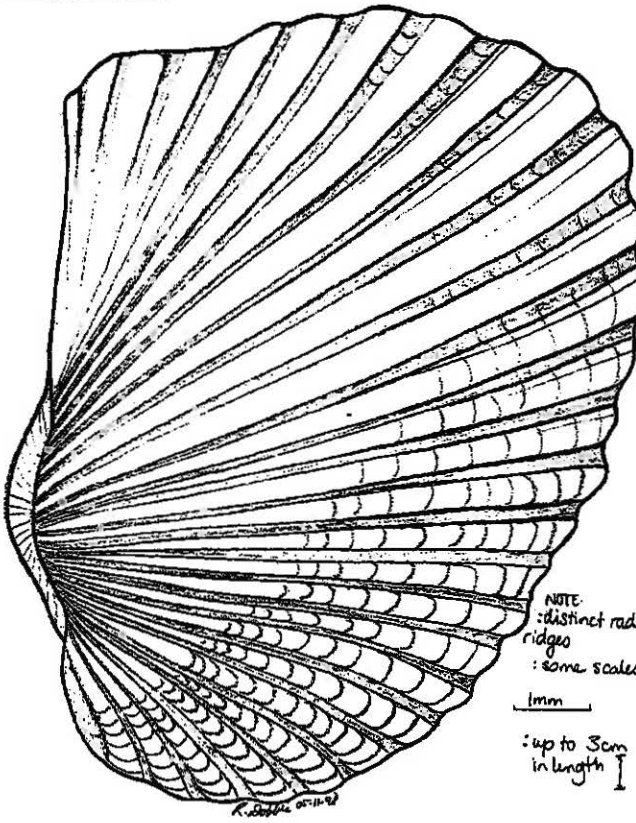




ıre 3c: Species from 4 major phyla of macrobenthic invertebrates - Bivalves (Shellfish)

ɔLLUSCA
ɪVALVIA
ᴇRCIDAE

CODE: BMBnA2nn ØØ1



NOTE:
: distinct radial ridges
: some scales.

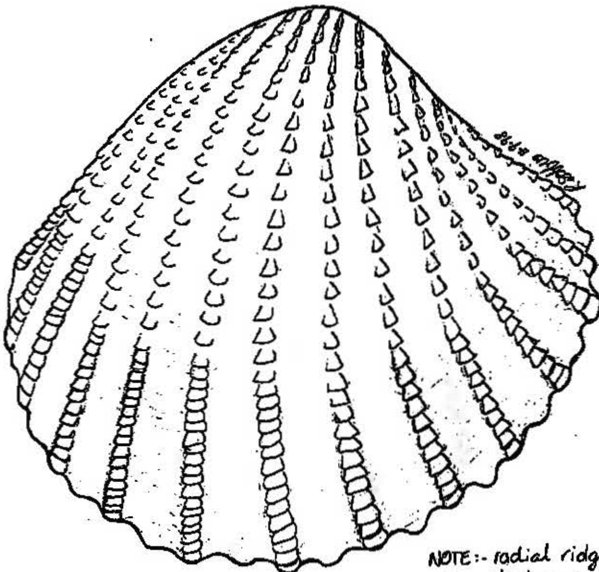
1mm

: up to 3cm in length

Illustrator: REBECCA DOBBIE 05/11/1998 Reference:

P. MOLLUSCA
C. BIVALVIA
O.
F. CARDITIDAE
Cardita sp.

CODE: BMBnC3Cn ØØ



1mm

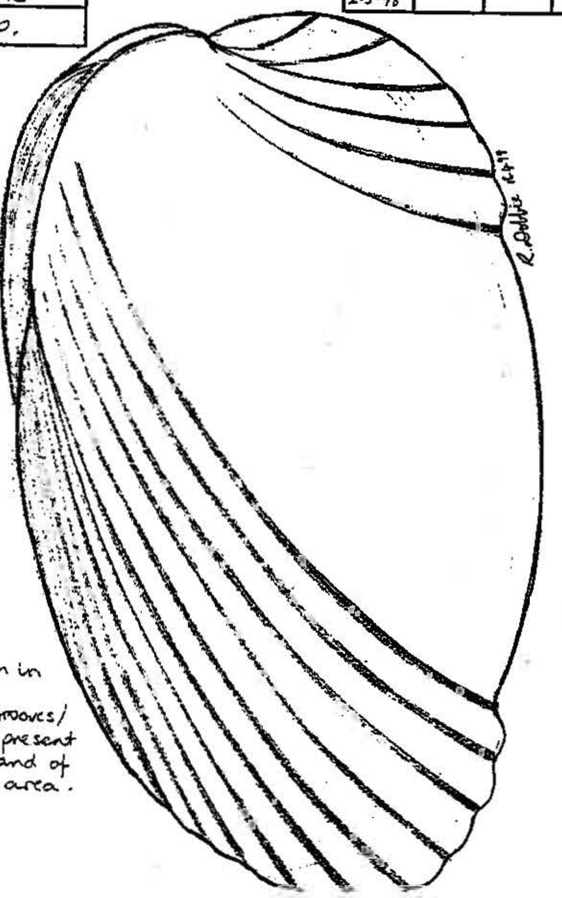
NOTE: - radial ridges are dominant - highly textured with scales
- faint marginal ridges

Illustrator: REBECCA DOBBIE 11/09/1998 Reference:

ɔLLUSCA
ɪVALVIA
ᴇCURTIDAE
…inus sp.

CODE: BMBnSaAn ØØ4

St 13 (5) 2-5-98			



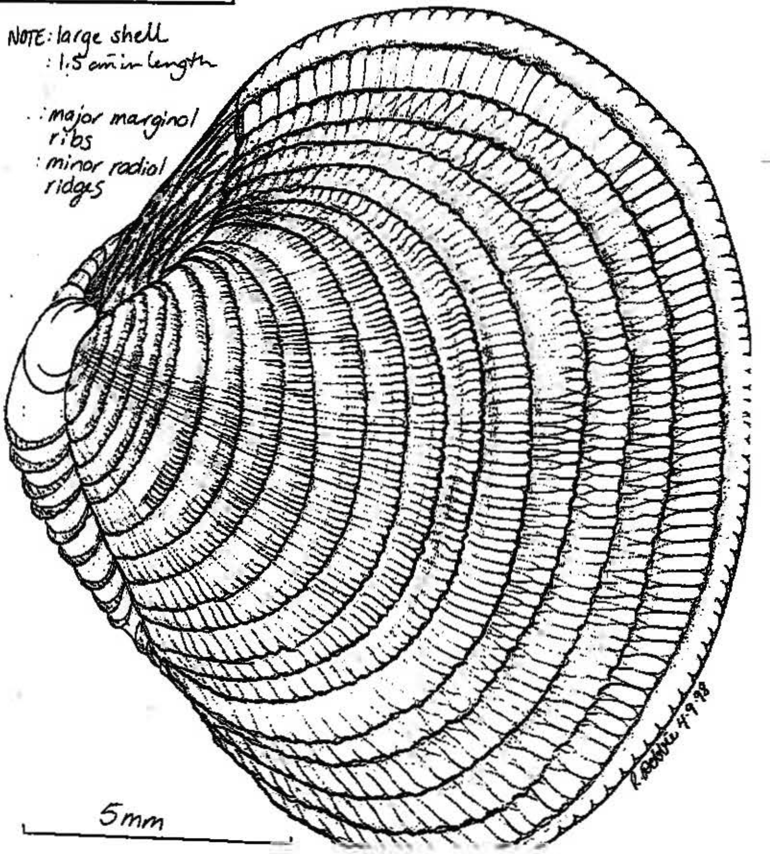
NOTE: brown in colour
- radial grooves/ ridges present
- large band of smooth area.

P. MOLLUSCA
C. BIVALVIA
O.
F.
:

CODE: BMBnnnnn Ø28

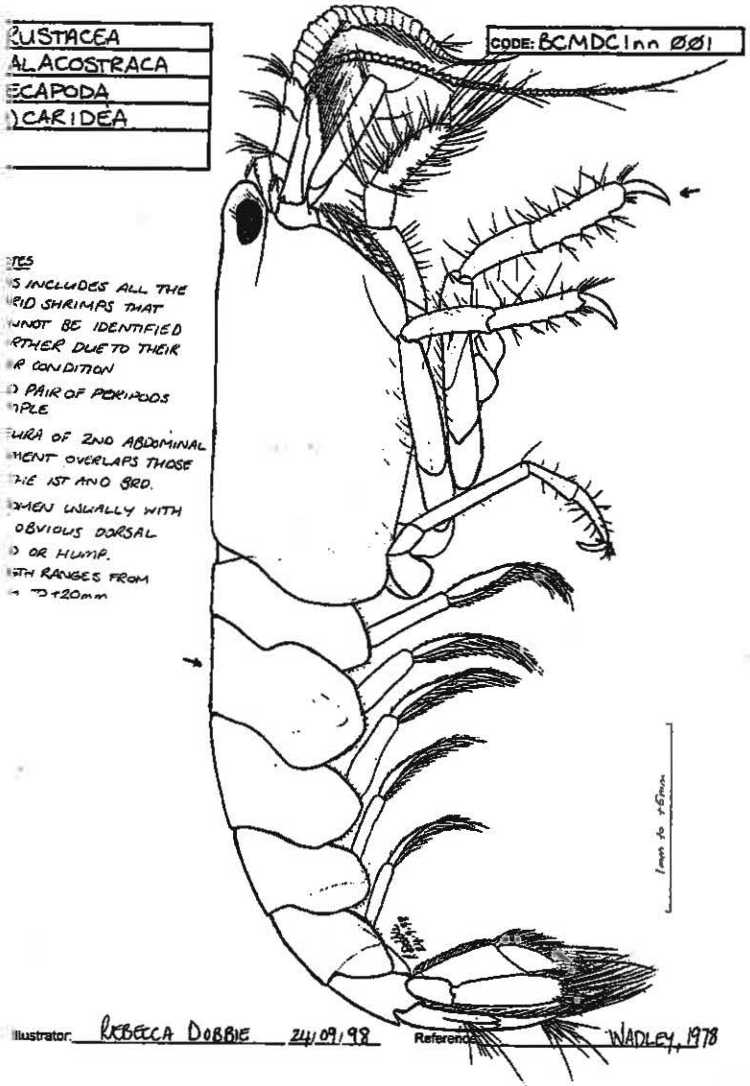
St 8 (6)

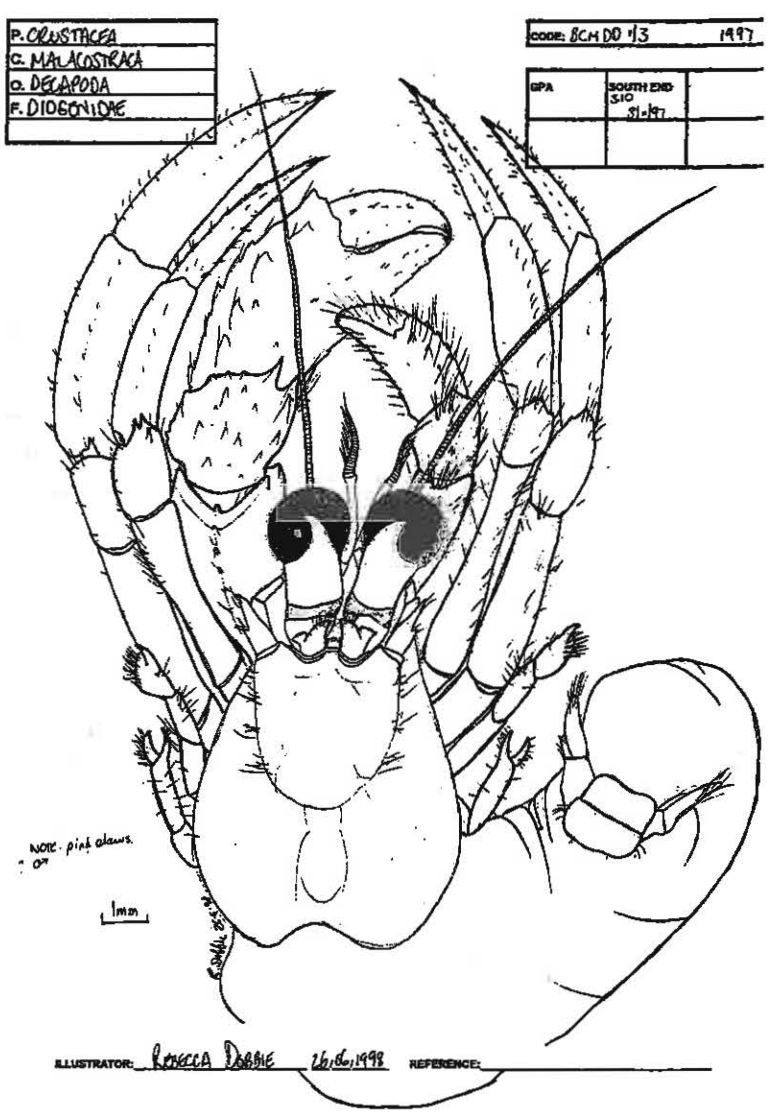
NOTE: large shell
: 1.5 cm in length
: major marginal ribs
: minor radial ridges

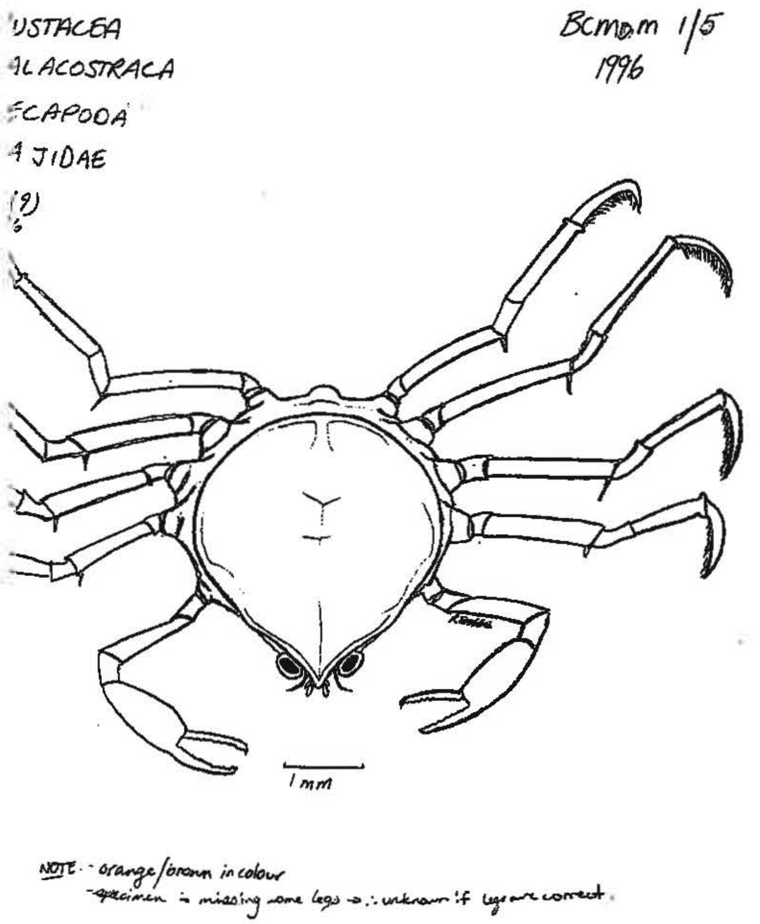


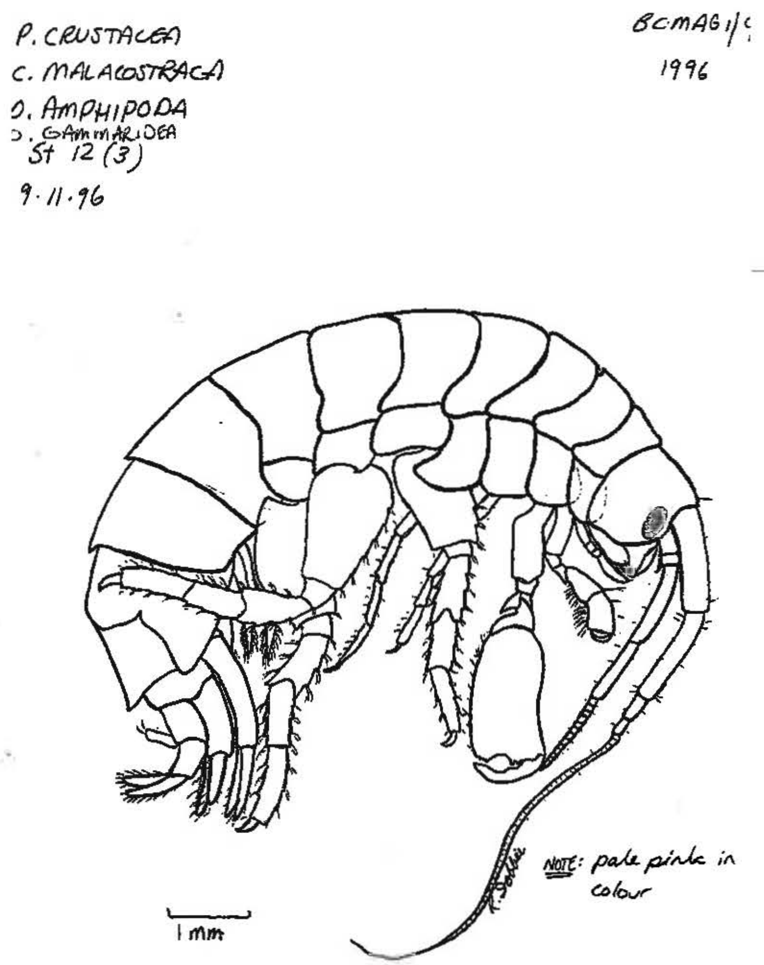
5mm

ure 3d: Species from 4 major phyla of macrobenthic invertebrates - Crustaceans (Prawns, Crabs, Sea lice)









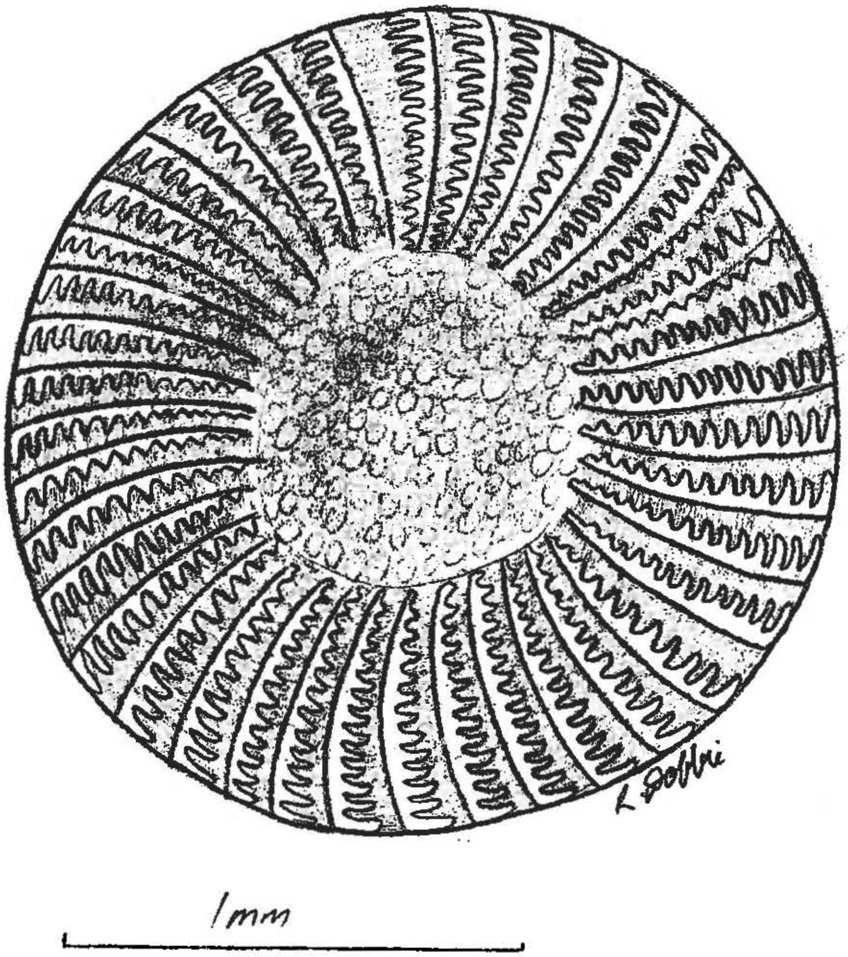
ıre 3e: A species of macrobenthic invertebrate – Foraminiferan (A single celled animal secreting a calcium carbonate shell).

BPRFEC 1/1
1996.
SPRFEC 1/1
1997

P. PROTOZOA
C. RHIZOPODEA
O. FORAMINIFERA
F. ELPHIDIIDAE
Cellanthus sp

SK 4.8
12.12.97

NOTE: colours range from black, grey, orange, yellow + white
: size ranges from 1-5mm in diameter



Appendix 1. GPS Markings for Macrobenthic Monitoring Sites.

STATION 1:	23° 50'01.7" E 151 ° 15'48.5" S	**STATION 13:**	23° 44'38.0" E 151 ° 10'14.6" S
STATION 2:	23° 49'52.8" E 151 ° 15'10.2" S	**STATION 14:**	23° 44'17.2" E 151 ° 09'54.0" S
STATION 3:	23° 49'29.4" E 151 ° 15'46.9" S	**STATION 15:**	23° 44'34.0" E 151 ° 10'22.2" S
STATION 4:	23° 49'36.7" E 151 ° 15'49.3" S	**STATION 16:**	23° 44'29.4" E 151 ° 11'07.9" S
STATION 5:	23° 49'16.4" E 151 ° 14'31.1" S	**STATION 17:**	23° 46'19.4" E 151 °09'51.7" S
STATION 6:	23° 48'55.7" E 151 ° 14'11.6" S	**STATION 18:**	23° 46'03.8" E 151 °09'41.8" S
STATION 7:	23° 48'31.5" E 151 ° 14'32.2" S	**STATION 19:**	23° 46'07.4" E 151 °10'12.0" S
STATION 8:	23° 49'13.4" E 151 ° 15'01.5" S	**STATION 20:**	23° 46'17.2" E 151 °10'06.7" S
STATION 9:	23° 47'44.8" E 151 ° 13'57.9" S	**STATION 21:**	23° 49'08.0" E 151 °11'50.0" S
STATION 10:	23° 47'41.3" E 151 °14'16.8" S	**STATION 22:**	23° 46'16.0" E 151 °11'19.0" S
STATION 11:	23° 47'45" E 151 ° 14'38.5" S	**STATION 23:**	23° 48'55.0" E 151 °11'05.0" S
STATION 12:	23° 47'49.5" E 151 ° 16'09.3" S	**STATION 24:**	23° 48'30.0" E 151 °10'30.0" S

2: Sieving of samples on board vessel.

e 1: The van Veen grab and macrobenthic sampling.