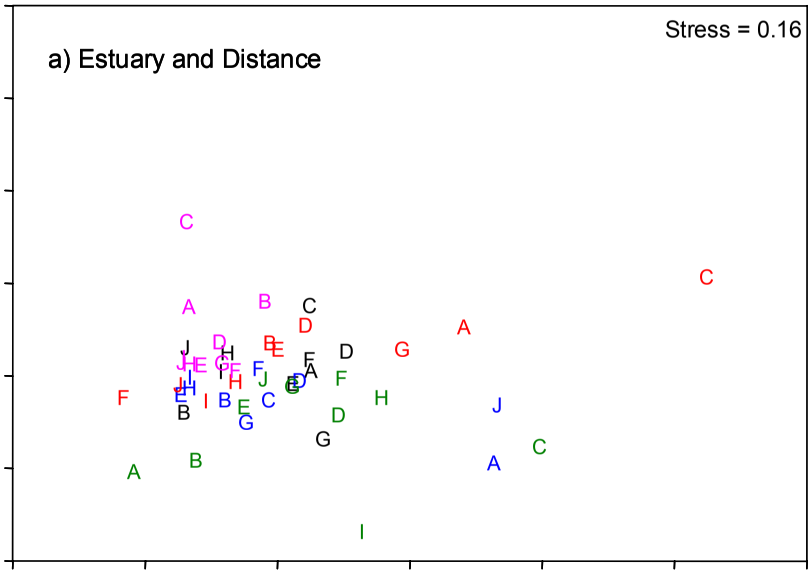
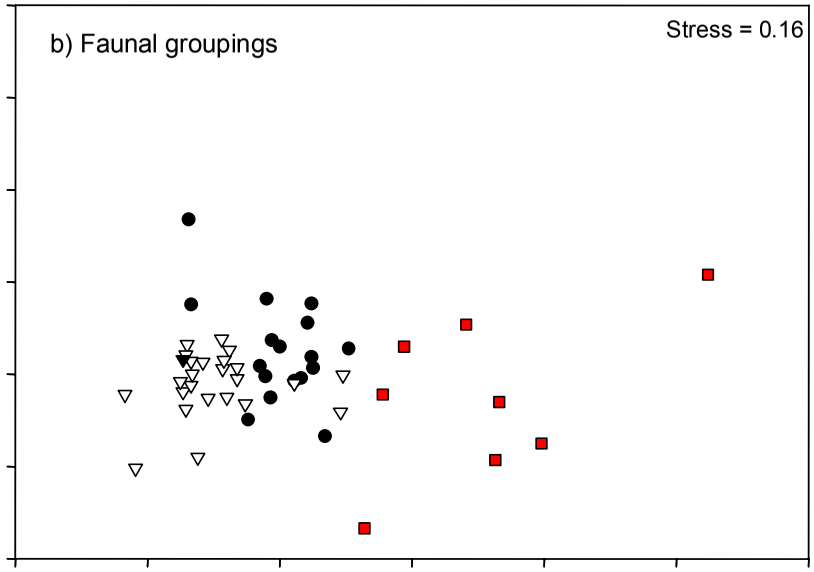




Blue = Puhoi sites A-J
Black = Okura sites A-J
Red = Orewa sites A-J
Pink = Maungamaungaroa sites A-J
Green = Waiwera sites A-J

Blank triangles = Group A
Black circles = Group B
Red squares = Group C

Fig. 11. MDS plots of environmental data for all sites in all estuaries. The analyses were based on the Normalised Euclidean dissimilarity measures of data. Observations were pooled at the site level (n=5). Plots show a) Estuary and distance b) environmental groupings. Sites are indicated by a coloured letter, the letter indicates the site within an estuary (A-J), the colour represents an estuary Blue = Puhoi, Green = Waiwera, Red = Orewa, Black = Okura and Pink = Maunagamaungaroa

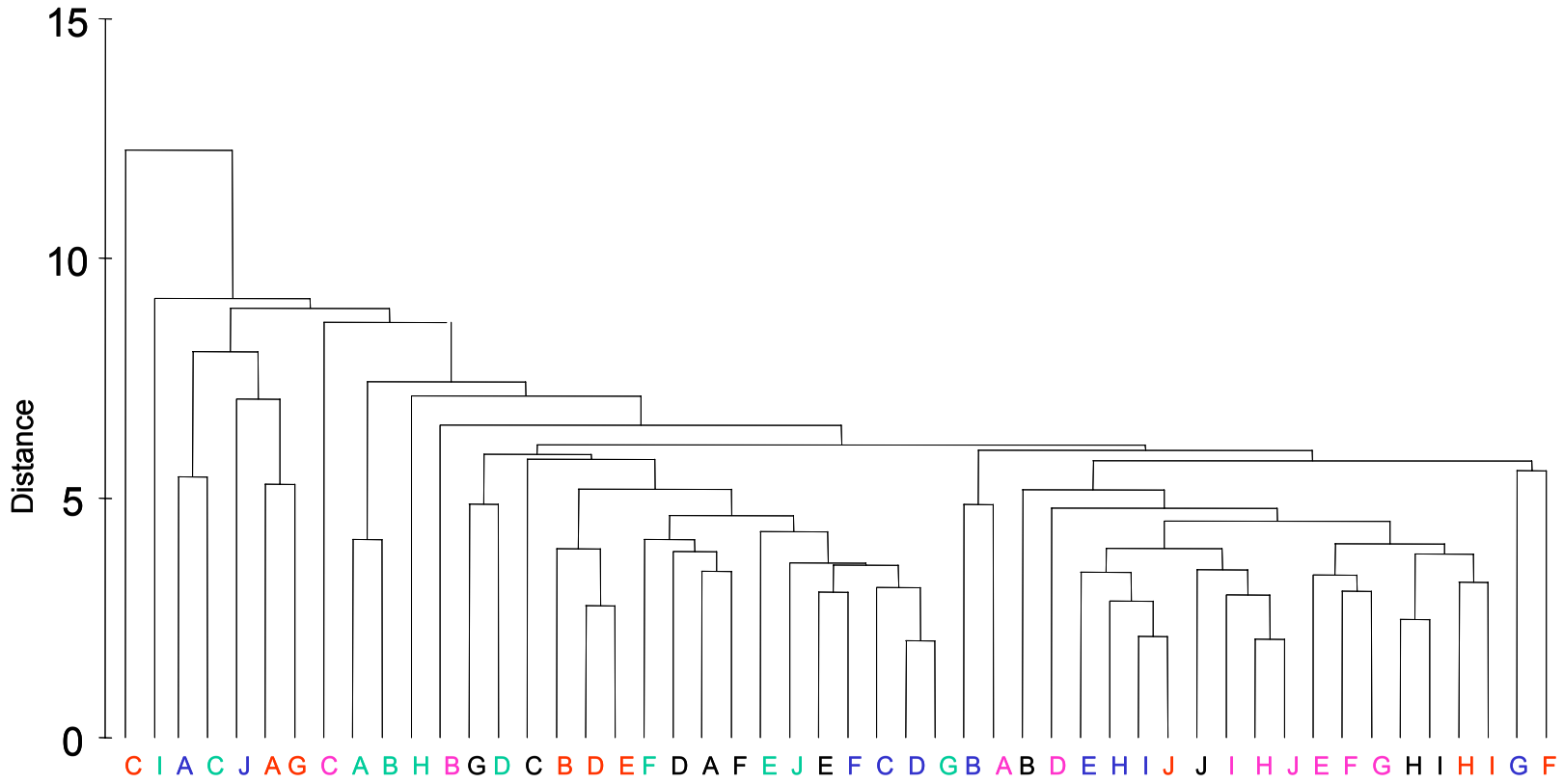


Fig. 12. Dendrogram for environmental data from all times of all sites in all estuaries. The analyses were based on the Normalised Euclidean measure calculated from environmental data. Observations were pooled at the site level. Sites are indicated by a coloured letter, the letter indicates the site within an estuary (A-J), the colour represents an estuary Blue = Puhoi, Green = Waiwera, Red = Orewa, Black = Okura and Pink = Maunagamaungaroa

Table 3. K-means generated clusters of environmental data. The analyses were based on the Euclidean measure calculated from normalised environmental data. Observations were pooled at the site level. The numbers below the group headings indicate the number of sites in each group.

ESTUARIES	Group A 25	Group B 17	Group C 8
OKURA	OB	OA	
	OH	OC	
	OI	OD	
	OJ	OE	
		OF	
		OG	
PUHOI	PB	PC	PA
	PE	PD	PJ
	PH	PF	
	PI	PG	
OREWA	RF	RB	RA
	RH	RD	RC
	RI	RE	RG
	RJ		
WAIWERA	WA	WJ	WC
	WB		WH
	WD		WI
	WE		
	WF		
	WG		
MAUNGAMAUNGAROA	ZD	ZA	
	ZE	ZB	
	ZF	ZC	
	ZG		
	ZH		
	ZI		
	ZJ		

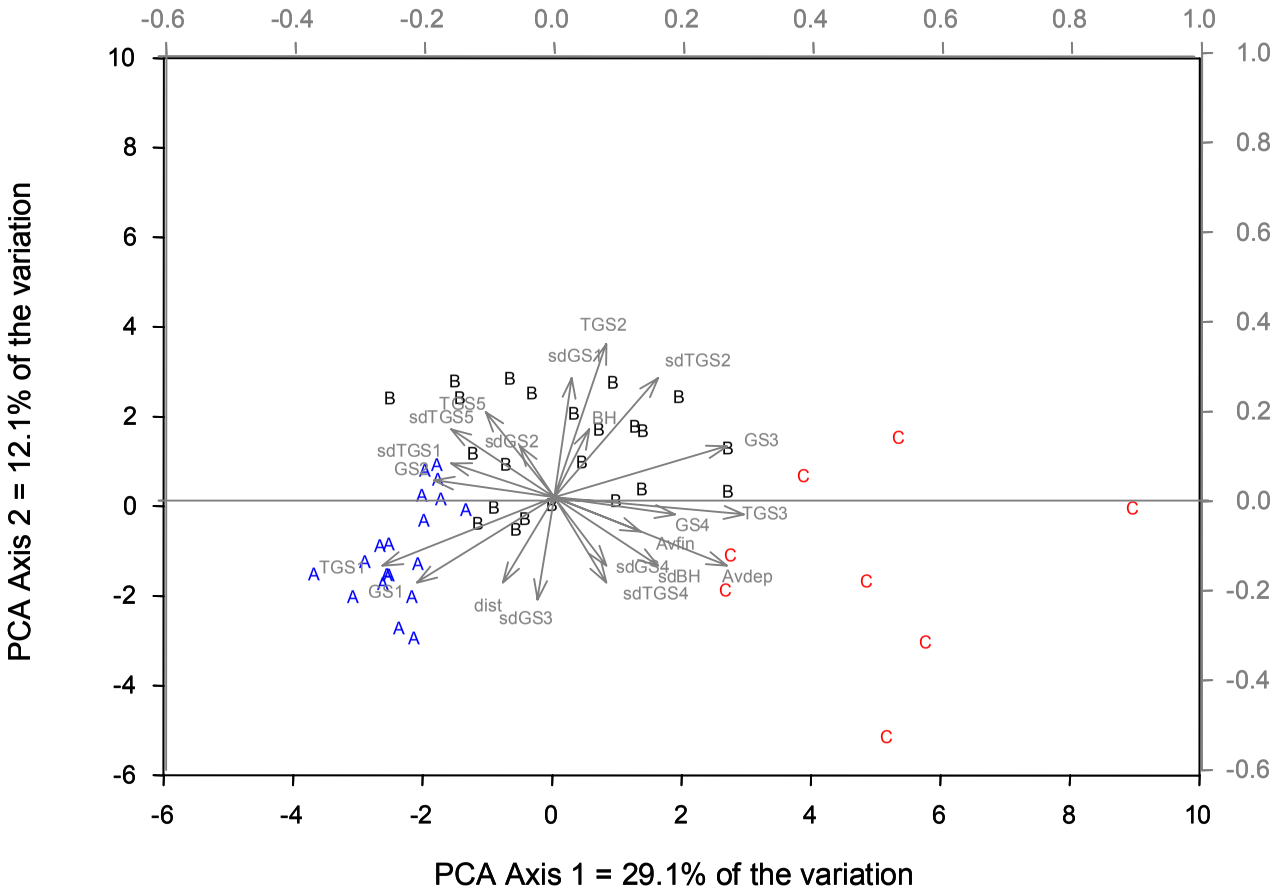


Fig. 13. Principal Coordinates Analysis (PCA) relating the environmental variables to the three environmental groupings. The analysis was obtained from Normalised Euclidean environmental data. Observations were pooled at the site level. Membership of groups A, B and C are shown in Table 6. The environmental variables sddep, GS3, TGS4, and sdTGS3 were not shown on the plot as they were highly correlated (correlation coefficient >0.8) with the variables Avdep, TGS3, sdTGS4, and sdTGS2 respectively. The variables sdGS1 is not shown due to their small arrow length, i.e. eigenvalues less than 0.2 on both axes. The axes values in grey relate to the correlation values (grey arrows)

3.1.b. Characterization of sites based on biological communities

A list of all taxa recorded (total = 100) and their total counts are given in Appendix B.

The effect of distance from the mouth of the estuary on faunal assemblages depended heavily on the particular estuary itself (i.e. a highly significant E x D interaction by NPMANOVA, Table 4). The factors of Estuary, Distance classification and their interaction together explained 75.7% of the variation in the assemblage data (as calculated from sums of squares). Pair-wise comparisons showed that Maungamaungaroa and Okura estuaries showed the least variation among sites (A-J), as these estuaries showed the least number of significant differences between sites within an estuary (Table 5). When the distances (A-J) were compared across estuaries, the outer sites (A-F) were all significantly different from one another. Inner sites showed less variability, with some non-significant differences among estuaries seen between sites labelled G, I or J. In addition, for Maungamaungaroa, there was an indication of a pattern of gradual change along the length of the estuary, with non-significant pair-wise comparisons occurring mainly just along the sub-diagonal (Table 5). That is, A did not differ from B, B did not differ from C, but A and C were different, and so on. These patterns were also seen in MDS ordinations (Fig. 14, Appendices D1-D3). MDS plots of sites at each time showed clumping of sites (relative similarity among assemblages) within Okura (in black) and within Maungamaungaroa (in pink), in comparison to the other estuaries on the plots. The relative similarity among assemblages at sites in the upper reaches of the estuaries (G, I, J) was also apparent, compared to the wider spread of sites A-F and H in the plots (Fig. 14, Appendices D1-D3).

Hierarchical agglomerative cluster analyses done separately at the four different times (Fig. 15, Appendices E1-E3) suggested that the assemblages at different sites could be consistently classified into three groups. Individual sites were therefore classified into one of three groups using k-means partitioning at each time. Sites were assigned to a group overall depending on which group they were most frequently assigned to over time (Table 6). These groups were relatively distinct, especially group 1 (Fig 14b, Appendices D1b-D3b). These groupings did not necessarily reflect, however, estuarine or distance classifications. For example, not all sites from Okura were classified together, although sites from the upper reaches of estuaries (H-J) did tend to be classified in group 1 (Table 6). All estuaries except Maungamaungaroa had at least one site in each faunal group.

SIMPER analyses showed that group structure was apparently influenced by seven key taxa. These seven taxa contributed to at least 49% of the similarity within any group and 28% of

the dissimilarity between any groups (Appendix F). The patterns in these taxa and the total number of taxa in groups 1, 2 and 3 are shown in Fig. 16. Group 1 was characterized by high numbers of worm-like organisms. High numbers of Nereid/Nicon polychaetes, Capitellids and Oligochaetes and intermediate counts of the polychaete *Prionospio* sp. were seen in Group 1. Group 2 was characterised by high numbers of the cockle *Austrovenus stutchburyi,* and the polychaetes *Notomastus* sp. and *Prionospio* sp. Group 2 also showed greater total numbers of taxa compared to the other two groups. Group 3 was the most distinct group (65% internally similar cf. Groups 1&2 = 49% internally similar each, measures are based on the average Bray-Curtis similarity measures between groups, Appendix E.a) and was characterised by high counts of the bivalve *Paphies* sp. and the crustaceans *Colorustylis lemurum* and *Waitangi* sp.

Table 4. NPMANOVA examining the effects of estuary, distance classification (A-J) and their interaction on the biological species data at all times of sampling. The analyses were based on the Bray-Curtis dissimilarity measure calculated from *ln* (*y* + 1)-transformed species data. Observations were pooled at the site level. *P*-values were obtained using 4999 permutations.

Source	df	SS	MS	F	P
Estuary (E)	4	58101.97	14525.49	25.13	**0.001**
Distance class (D)	9	60461.77	6717.98	11.62	**0.001**
E x D	36	151789.30	4216.37	7.29	**0.001**
Residual	150	86711.77	578.08		
Total	199	357064.81			

Table 5. Pair-wise comparisons (obtained using the NPMANOVA *t*-statistic and permutations) among estuaries for each distance class (left-hand side) and among distance classes for each estuary (right-hand side). Numbers shown are *P*-values, with * = $P < 0.05$. A-J = sites, P= Puhoi, R= Orewa, W= Waiwera, O= Okura and Z = Maungamaungaroa.

Sites A-F

	O	P	R	W
P	*			
R	*	*		
W	*	*	*	
Z	*	*	*	*

Site G

	O	P	R	W
P	*			
R	**0.06**	*		
W	**0.07**	*	*	
Z	*	*	*	*

Site H

	O	P	R	W
P	*			
R	*	*		
W	*	*	*	
Z	*	*	*	*

Site I

	O	P	R	W
P	*			
R	*	**0.06**		
W	*	*	*	
Z	*	*	*	*

Site J

	O	P	R	W
P	*			
R	**0.06**	*		
W	*	*	*	
Z	**0.38**	*	*	*

Okura

	A	B	C	D	E	F	G	H	I
B	*								
C	*	*							
D	**0.09**	*	*						
E	*	*	**0.05**	*					
F	*	*	*	*	*				
G	*	*	*	*	**0.35**	**0.06**			
H	*	*	*	*	**0.06**	*	*		
I	*	*	*	*	*	*	*	**0.06**	
J	*	**0.21**	*	*	*	*	*	*	**0.10**

Puhoi

	A	B	C	D	E	F	G	H	I
B	*								
C	*	*							
D	*	*	*						
E	*	*	*	*					
F	*	*	*	*	*				
G	*	*	*	*	*	*			
H	*	**0.22**	*	*	*	*	*		
I	*	**0.17**	*	*	*	*	*	**0.56**	
J	*	*	*	*	*	*	*	*	*

Orewa

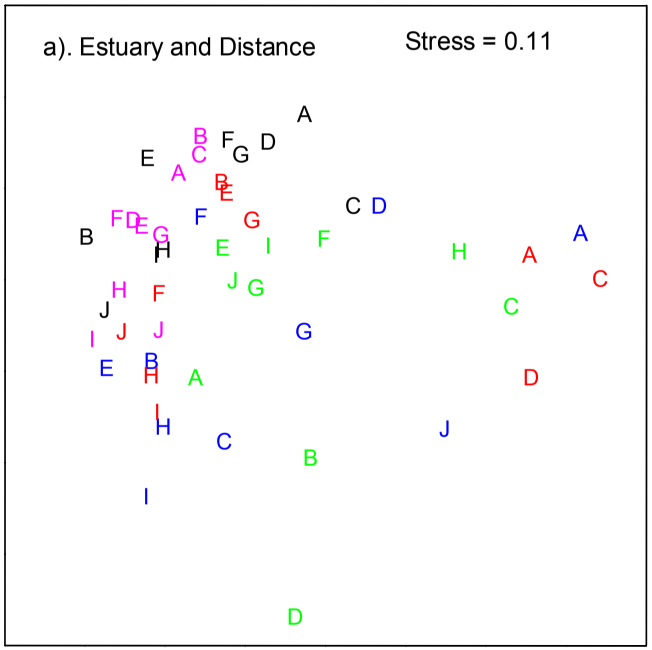
	A	B	C	D	E	F	G	H	I
B	*								
C	*	*							
D	*	*	*						
E	*	**0.11**	*	*					
F	*	*	*	*	*				
G	*	*	*	*	*	*			
H	*	*	*	*	*	*	*		
I	*	*	*	*	*	*	*	**0.07**	
J	*	*	*	*	*	**0.10**	*	*	**0.05**

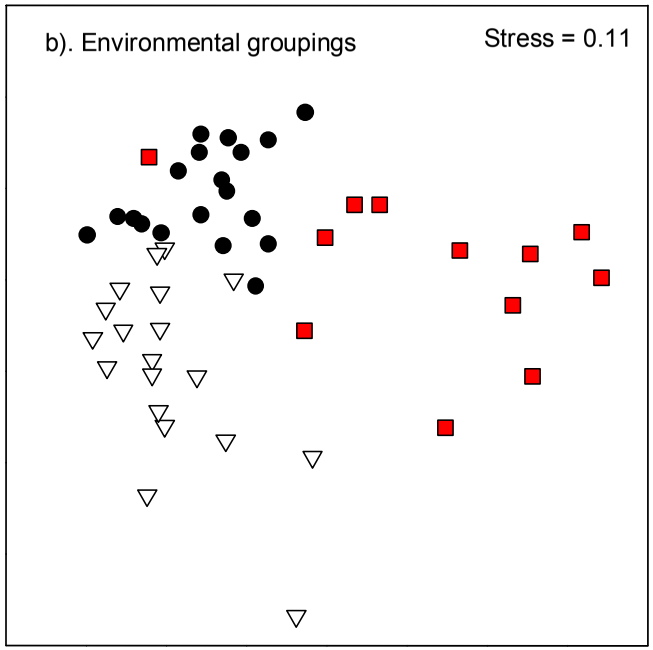
Waiwera

	A	B	C	D	E	F	G	H	I
B	*								
C	*	*							
D	*	*	*						
E	*	*	*	*					
F	*	*	*	*	*				
G	*	*	*	*	**0.17**	*			
H	*	*	*	*	*	**0.12**	*		
I	*	*	*	*	*	*	*	*	
J	*	**0.08**	*	*	*	*	*	**0.42**	*

Maungamaungaroa

	A	B	C	D	E	F	G	H	I
B	**0.61**								
C	*	**0.06**							
D	*	*	*						
E	*	*	*	**0.23**					
F	*	*	*	*	*				
G	*	*	*	**0.08**	**0.16**	**0.06**			
H	*	*	*	*	**0.09**	*	*		
I	*	*	*	*	**0.06**	*	*	**0.48**	
J	*	*	*	*	**0.13**	*	*	**0.68**	**0.43**





Blue = Puhoi sites A-J
Black = Okura sites A-J
Red = Orewa sites A-J
Pink = Maungamaungaroa sites A-J
Green = Waiwera sites A-J

White triangles = Group 1
Black circles = Group 2
Red squares = Group 3

Fig. 14. MDS plot of assemblage data from August 2002 showing a) estuary and distance information, b) faunal groupings. The analyses were based on the Bray-Curtis dissimilarity measure calculated from $ln(y+1)$-transformed species data. Observations were pooled at the site level (n=5).

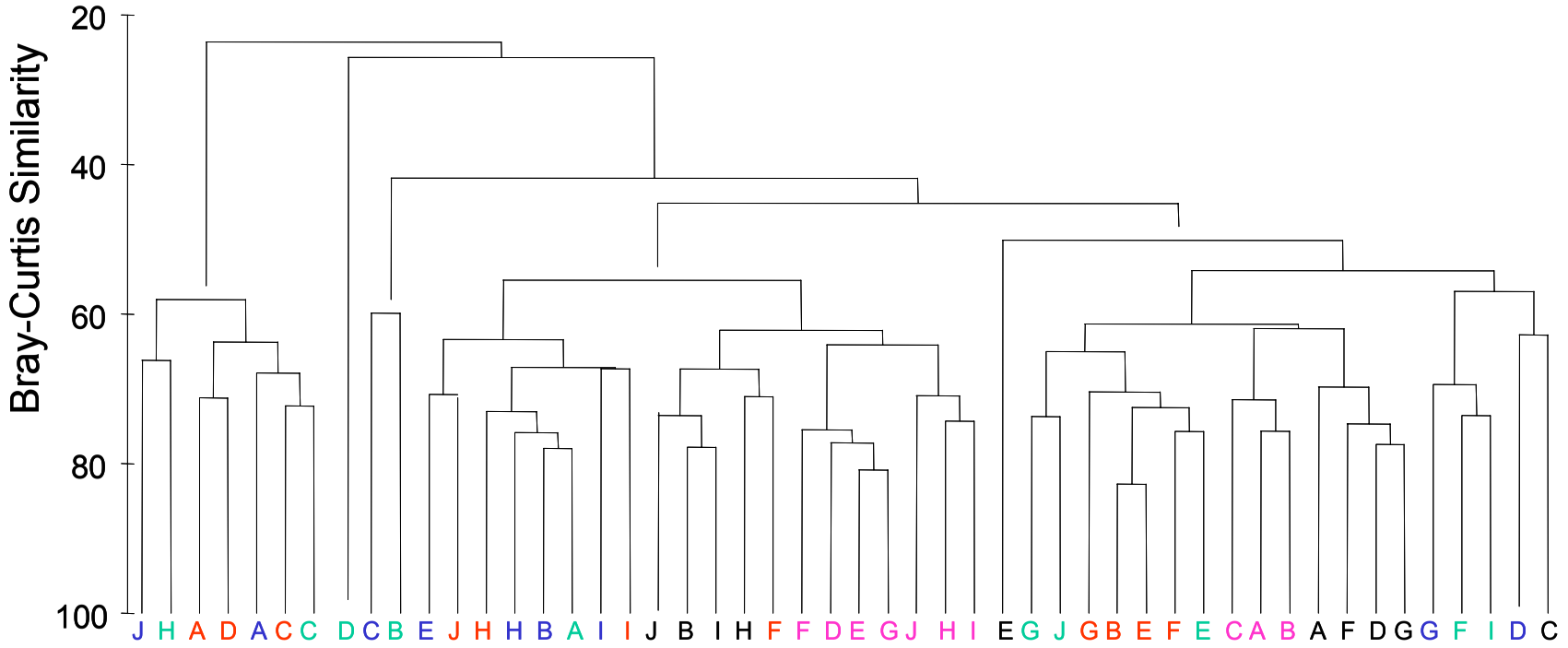


Fig. 15. Dendrogram from the hierarchichial agglomerative cluster analysis of assemblage data from August 2002 of all sites in all estuaries. The analyses were based on the Bray-Curtis dissimilarity measure calculated from $ln(y + 1)$-transformed species data. Observations were pooled at the site level (n=5). Sites are indicated by a coloured letter, the letter indicates the site within an estuary (A-J), the colour represents an estuary Blue = Puhoi, Green = Waiwera, Red = Orewa, Black = Okura and Pink = Maunagamaungaroa

Table 6. Results of k-means partitioning of sites into one of three groups based on assemblage data from all times of sampling. The analyses were based on the Bray-Curtis dissimilarity measure calculated from $ln(y+1)$-transformed species data. Observations were pooled at the site level. The numbers below the group headings indicate the number of sites in each group. The numbers in brackets indicate the number of times (out of a possible maximum of 4) that a site was assigned to that group. Three sites OI, OE and WJ were evenly split between group 2 and another group. In all cases these sites were assigned away from group 2 to create a greater balance in the number of sites in different groups.

ESTUARIES	Group 1 19	Group 2 19	Group 3 12
OKURA	OH (4) OI (2) OJ (4)	OA (4) OB (3) OD (4) OF (4) OG (4)	OC(3) OE (2)
PUHOI	PB (4) PC (4) PE (4) PH (4) PI (4)	PF (4)	PA (4) PD (3) PG (3) PJ (3)
OREWA	RF (3) RH (4) RI (4) RJ (4)	RB (4) RE (4) RG (4)	RA (4) RC (4) RD (4)
WAIWERA	WA (4) WB (4) WD (4) WJ (2)	WE (4) WG (4) WI (4)	WC (4) WF (4) WH (4)
MAUNGAMAUNGAROA	ZH (4) ZI (4) ZJ (4)	ZA (4) ZB (4) ZC (4) ZD (4) ZE (3) ZF (4) ZG (4)	

3.2 Relationships of Fauna with Environmental Variables

3.2.a. Models

There were several environmental variables that characterised individual sites and therefore could be used as a potential model of species data at the site level. These are listed in Table 2 and some combinations of the variables formed natural groupings, also shown in the Table. As the modelling was done at the site level, there were 4 times of sampling for each of 50 sites, for a total of 200 observations. A total of 100 taxa were recorded from those 200 observations.

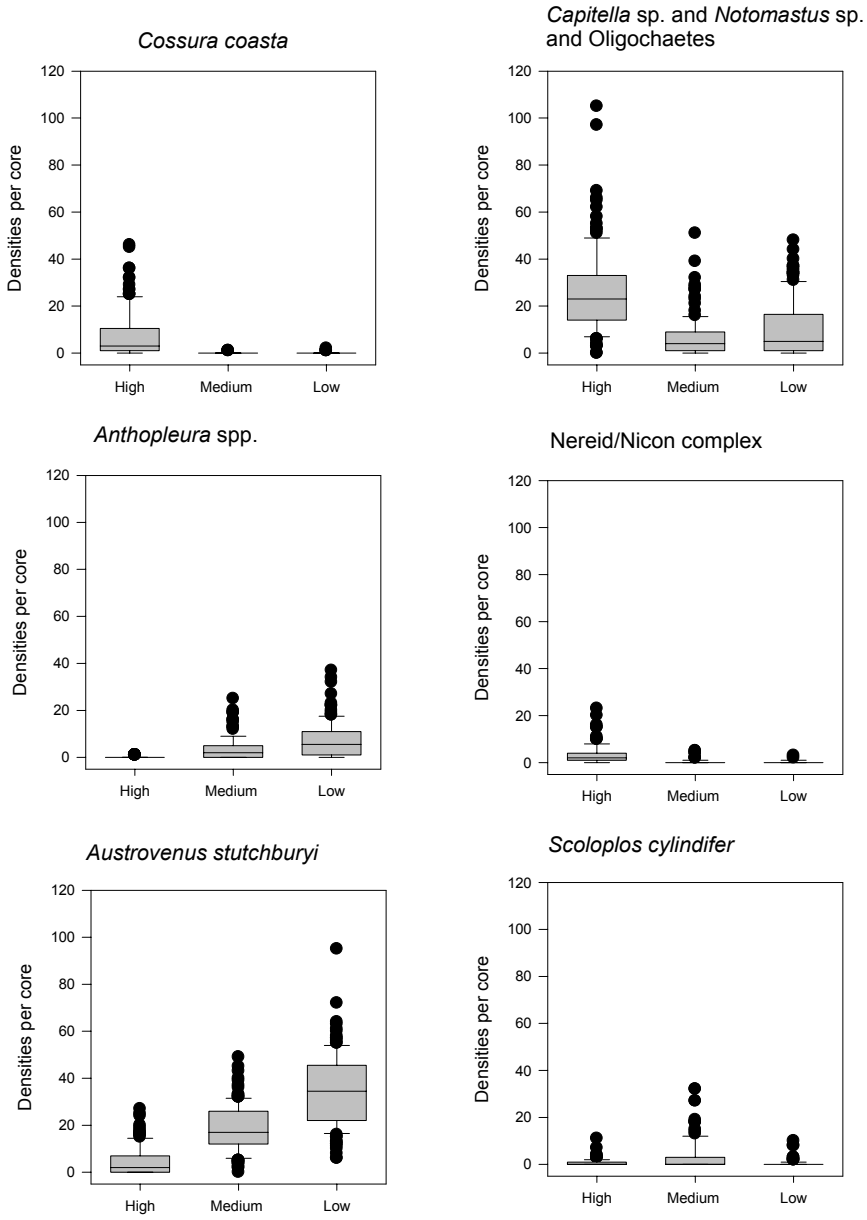


Fig. 16. Boxplots of densities of individual taxa for all sampling times from 2001-2003 in High, Medium or Low depositional sites. There were 120 cores within each all group.

When building a model, consideration must be given to the extent to which the environmental variables overlap in what they explain of the species information. That is, the environmental variables are, themselves, correlated. Thus, a sequential model was built using forward selection, which produced the model shown in Table 7b. Nonparametric multivariate regression (McArdle and Anderson, 2001) showed that 12 variables together explained 36.6% of the variance in the species data, which was highly significant ($F = 3.092$, $P = 0.01$, Table 7). The variable that alone explained the greatest amount of variation in the species

data was the average percentage of trapped fine sediment (<63 μm). The following variables: TGS3, sdTGS1, TGS2, BH, Sddep, sdGS4, sdBH, sdGS3, D, sdGS1, sdTGS3 did not have a significant relationship with the species data, when considered after fitting other environmental variables ($P > 0.05$ in each case, Table 7). Environmental variables that were highly correlated with other environmental variables can be seen by those deleted from Fig. 17 (sddep, GS3, TGS3, TGS4), and additionally those that had high % Var. scores in Table 7a (environmental variables fitted individually), but not Table 7b, e.g., sdTGS3.

The analyses of groups (whole sets) of variables are shown in Table 8. The set of variables with the greatest explanatory power was the set of ambient grain size variables, which alone explained 23.4% of the variation in the species data. Once the ambient grain size variables were fitted, the next most important component was the information from trapped sediments (i.e. short-term sediment deposition information, TrapTot, TrapSdGS and TrapGS), which explained another 14% of the variance in the species data (Table 8b). AmbChGS and Distance explained 2 and 1% of the species' variation once GS and Trapped variables were included in the model (Table 8b). Erosion variables were redundant in the model being statistically non-significant ($P > 0.05$, Table 8b). All sets of environmental variables were strongly correlated to each other as evidenced by the > 60% decrease in values for %Var between Table 8a and 8b (excluding the first fitted variable).

Table 7. Results of non-parametric multiple regression of individual environmental variables on the species data for (a) each variable taken individually (ignoring other variables) and (b) forward selection of variables, where the amounts explained by each variable added to the model takes into account the variability explained by variables already in the model (i.e. those variables listed above it). %Var = the percentage of the variance in the species data explained by that variable.

(a) Variables taken individually			
Variable	**% Var**	**pseudo-*F***	***P***
TGS1	14.12	32.56	**0.0001**
TGS3	12.94	29.42	**0.0001**
GS3	11.99	26.98	**0.0001**
GS1	11.77	26.42	**0.0001**
Avdep	10.73	23.79	**0.0001**
Sddep	9.47	20.72	**0.0001**
sdTGS2	8.08	17.40	**0.0001**
sdTGS3	7.97	17.15	**0.0001**
GS2	5.75	12.09	**0.0001**
sdTGS1	5.63	11.81	**0.0001**
sdBH	5.20	10.87	**0.0001**
sdTGS4	5.10	10.64	**0.0001**
D2	4.59	9.51	**0.0001**
D	4.55	9.43	**0.0001**
Avfin	4.53	9.40	**0.0001**
GS4	4.06	8.37	**0.0001**
TGS2	4.04	8.34	**0.0001**
sdGS4	3.95	8.15	**0.0001**
TGS4	3.08	6.30	**0.0003**
sdGS2	1.95	3.94	**0.0016**
BH	1.30	2.60	**0.0179**
sdGS1	1.26	2.54	**0.0213**
sdGS3	0.76	1.52	0.1379

(b) Variables fitted sequentially				
Variable	**pseudo-*F***	***P***	**% Var**	**% Var cumulative**
TGS1	32.55	**0.0001**	14.12	14.12
GS1	16.72	**0.0001**	6.72	20.84
Avdep	8.37	**0.0001**	3.24	24.08
Avfin	7.95	**0.0001**	2.98	27.06
D2	6.70	**0.0001**	2.43	29.49
sdTGS4	4.26	**0.0002**	1.52	31.01
GS2	3.00	**0.0022**	1.06	32.07
sdTGS2	2.39	**0.0142**	0.84	32.91
sdGS2	2.48	**0.0107**	0.86	33.77
TGS4	2.69	**0.0070**	0.93	34.70
GS4	2.43	**0.0124**	0.83	35.54
GS3	3.09	**0.0031**	1.05	36.58
TGS3	1.77	0.0616	0.60	37.18
sdTGS1	1.67	0.0781	0.56	37.75
TGS2	1.77	0.0671	0.59	38.34
BH	1.50	0.1244	0.50	38.84
Sddep	1.40	0.1666	0.47	39.31
sdGS4	1.51	0.1281	0.50	39.81
sdBH	1.67	0.0845	0.55	40.36
sdGS3	1.46	0.1365	0.48	40.85
D	1.65	0.0893	0.54	41.39
sdGS1	1.57	0.1043	0.51	41.90
sdTGS3	1.11	0.3285	0.36	42.27

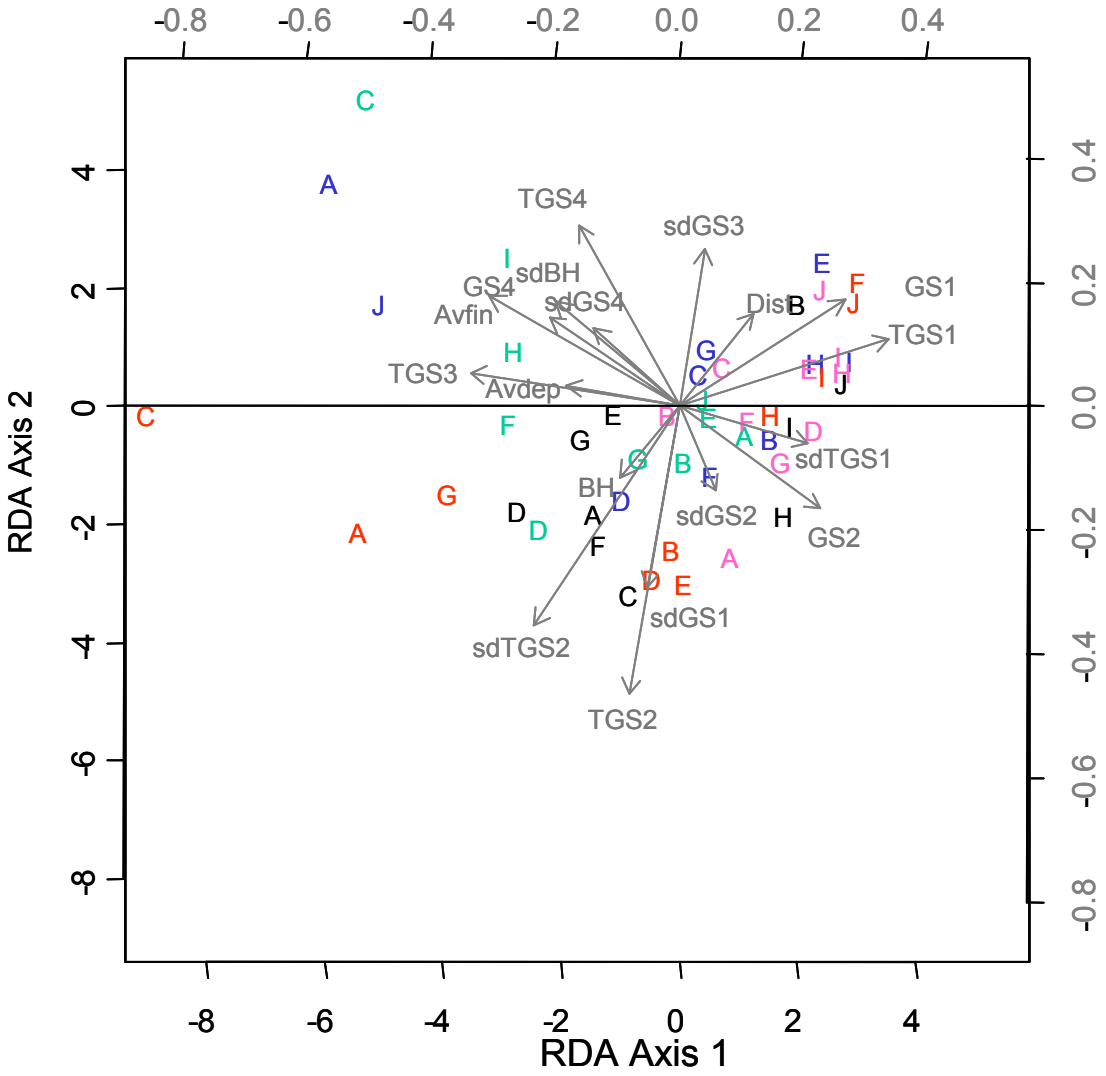


Fig. 17. Distance-based RDA ordination relating the environmental variables to the 87 taxonomic variables for the August 2002 sampling. The analysis was done on principal coordinate axes obtained from Bray-Curtis dissimilarities of ln(y + 1) transformed species counts, with correction method 1 for negative eigenvalues (see Legendre and Anderson 1999). Observations were pooled at the site level. Sites within estuaries are indicated by a coloured letter as in previous plots. Names of variables are given in Table 5. The environmental variables sddep, GS3, TGS4, and sdTGS3 were not shown on the plot as they were highly correlated (correlation coefficient >0.8) with the variables Avdep, TGS3, sdTGS4, and sdTGS2 respectively. The axes values in grey relate to the bipolt arrows (also in grey).

Table 8. Results of non-parametric multiple regression of sets of environmental variables on the species data for (a) each set of variables taken individually (ignoring other sets) and (b) forward selection of sets of variables, where the amounts explained by each set added to the model takes into account the variability explained by sets of variables already in the model (i.e. those sets of variables listed above it). %Var = the percentage of the variance in the species data explained by that set of variables.

(a) Sets taken individually

Variable	pseudo-*F*	*P*	% Var
AmbGS	14.93	**0.0001**	23.44
TrapGS	11.63	**0.0001**	19.26
TrapSdGS	10.52	**0.0001**	17.75
TrapTot	13.73	**0.0001**	17.36
AmbChGS	4.18	**0.0001**	7.90
Erosion	6.79	**0.0001**	6.45
Distance	6.14	**0.0001**	5.87

(b) Sets fitted sequentially

Variable	pseudo-*F*	*P*	% Var	% Var cumulative
AmbGS	14.93	**0.0001**	23.44	23.44
TrapTot	6.63	**0.0001**	7.19	30.63
TrapSdGS	2.90	**0.0001**	4.03	34.65
TrapGS	2.22	**0.0004**	3.01	37.66
AmbChGS	1.74	**0.0073**	2.32	39.98
Distance	1.89	**0.0173**	1.25	41.23
Erosion	1.58	0.0574	1.04	42.27

3.2.b. Direct gradient analysis (dbRDA)

To visualize these multivariate patterns, a redundancy analysis was done to compare the environmental variables to the species data (Fig. 17, Appendices G1-G3). The first two dbRDA axes on all plots explained 28.1 to 34.3% of the variability in the species data and 48.0 to 55.1% of the relationship between the species and the environmental variables.[1] In dbRDA plots there were no clear patterns with regard to the specific identity of the estuary, or distance from the mouth. In addition, although correlation among environmental variables existed, there were axes in many directions in the biplot, indicating that many environmental factors were exerting influences on the biota in different directions.

The variables that appeared to be most important in driving the environmental-biotic relationship were reasonably consistent between the dbRDA analysis (Fig. 17) and the modelling using multivariate multiple regression based on the Bray-Curtis measure (Table 7b). For example, the dbRDA plot showed GS1, GS2, TGS1, TGS2, sdGS1, sdGS2, sdTGS1 and sdTGS2 having strong relationships with the axes and all generally pointing towards the lower right-hand diagonal of the plot. Most of these variables were also included as individual variables in the forward selection procedure using DISTLM (above) and indicate that the proportion of sediments of finer grain sizes in either trapped or ambient sediments at a site are strong indicators of assemblage structure. In addition, the variables GS4, sdGS3, sdGS4, TGS3, TGS4, Avdep, Avfin, BH and sdBH generally pointed towards the upper left-hand diagonal of the dbRDA plot. This suggests that the proportion of large grain sizes in ambient

[1] Note that these percentages will differ from those seen for the DISTLM linear modelling procedure because the use of a correction for negative eigenvalues required in dbRDA inflates the total variance in the system. See Legendre and Anderson (1999) and McArdle and Anderson (2001) for more details.

or trapped sediments, the total amount of sediment deposited in traps and the amount of bed height movement (characteristic of high-energy sites) were also important in determining assemblage structure. The contrast between these two sets of variables, therefore, can provide a useful model of the biological communities.

3.2.c. Indirect gradient analysis

A further investigation of the relationship between the biological communities and the environmental data is provided by considering how well the gradient among the sites obtained using the environmental information alone (as quantified explicitly using PC axis 1 from Fig. 13) relates to patterns in the MDS plot obtained using the assemblage data alone. We examined this using bubble plots, superimposing the values for sites along the PC axis (which represents the environmental gradient from relatively high-energy sites to relatively low-energy sites) onto the biological MDS plot.

There was clearly a strong correlation between the environmental gradient we identified and the biological communities in these plots (Fig 18, Appendices H1-H3). More specifically, the more hydrodynamically active sites (coarse sediments, high amounts of sediment deposition and high variability in bed height) were clearly associated with biological communities on the right-hand side of the MDS plots (large bubbles). These communities were usually Group 3 communities, which are characterised by high counts of *Paphies* sp., and the crustaceans *Waitangi* sp. and *Colorustylis lemurum.* The less hydrodynamically active sites (fine sediments, low amounts of sediment deposition and low variability in bed height) were associated with biological communities on the left-hand side of the MDS plot (small bubbles). These communities were usually Group 1 communities, characterised by high counts of polychaetes, particularly the *Nereid/Nicon* polychaetes, Capitellids and Oligochaetes. The communities occurring along intermediate values of the environmental gradient (medium-sized bubbles) showed high counts of the cockle *Austrovenus stutchburyi,* and the polychaetes *Notomastus* sp. and *Prionospio* sp. These also showed larger numbers of taxa than either of the biological communities occurring at the hydrodynamic extremes. A map showing which sites are in which environmental groupings is shown in fig. 19.

3.2.d. Estuary-specific effects

We considered that there could be special effects due to individual estuaries that were not taken into account by modelling sites using the measured environmental variables alone. The sums of squares in Table 4 indicate that the variation in the species data explained by the individual estuaries (ignoring everything else) is 16.27%. However, after taking into account the variation explained by the environmental variables (42.27%), the variation explained by

individual estuaries was reduced to 3.6% (Table 9). Although only a small percentage, this was, nevertheless, statistically significant (Table 9), indicating that there were slight environmental differences among estuaries that were not measured by the environmental variables included in this study.

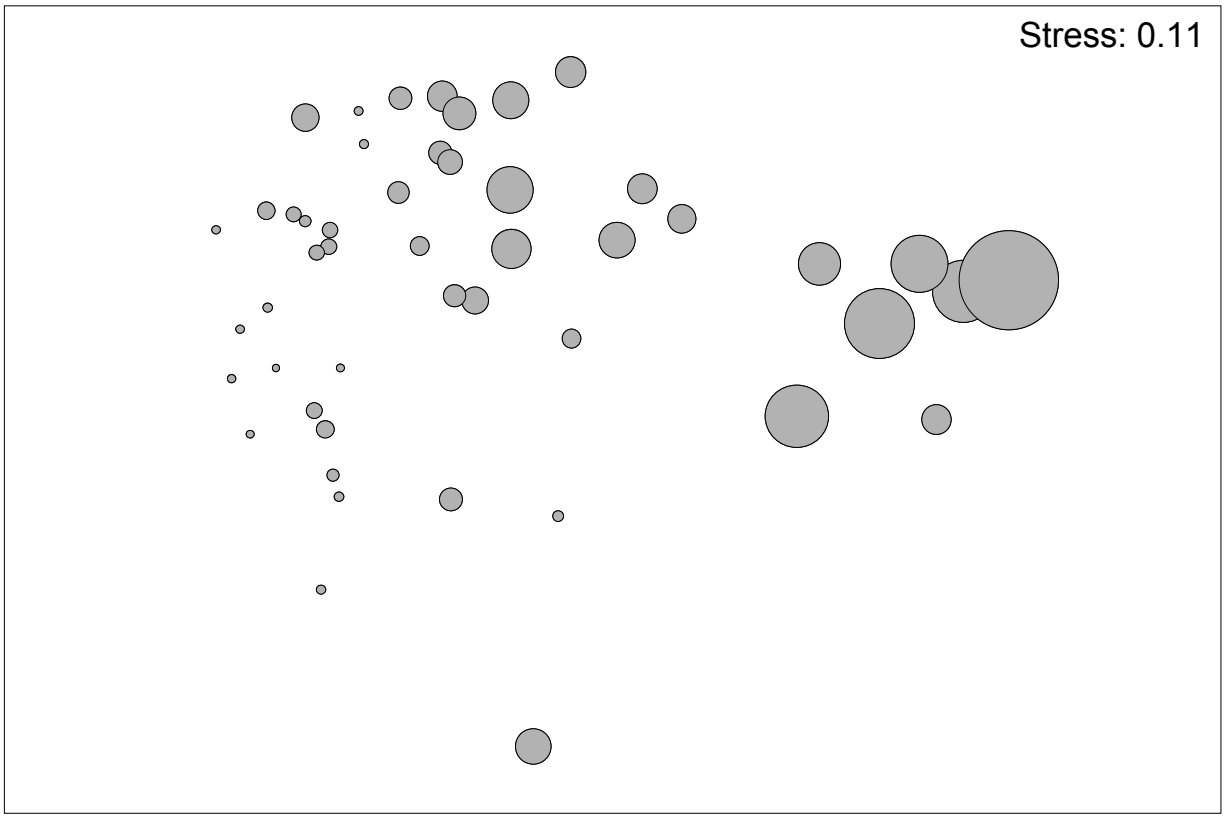


Fig. 18. Bubble plots showing the correlation of PCA axis 1 from Figure 13 (environmental data) with the biological data from August 02. The analysis was done on principal coordinate axes obtained from Normalised Euclidean environmental data, with correction method 1 for negative eigenvalues (see Legendre and Anderson 1999). Environmental data was normalized then underwent a Euclidean dissimilarity measure. Small bubbles to the left of the plot and large bubbles to the right indicate a strong correlation between the environmental and biological data.

Table 9. Results of non-parametric multivariate analysis of covariance on effects of different estuaries on the species data over and above what was explained by environmental variables. %Var = the percentage of the variance in the species data explained.

Source	df	% Var.	MS	F	P
Environmental variables (covariables)	23	42.27	3219.10		
Estuaries *given* Environmental variables	4	3.61	1123.63	2.86	**0.0003**
Residual	172	54.13			
Total	199				

Table 10. Results of NPMANOVA investigating the effects Season and Precipitation macrofaunal species abundance and composition within the different assmblage groups (a = group 1, b = group 2, c = group 3). The analysis was based on Bray-Curtis dissimilarities on data for 100 variables (taxa) transformed to $\ln(y + 1)$. *P*-values were obtained using 4999 permutations of units shown in the far right-hand column.

a) Group 1

Source	df	SS	MS	F	P
Season (Se)	1	4496.773	4496.773	3.5676	**0.002**
Precipitation (P)	1	2465.303	2465.303	1.9559	**0.046**
SexP	1	1267.42	1267.42	1.0055	0.411
Residual	72	90752.27	1260.448		
Total	75	98981.77			

b) Group 2

Source	df	SS	MS	F	P
Season (Se)	1	2713.008	2713.008	3.059	**0.001**
Precipitation (P)	1	1420.272	1420.272	1.6014	0.086
SexP	1	757.6154	757.6154	0.8542	0.607
Residual	72	63856.03	886.8893		
Total	75	68746.93			

c) Group 3

Source	df	SS	MS	F	P
Season (Se)	1	1564.429	1564.429	1.1514	0.287
Precipitation (P)	1	1119.675	1119.675	0.824	0.532
SexP	1	536.477	536.477	0.3948	0.939
Residual	44	59785.9	1358.77		
Total	47	63006.48			

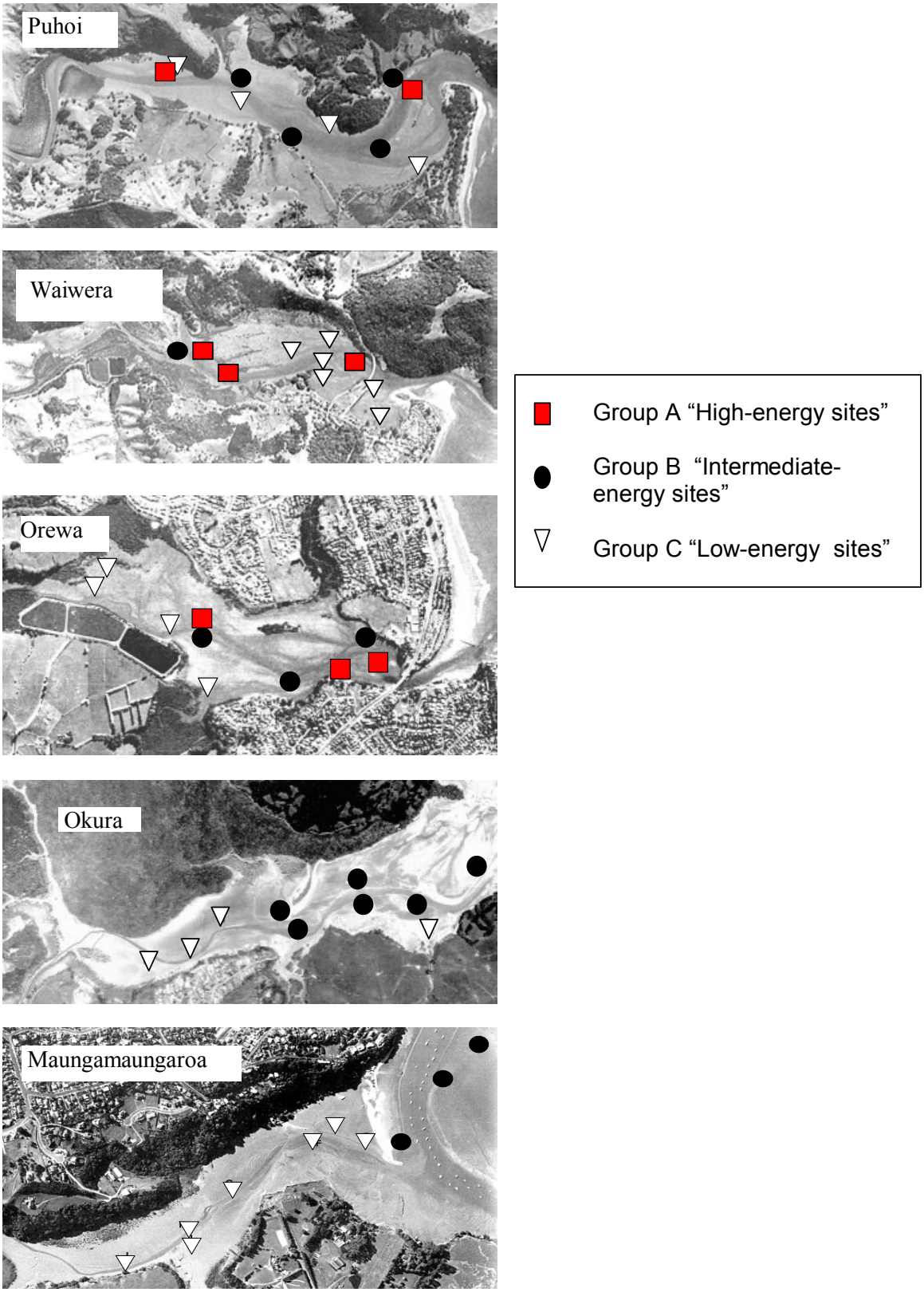


Fig. 19. Maps of all estuaries showing which sites belong to which environmental groupings.

3.3. Temporal patterns across all estuaries

The assemblage groupings identified in section 3.1.b. provide us with biologically similar communities across all estuaries that we can examine to determine whether any seasonal or rain related patterns are present. These groupings will eliminate much of the spatial variability and should allow us to detect weaker effects than would have been possible using the entire dataset. Each assemblage grouping (1,2 and 3) underwent an NPMANOVA using Season and Precipitation as factors (Table 10). In general the more hydrodynamically energetic assemblages showed fewer significant effects than the less hydrodynamically energetic assemblages. Assemblage group 1 showed significant effects of Season (P = 0.002) and Precipitation (P = 0.046). Assemblage group 2 showed significant effects of Season (P = 0.001) only. Assemblage group 3 showed no significant effects of Season or Precipitation.

3.3.a. Seasonal effects

Significant seasonal affects were seen in assemblage groups 1 and 2 (Table 10a,b) Allocation successes scores from the CAP analysis for the different season show that the seasonal affect appears relatively consistent between the two assemblage groups (75-81% for both assemblage groups Table 11a). A comparison of the MDS plot (which shows the axes of most variation) and CAP plots (which show the axes most correlated with the seasonal difference (Fig 20-21)) indicates that although seasonal effects are significant and present they are not the main source of variation in either of these assemblages. Taxa that showed strong correlations with seasonal effects in assemblage 1 (Sipunculids, *Zeacumantus* sp. Chaetognaths and *Scolecolepis* sp.) were all rare taxa (on average <1 per site, and in total no more than 11 over the sampling year 2002-2003) and differences in these taxa on average between seasons were small (<0.2 organisms). In contrast, two taxa were present in assemblage 2 that showed strong correlations with seasonal effects but were not rare (>1 on average per site) and showed much larger average differences between seasons (>2 organisms). The small bivalve *Arthritica bifurcata* and the crabs in the *Helice/Hemigrapsus* complex both showed higher densities in Winter/Spring (3.2 and 7.4 on average per site) then in Late Summer (0.5 and 2.6 on average per site).

3.3.b. Effects of rainfall

The effect of rainfall was significant on biota in assemblage 1 only (Table 10b). Allocation success scores for the CAP analysis shows that the rainfall effect (71%) is of similar strength to the seasonal effects (75%) for biota in assemblage 1 (Table 11a and b). A comparison of the MDS plot (which shows the axes of most variation) and CAP plots (which show the axes

most correlated with the precipitation difference (Fig. 22)) indicates that although effect of heavy rainfall was significant and present it is not the main source of variation in either of these assemblages. The taxa that showed the strongest correlation with precipitation effects in assemblage 1 (*Psuedosphaeroma* sp. and *Theora* sp.) were both rare species (on average <1 per site). Psuedosphaeroma sp. showed higher average densities in dry samplings (0.08) than in rain samplings (0.05). *Theora* sp. showed higher average densities after heavy rain (0.7) than in dry samplings (0.2).

Table 11. Results of CAP analyses examining effects of a) Season and b) Precipitation within each assemblage grouping. m = the number of principal coordinate (PCO) axes used in the CAP procedure, %Var = the percentage of the total variation explained by the first m PCO axes, Allocation success = the percentage of points correctly allocated into each group, δ_1^2 is the first squared canonical correlations. P-values were obtained using 4999 random s.

a) Season

			Allocation success (%)				
	m	**%Var**	**W/S**	**LS**	**Total**	δ_1^2	***P***
Assemblage Group 1	8	82.2	78	81	79	0.467	**0.001**
Assemblage Group 2	14	90.9	75	75	75	0.445	**0.002**

b) Precipitation

			Allocation success (%)				
	m	**%Var**	**Dry**	**Rain**	**Total**	δ_1^2	***P***
Assemblage Group 1	14	97.6	67	75	71	0.323	**0.024**

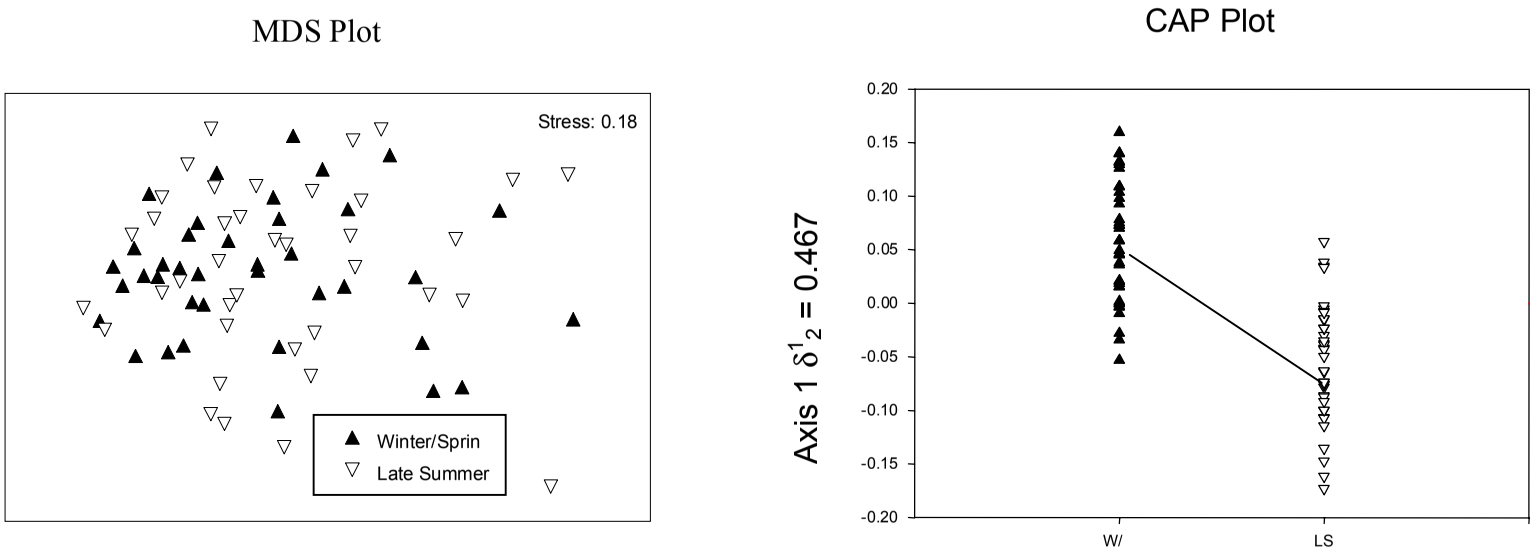


Fig. 20. Non-metric MDS plot (left-hand side) and CAP plot (right-hand side) showing the effects of Season in assemblage group 1 for the 2002-2003 year. Analyses were based on Bray-Curtis dissimilarities of 80 variables that were transformed to $\ln(y + 1)$. Each point represents pooled information from $n = 5$ cores

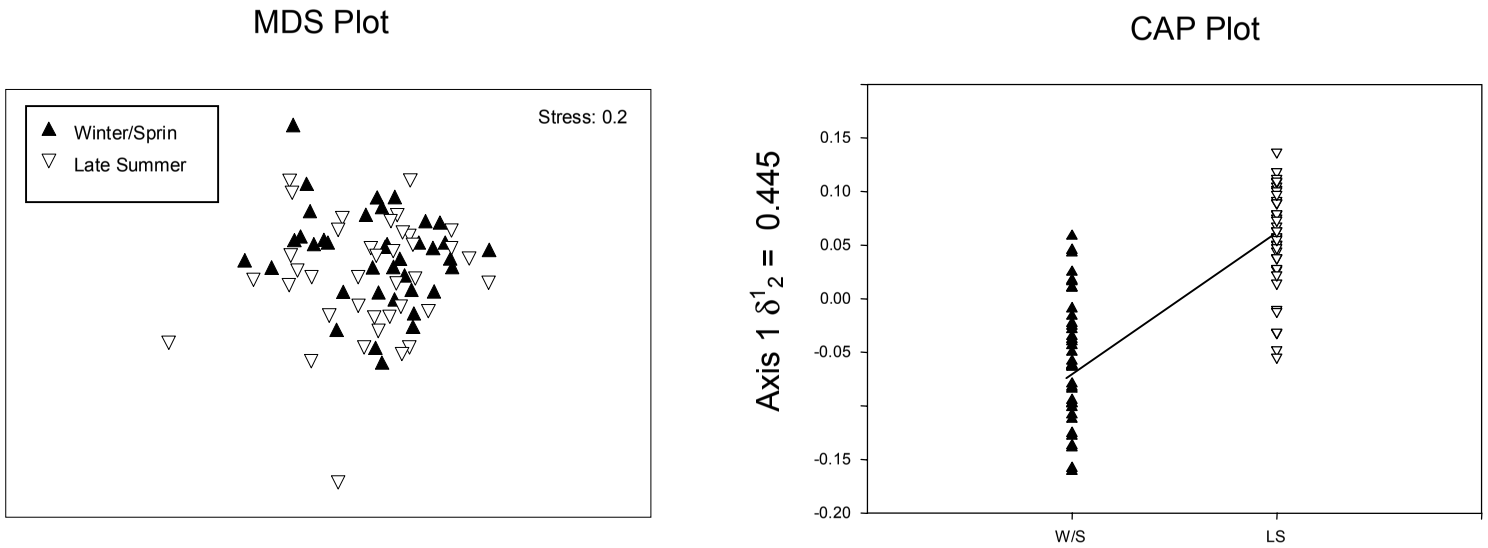


Fig. 21. Non-metric MDS plot (left-hand side) and CAP plot (right-hand side) showing the effects of Season in assemblage group 2 for the 2002-2003 year. Analyses were based on Bray-Curtis dissimilarities of 92 variables that were transformed to ln(y + 1). Each point represents pooled information from n = 5 cores

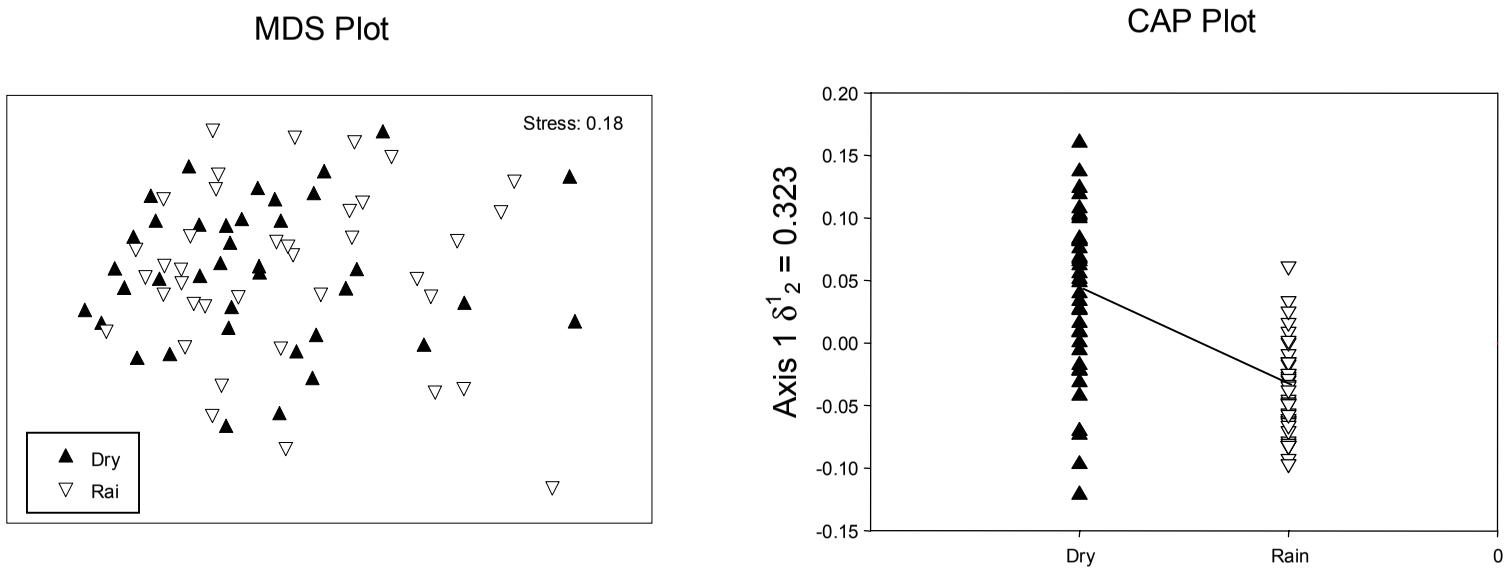


Fig. 22. Non-metric MDS plot (left-hand side) and CAP plot (right-hand side) showing the effects of Precipitation in assemblage group 1 for the 2002-2003 year. Analyses were based on Bray-Curtis dissimilarities of 80 variables that were transformed to ln(y + 1). Each point represents pooled information from n = 5 cores

3.4. Temporal and spatial effects within Okura estuary

3.4.a. Overall results

The past two years of monitoring Okura estuary provided an opportunity to examine the potential temporal effects of year, season and precipitation events on assemblages and how these factors' effects may have differed among different sites and depositional environments. The following NPMANOVA used data from 2 years of (2001-2002, 2002-2003) monitoring in Okura estuary: two seasons (Winter/Spring and Late Summer), two levels of precipitation (Rain and Dry), three levels of deposition (High, Medium and Low), three sites nested within each level of deposition and 5 replicate cores from each site. There was important small-scale spatial variability in the soft-sediment assemblages (i.e. from site to site for each time of sampling), as evidenced by the significant 5-way interaction for Year by Season by Precipitation by Site by Deposition (i.e. $P < 0.05$ for YexSexPxSi(D), Table 12). The order in the strength of the effects, as suggested by the analysis (i.e. relative sizes of components of variation, estimated using the mean squares in Table 12), was that depositional effects were the strongest, followed by site effects, followed by year effects then seasonal effects and, finally, effects of precipitation, which were the weakest Table 13.

Differences in the sizes of effects were also apparent visually in an MDS plot of the entire data set, which included samples from the 2000-2001 year (Fig. 23). Here, a single observation on the plot corresponds to the counts combined across 10 cores (5 cores in each of 2 sites). This plot shows clear definition between assemblages occurring in High depositional areas and those in Medium or Low depositional areas. The separation between assemblages in Medium and Low depositional areas was less distinct, as seen in previous investigations (Anderson et al. 2002). As the strength of effects decreases (see Figs. 23a-d, sequentially) the distinction among the groups decreases. That is, the separation between deposition classifications (Fig. 23a) is more clear than the separation between years (Fig. 23b), which is clearer than the separation between seasons (Fig. 23c), which is clearer than the separation between rain and dry samplings (Fig. 23d).

Depositional classification affected assemblage type significantly and consistently over this two-year period (significant Dep effect $P = 0.0205$, Table 12). The significant YexP interaction ($P = 0.0302$, Table 12) means that the effect of rainfall in Okura needs to be considered separately within each Year.

Table 12. Results of NPMANOVA investigating the effects of Year, Season, Precipitation, Deposition and Site on macrofaunal species abundance and composition at Okura estuary over time. The analysis was based on Bray-Curtis dissimilarities on data for 44 variables (taxa) transformed to $\ln(y + 1)$. *P*-values were obtained using 4999 permutations of units shown in the far right-hand column. Monte Carlo *P*-values (shown in italics) were used whenever the number of permutable units was too small to get a reasonable permutation test.

Source	df	SS	MS	F	P(perm)	Denom MS	Permutable units
Year =Y	1	1.260	1.2595	3.555	**0.0322**	YexSi(De)	18 YexSi(De) units
Season =Se	1	1.128	1.1277	5.400	**0.0080**	SexSi(De)	18 SexSi(De) units
Precipitation = P	1	0.552	0.5515	3.762	**0.0031**	PxSi(De)	18 PxSi(De) units
Deposition = D	2	17.433	8.7164	4.326	***0.0003***	Si(De)	9 Si(De) units
Si(De) = Si(D)	6	12.088	2.0147	26.506	**0.0001**	Res	360 Raw data units
YexSe	1	0.207	0.2068	1.297	0.2797	YexSexSi(De)	36 YexSexSi(De) units
YexP	1	0.356	0.3561	3.606	**0.0302**	YexPxSi(De)	36 YexPxSi(De) units
YexDe	2	0.720	0.3602	1.017	0.4293	YexSi(De)	18
YexSi(De)	6	2.126	0.3543	4.661	**0.0001**	Res	360 Raw data units
SexP	1	0.167	0.1665	1.075	0.3643	SexPxSi(De)	36 SexPxSi(De) units
SexDe	2	0.461	0.2303	1.103	0.3837	SexSi(De)	18 SexSi(De) units
SexSi(De)	6	1.253	0.2088	2.747	**0.0001**	Res	360 Raw data units
PxDe	2	0.442	0.2209	1.507	0.2262	PxSi(De)	18 PxSi(De) units
PxSi(De)	6	0.880	0.1466	1.929	**0.0016**	Res	360 Raw data units
YexSexP	1	0.160	0.1592	1.279	0.2921	YexSexPxSi(De)	72 YexSexPxSi(De) units
YexSexDe	2	0.388	0.1942	1.218	0.3231	YexSexSi(De)	36 YexSexSi(De) units
YexSexSi(De)	6	0.957	0.1595	2.098	**0.0006**	Res	360 Raw data units
YexPxDe	2	0.405	0.2027	2.052	0.0969	YexPxSi(De)	36 YexPxSi(De) units
YexPxSi(De)	6	0.593	0.0988	1.299	0.1118	Res	360 Raw data units
SexPxDe	2	0.191	0.0953	0.615	0.0731	SexPxSi(De)	36 SexPxSi(De) units
SexPxSi(De)	6	0.929	0.1549	2.038	**0.0011**	Res	360 Raw data units
YexSexPxDe	2	0.193	0.0965	0.775	0.6274	YexSexPxSi(De)	72 YexSexPxSi(De) units
YexSexPxSi(De)	6	0.747	0.1245	1.639	**0.0120**	Res	360 Raw data units
Residual	288	21.891	0.0760				
Total	359	65.524					

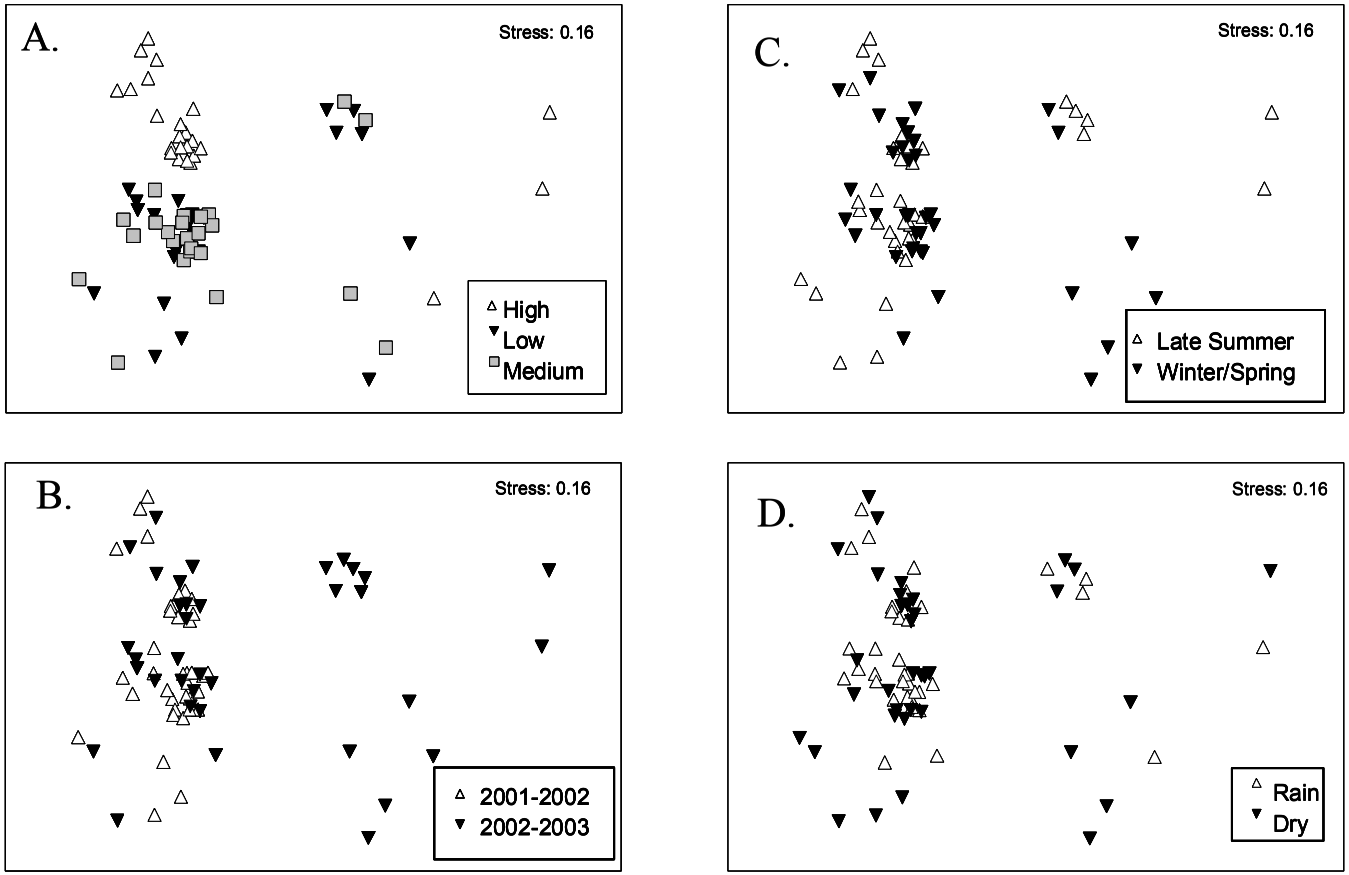


Fig. 23. Non-metric MDS plots of Okura assemblages monitored through time from 2000 – 2003. The analysis was based on the Bray-Curtis dissimilarity measure calculated from $ln(y + 1)$-transformed species data. Observations (n=10) were pooled at the level of deposition within each sampling time (i.e. 5 reps in each of 2 sites). Separate plots show labels, which identify comparisons according to particular factors in the anaysis: A. Deposition, B. Year, C. Season, D. Precipitation.

Table 13. Percentages of variance explained by the main effects of the NPMANOVA in Table 7.

Source	% variance explained	% cummulative variance explained
Deposition	26.61	26.61
Site	18.45	45.06
Year	1.92	46.98
Season	1.72	48.70
Precipitation	0.84	49.57

3.4.b. Effects of Deposition

CAP analyses (Table 14) showed that communities from High depositional sites were consistently clear and differentiable from communities in Medium or Low depositional environments (allocation success = 100%, Fig. 24). However, communities from Medium or Low depositional sites were less distinct (64% and 81% allocation success, respectively). In contrast, when we examine the different depositional classifications over the two years of sampling, the High and Low depositional sites were the most variable, while from sampling time 5-10 the Medium depositional sites were highly similar (Fig. 25). The six taxa that showed the strongest correlations ($|r| > 0.6$) with the first canonical axis corresponding to depositional differences are shown graphically in Fig. 26. High depositional sites showed the greatest denisities of Nereid/Nicon polychaetes, *Cossura coasta* and *Capitella* sp. plus *Notomastus* sp. plus Oligochaetes. Medium deposition sites were characterised by high densities of cockles *Austrovenus stutchburyi* and the orbinid polychaete *Scoloplos cylindifer*. Low deposition sites showed the highest densities of the anemone *Anthopleura* sp.

Table 14. Results of CAP analyses examining effects of Deposition within each combination of Year and Deposition. *m* = the number of principal coordinate (PCO) axes used in the CAP procedure, %Var = the percentage of the total variation explained by the first *m* PCO axes, Allocation success = the percentage of points correctly allocated into each group, δ_1^2 and δ_2^2 are the first two squared canonical correlations. *P*-values were obtained using 4999 random permutations.

			Allocation success (%)						
	m	**%Var**	**H**	**M**	**L**	**Total**	δ_1^2	δ_2^2	***P***
2001 – 2003 Data	11	93.7	100	64	81	82	0.838	0.256	**0.001**

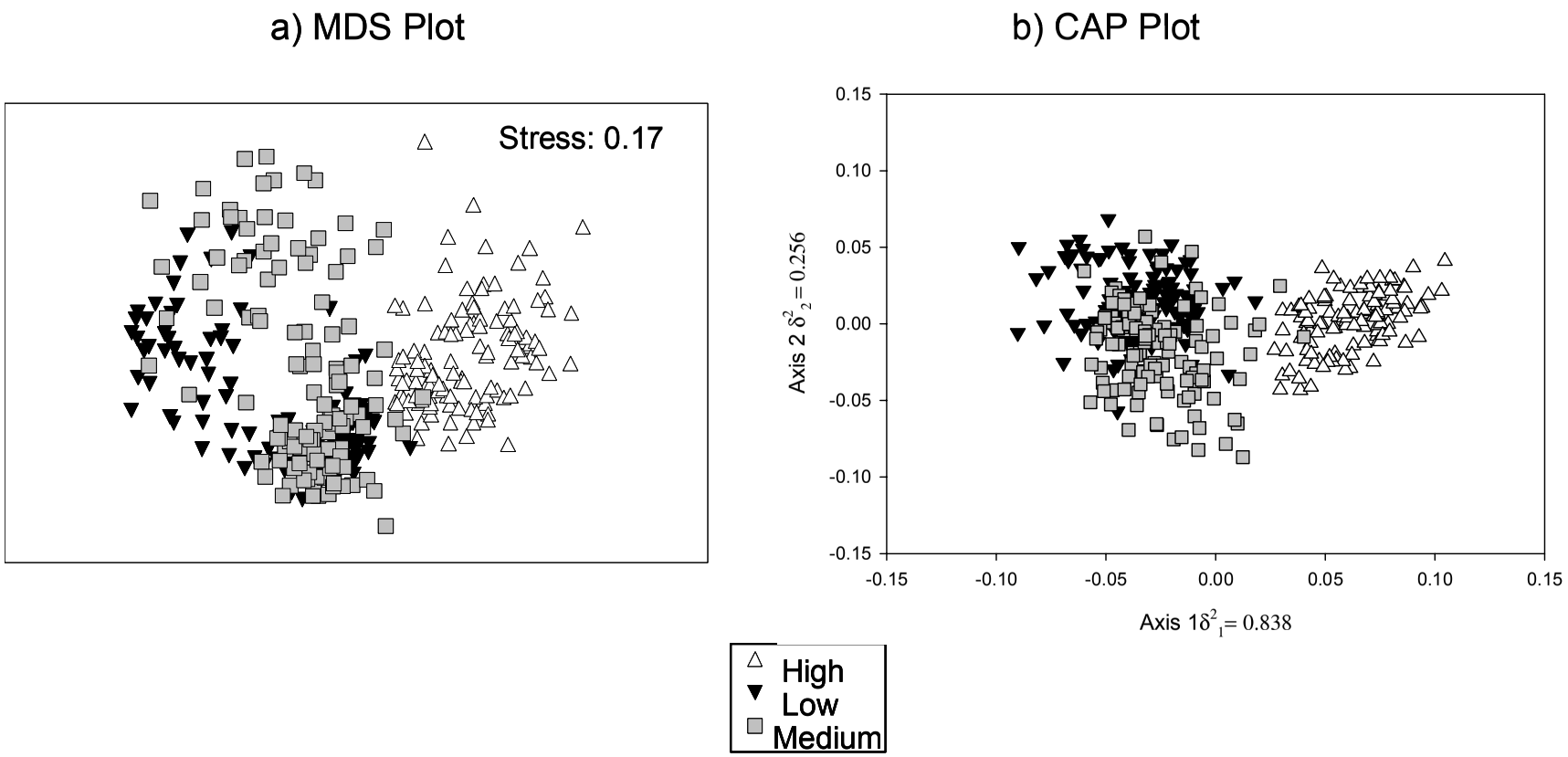


Fig. 24. Non-metric MDS plot (left-hand side) and CAP plot (right-hand side) showing the effects of Deposition for all times of sampling across both years (2001-2002 and 2002-2003). Analyses were based on Bray-Curtis dissimilarities of 44 variables that were transformed to $\ln(y + 1)$. Each point represents pooled information from $n = 5$ cores

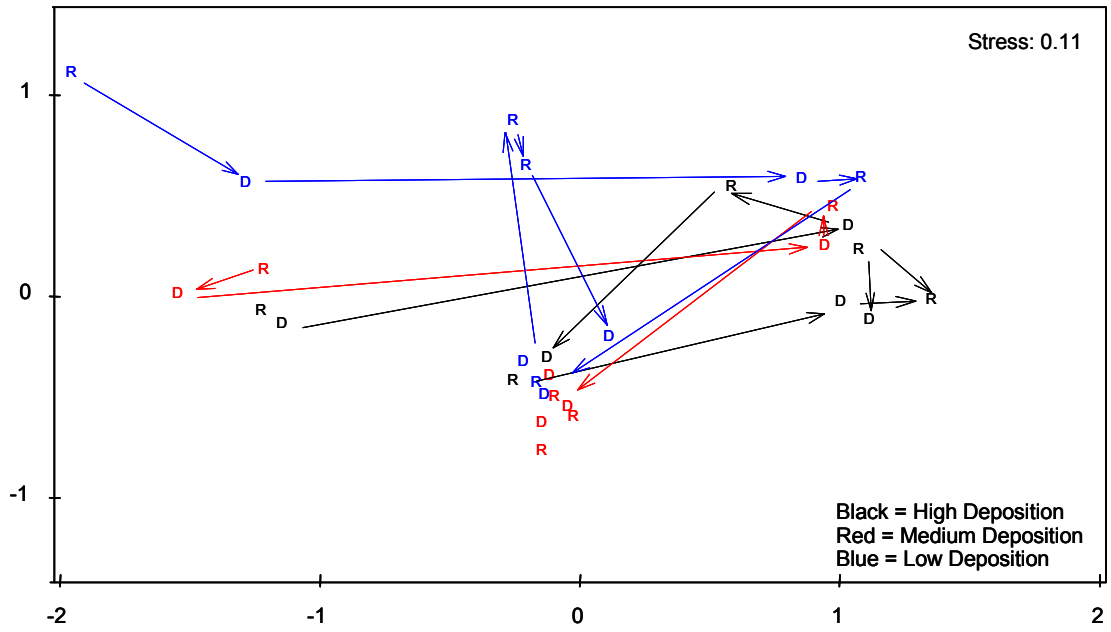


Fig. 25. MDS plot of effects of Deposition (High, Medium or Low), Time (all sampling times in years 2001-2003) and Precipitation (Rain or Dry). The coloured lines join points from the same Deposition status in order of time, the R and D indicate Rain and Dry samplings respectively. Distances between points represent Bray-Curtis dissimilarities on summed abundances from the 5 cores x 3 sites for each combination of the above factors for 44 taxa, transformed to $\ln(y + 1)$.

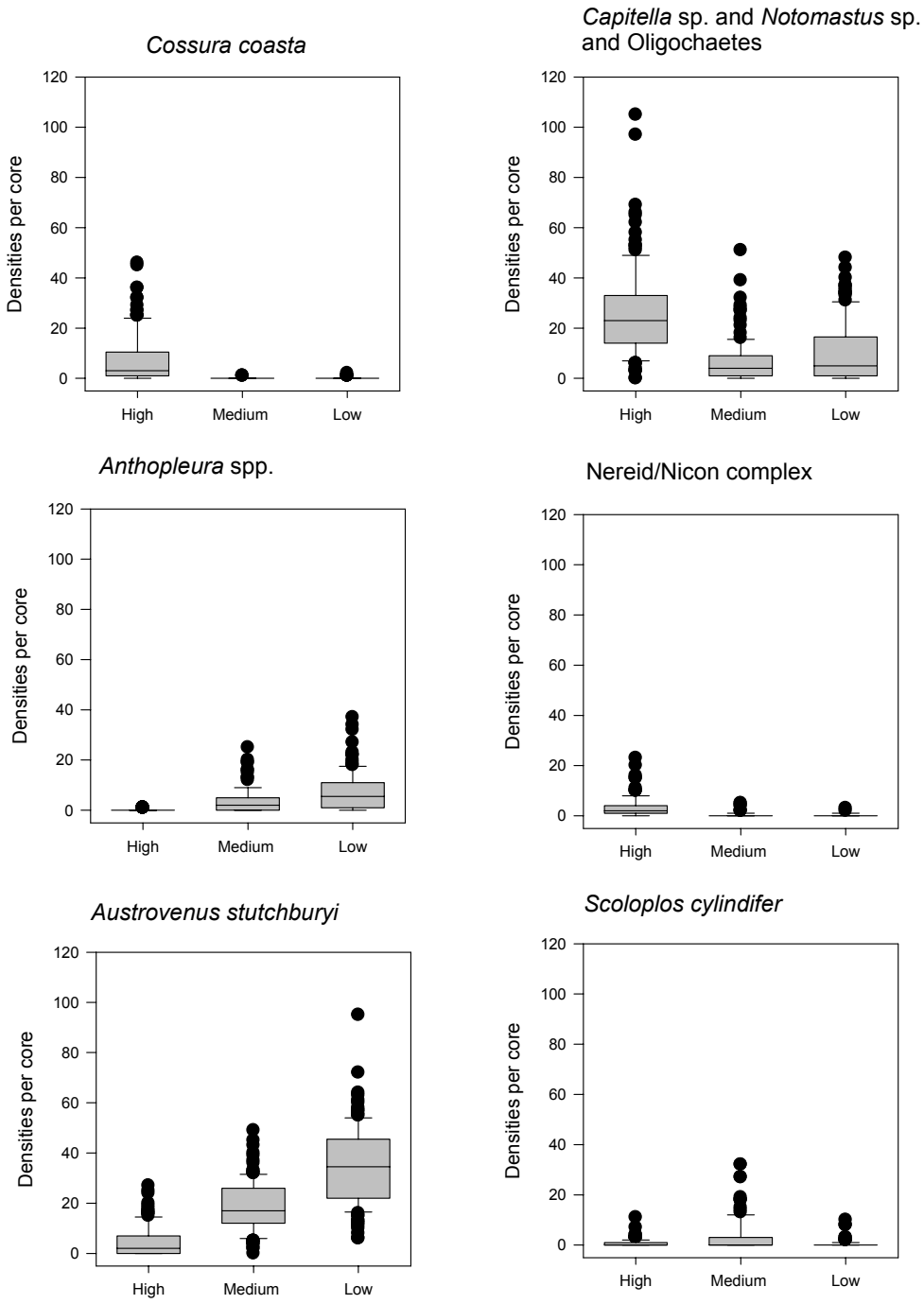


Fig. 26. Boxplots of densities of individual taxa for all sampling times from 2001-2003 in High, Medium or Low depositional sites. There were 120 cores within each all group.

3.4.c. Effects of Rainfall

CAP analyses (Table 15, Fig. 27) showed that there was a statistically significant difference between assemblages sampled after rain compared to those sampled after dry periods in both years. The taxa that showed the strongest correlations with the difference between Rain and Dry samplings showed differences in different directions in different years. The Capitellids, Oligochates and Notomastus complex had an average density of 14.3 per core at dry samplings and 8.7 per core in rain samplings in 2001-2002. In 2002–2003 this pattern was

reversed with these taxa having average densities of 20.5 per core at dry samplings and 14.3 per core in rain samplings. The next largest difference for a single taxon between rain and dry samplings was in the 2002-2003 year where polychaetes of the genus *Psuedopolydora* were more numerous in dry samplings (average density of 4.0) than in rain samplings (average density of 0.9). No other species showed average density differences as large as 1.5 individuals per core between rain and dry samplings.

Table 15. Results of CAP analyses examining effects of Precipitation within each year. *m* = the number of principal coordinate (PCO) axes used in the CAP procedure, %Var = the percentage of the total variation explained by the first *m* PCO axes, Allocation success = the percentage of points correctly allocated into each group, δ_1^2 and δ_2^2 are the first two squared canonical correlations. *P*-values were obtained using 4999 random permutations.

			Allocation success (%)				
Year x Deposition	***m***	**%Var**	**Dry**	**Rain**	**Total**	δ_1^2	***P***
2001-2	9	89.7	73	58	66	0.168	**0.001**
2002-2	7	84.6	68	60	64	0.115	**0.006**

3.4.d. Long term patterns for Okura

Multivariate control charts for all 36 months of monitoring in Okura estuary to date, from April 2000 to April 2003, are shown in Fig. 28. Control charts emphasizing sudden changes in assemblages (i.e. the (t – 1) charts on the right-hand side of Fig. 28) showed that sharp changes in assemblage structure (above the 95% confidence bound) appeared more frequently at Low depositional sites than at Medium or High depositional sites. The tendency of most sites to return to below the 95% confidence bound indicated that such changes to assemblage structure were transitory. Control charts designed to detect cumulative change (i.e. the t = 1 charts on the left-hand side of Fig. 28) suggested a gradual change in assemblage structure may be occurring at the Low and Medium depositional sites, but not at the High depositional sites. At this stage, however, deviations have not exceeded the 95% upper bound. Ongoing monitoring will be needed to allow future reassessment of any further directional changes of assemblages at Okura.

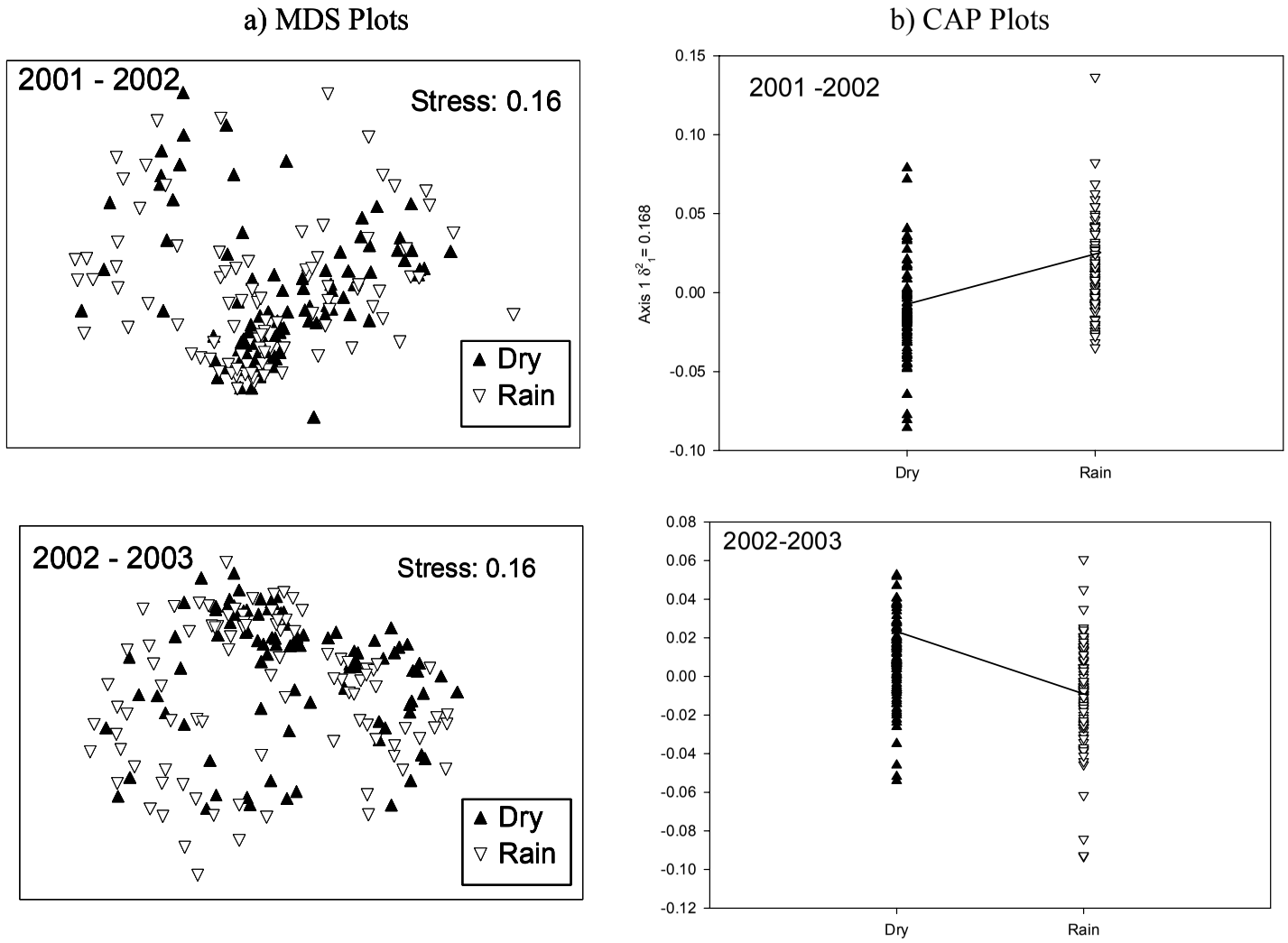


Fig. 27. Non-metric MDS plots (left-hand side) and CAP plots (right-hand side) showing the effects of Precipitation in each year. Analyses were based on Bray-Curtis dissimilarities of 44 variables that were transformed to ln(y + 1). Each point represents pooled information from n = 5 cores

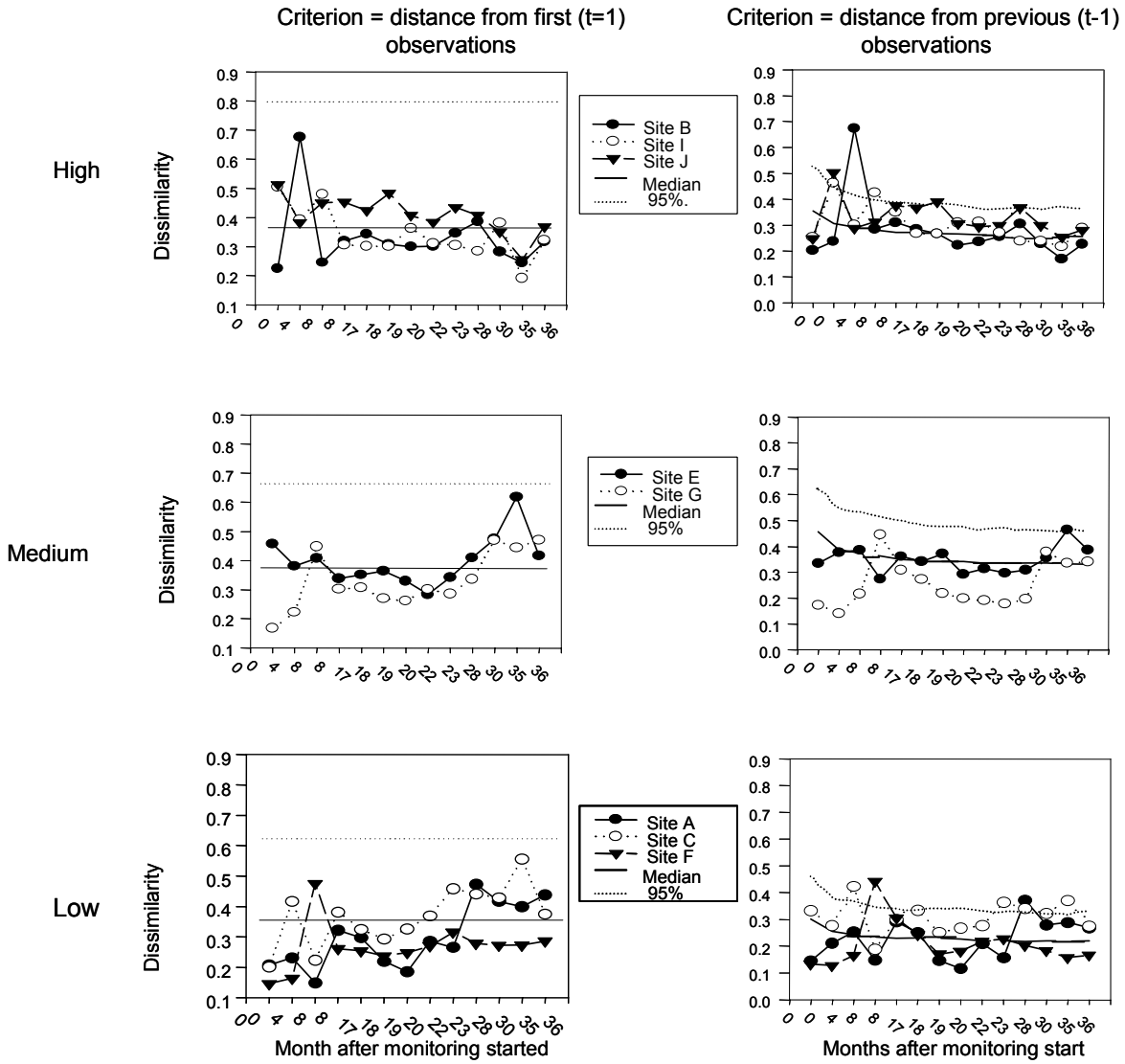


Fig. 28. Control Charts for the different deposition environments at Okura estuary. The analysis was done on principal coordinate axes obtained from Bray-Curtis dissimilarities of ln(y + 1) transformed species counts. The heading t=1 refers to control charts where the deviation is calculated from the first sampling time only; these charts will tend to emphasise trends over time in assemblage . The heading t-1 refers to control charts where the deviation is calculated from the all samplings up until the sampling in question; these charts will tend to sudden changes in assemblage structure (Anderson and Thompson 2003). C.I. = Confidence Intervals.

4. DISCUSSION

Sampling of biota in the Okura estuary has been ongoing for 3 years by Auckland Uniservices under the Okura Estuary monitoring programme. In 2000 – 2001 the sampling characterized the benthic infuanal assemblages (Anderson et al. 2001). In 2001 – 2002 the sampling again characterized the assemblages, but also linked the benthic assemblages to the environmental characteristics (particularly measures of ambient and deposited sediment) in the Okura estuary. This year the sampling has again encompassed these first two goals, but also expanded to try and place Okura estuary in a regional context so that impacts upon the whole estuary can be detected in the future.

The discussion will focus first upon the questions that relate to all 5 estuaries, where we have gathered one years worth of information. Questions relating to differential impacts within Okura estuary (where we have greater than one years information) will then be addressed.

Okura estuary is intermediate to the extremes measured in the other four estuaries in terms of ambient sediment grain size, quantity of trapped sediment, the grain size of trapped sediment and bed height change. This dataset therefore makes it possible to see a larger gradient in environmental factors than is seen in just the Okura estuary. For example, sites H, I and J at Maungamaungaroa show highly similar community types (Fig. 12), high rates of fine sediment deposition and a high percentage of fine sediments in the bed. If more fine sediments become present in Okura estuary the assemblage at sites H, I and J at Okura may become more similar to sites H, I and J at Maungamaungaroa. In this data set there are also sites of similar characteristics to Okura sites i.e. Okura site D and Waiwera site F, Okura site H and Puhoi site I (see Fig 12) which allow strong statements to be made regarding estuarine specific impacts. For example, if all Okura sites change in terms of environmental characteristics and assemblages but the highly environmentally similar sites at other estuaries do not change then we have strong evidence linking change in Okura estuary to something happening in that catchment as opposed to in that region.

A gradient of environmental factors was seen across all estuaries. Three classes of sites could be defined that correlated to high, medium and low-energy environments. Three corresponding assemblage types could be defined from the assemblage data. Communities in the most energetic environments were charcterised by high counts of *Paphies* spp., and the crustaceans *Waitangi* sp. and *Colorustylis lemurum*. The least hydrodynamically active sites were characterised by high counts of polychaetes, particularly the *Nereid/Nicon complex*, and Capitellids and Oligocaheates. The intermediate communities in terms of environmental variables show high counts of the cockle *Austrovenus stuchburyi,* and the polychaetes *Notomastus* sp. and *Prionospio* sp and more taxa then either biological community at the hydrodynamic extremes. This classification scheme allows Okura to be placed into context as an estuary with medium to low-energy hydrodynamic sites. It also allows new sites to be placed along this gradient due to their environmental characteristics,

which aids in comparing this work to other studies. For example, the study of Hewitt et al. (2003) showed that areas that are more hydrodynamically active will recolonise more quickly from disturbances. The classification of low-energy sites used in this study therefore shows us sites more likely to exhibit slow colonisation following disturbance, e.g., sedimentation.

The variation that was estuarine specific was small compared to the amount that could be explained by environmental factors. Consideration of greater than one estuary meant that a lower proportion of assemblage variation could be explained in this report (71% last year just for Okura estuary Anderson et al. (2002), compared to 46 % in this report for 5 estuaries) than in the previous report. The decrease in variation explained in this year compared to the previous year is predictable given the greater range of factors likely to be influencing assemblage structure when more estuaries are sampled. The environmental factors most strongly correlated with assemblage differences were the average amount and variation in the finer grain sizes of both the ambient and trapped sediments (GS1, GS2, TGS1, TGS2, sdGS1, sdGS2, sdTGS1 and sdTGS2). This pattern was highly consistent between times due to the relatively small impact of temporal factors when compared to spatial factors (Table 13). Approximately 3.5% of the 46% of variation explained this year was attributable to estuarine specific factors. The small estuarine specific component of variation meant that biological communities appeared to respond to environmental factors relatively consistently across the region.

Temporal effects were small compared to spatial effects, over all estuaries, however significant spatial effects were still observed (Table 10). Temporal effects were examined across all estuaries within the three different assemblage groupings in order to better detect these more subtle effects. The assemblages at "low-energy sites" showed the most significant temporal effects, showing both effects of Season and Precipitation, whereas the assemblages at high-energy sites showed no significant temporal effects. Intermediate-energy sites showed fewer significant temporal effects than low-energy sites and more significant temporal effects than high-energy sites. Temporal affects were mainly associated small differences between rare species (>1 on average per site) in different seasons or in rain versus dry samplings. This low temporal variation means a relatively stable baseline exists which we can then compare impacts against.

The longer time-series of data from the Okura estuary allowed us to examine the consistency of effects in Okura over time. The order of strength of effect from strongest to weakest was deposition, site, year, season and precipitation. Spatial effects (deposition and site) were much stronger than temporal effects (year, season and precipitation). The strength of depositional effects and precipitation effects are similar in this report as seen in previous years. Depositional effects accounted for between 20.6 and 22.4 percent of the variation in the assemblage data previously (Anderson *et al.* 2001b, 2002), in this report they account for 26.6 percent of the variation. Precipitation effects accounted for 0.5% of the variation in the assemblage data previously (Anderson *et al.* 2002) in this report they account for 0.8 percent of the variation. Percentages of variation explained by the different factors were calculated from Sums of Squares in NPMANOVA tables in the respective reports.

This report confirmed the finding of Anderson et al. (2002) that the depositional classification of Cooper et. al. (1999) was still relevant in terms of classifying benthic communities in the Okura estuary. High deposition sites showed the greatest denisities of the polychaetes: Nereid/Nicon complex, *Cossura coasta* and *Capitella* sp. plus *Notomastus* sp. plus Oligochaetes. Medium deposition sites were characterised by high densities of cockles *Austrovenus stutchburyi* and the orbinid polychaete *Scoloplos cylindifer*. Low deposition sites showed the highest densities of the anemone *Anthopleura* sp. The depositional effects are relatively consistent in terms of which taxa characterise High Medium and Low Depositional sites within Okura estuary. In all three monitored years 2000-2001, 2001-2002 and 2002-2003 capitellid polychaetes and have been more numerous in High deposition areas than Medium or Low depositional areas. Whilst Medium and Low depositional areas have been characterised by higher numbers of bivalves, most particularly the cockle *Austrovenus stutchburyi*. Rarer taxa have been reported as characteristic of these environments in different reports, however the capitellids and the cockle have consistently been present in high densities and characteristic of these depositional environments across all years sampled. By contrast the taxa correlated with the weaker precipitation effects differed between last years sampling (Anderson et al. 2002b) and the present report. In the present report the polychaetes of the capitellid family and the *Psuedopolydora* complex were more numerous in dry samplings. In 2001-2002 (Anderson et al. 2002b) the bivalve *Nucula hartvigiana* was more numerous in dry samplings.

Assessing trends over years in entire communities is difficult given seasonal trends and only three years data. When these separate depositional communities (High, Medium and Low deposition) are tracked over time (2000 – 2003) we can, however, start to get an idea of how each community is changing. High and Low deposition communities appeared to be changing in a similar direction in contrast to Medium deposition sites, which appeared to be more stable. Ongoing monitoring is needed to extend this time series so that assertions about trends in community structure can be made more strongly. Sharp changes in community structure were seen in all depositional environments, however these effects appear transitory, with communities usually returning to a more 'normal' composition at the following sampling. These sharp changes in community structure did not appear related to any of our monitored environmental parameters, including rainfall events.

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Appendix A. Global Positioning System (GPS) coordinates of sites

Site coordinates are given in the following format: Compass direction(South (S) or East (E)), Degrees (36 or 174), minutes (31-57). Percentage of minutes (0-99).

	Puhoi (P)		Waiwera (W)		Orewa (R)		Okura (O)		Maunagamaungaroa (Z)	
Site	**Latitude**	**Longitude**	**Latitude**	**Longitude**	**Latitude**	**Longitude**	**Latitude**	**Longitude**	**Latitude**	**Longitude**
A	S36 31.61	E174 42.60	S36 32.56	E174 42.34	S36 35.95	E174 41.82	S36 39.55	E174 44.42	S36 54.44	E174 57.47
B	S36 31.88	E174 42.58	S36 32.52	E174 42.36	S36 35.88	E174 41.71	S36 40.63	E174 43.54	S36 54.60	E174 57.39
C	S36 31.61	E174 42.52	S36 32.45	E174 42.31	S36 35.92	E174 41.65	S36 40.37	E174 43.47	S36 54.67	E174 57.33
D	S36 31.82	E174 42.44	S36 32.47	E174 42.17	S36 35.92	E174 41.65	S36 40.61	E174 43.38	S36 54.67	E174 57.27
E	S36 31.73	E174 42.27	S36 32.39	E174 42.23	S36 35.87	E174 41.15	S36 40.51	E174 43.36	S36 54.66	E174 57.23
F	S36 31.80	E174 42.15	S36 32.45	E174 42.15	S36 36 02	E174 41.16	S36 40.13	E174 43.29	S36 54.68	E174 57.20
G	S36 31.66	E174 42.01	S36 32.43	E174 42.07	S36 35.84	E174 41.11	S36 40.15	E174 43.19	S36 54.80	E174 56.98
H	S36 31.66	E174 41 94	S36 32.48	E174 41.90	S36 35.85	E174 40.95	S36 40.17	E174 43.12	S36 54.86	E174 56.91
I	S36 31.54	E174 41 67	S36 32.44	E174 41.79	S36 35.73	E174 40.76	S36 40.25	E174 43.36	S36 54.88	E174 56.93
J	S36 31.57	E174 41 64	S36 32.42	E174 41.73	S36 35.68	E174 40.77	S36 40.28	E174 42.56	S36 54.94	E174 56.79

Appendix B. List of taxa with their corresponding taxonomic group and the total number identified and recorded.

MOLUSCS	Group	Total
Austrovenus stutchburyi	Bivalvia	12045
Paphies australis	Bivalvia	11977
Nucula hartvigiana	Bivalvia	3995
Macomona lilliana	Bivalvia	1500
Notoacmea spp.	Gastropoda	782
Arthritica bifurcata	Bivalvia	243
Cominella glandiformis	Gastropoda	101
Sypharochiton pelliserpentis	Polyplacophora	64
Theora sp.	Bivalvia	61
Diloma subrostratum	Gastropoda	44
Musculista senhousia	Bivalvia	16
Opisthobranch other	Opistobranchia	9
Bivalve unknown	Bivalvia	8
Amphibola crenulata	Gastropoda	7
Cominella adspersa	Gastropoda	5
Soletellina selaqua	Bivalvia	5
Corbula zelandica	Bivalvia	4
Microlenchus sp.	Gastropoda	4
Gastropod unknown	Gastropoda	3
Haminoea zelandiae	Opistobranchia	3
Crassostrea sp.	Bivalvia	3
Zeacumantus sp.	Gastropoda	2
Cominella maculosa	Gastropoda	1

POLYCHAETES	Group	Total
Prionospio spp. complex	Spionidae	9773
Notomastus sp.	Capitellidae	5978
Nereid/Nicon spp. complex	Nereidae	2762
Psuedopolydora complex	Spionidae	1606
Scoloplos cylindifer	Orbiniidae	1538
Aonides spp.	Spionidae	1519
Exogonid sp.	Syllidae	1216
Cossura coasta	Cossuridae	1148
Scolelepis sp.	Spionidae	450
Glycera lamellipoda	Glyceridae	397
Timarete anchylochaeta	Cirratulidae	386
Glycera spp. other	Glyceridae	342
Scolecolepides sp.	Spionidae	324
Paraonis sp.	Paraonidae	212
Pectinaria sp.	Pectinariidae	188
Orbinia papillosa	Orbiniidae	160
Magelona dakini	Magelonidae	127
Orbinid other	Orbiniidae	77
Glycera sp. (tiger stripe)	Glyceridae	72
Armandia sp.	Opheliidae	41
Minuspio sp.	Spionidae	41
Aricidea sp.	Paraonidae	27
Syllid other	Syllidae	27

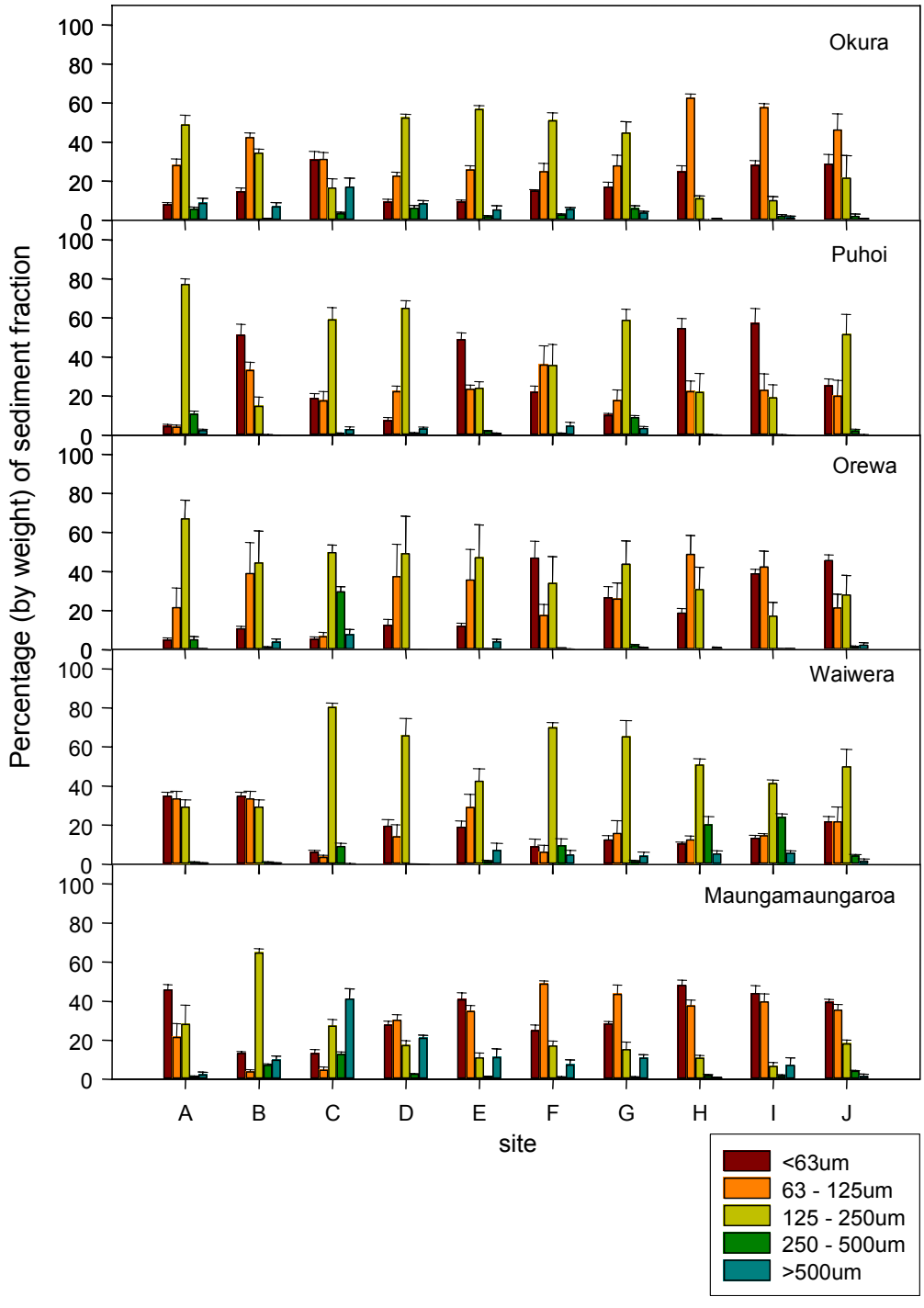
Turbo smaragdus	Gastropoda	1
Xenostrobus pulex	Bivalvia	1

CRUSTACEANS	**Group**	**Total**
Waitangi sp.	Amphipoda	4573
Colorustylis lemurum	Cumacea	4519
Elimnius modestus	Cirripedia	3633
Paracorophium sp.	Amphipoda	3619
Isopod sp. (thin head)	Isopoda	2255
Copepod sp.	Copepoda	1702
Parakalliope sp.	Amphipoda	1341
Helice/Hemigrapsus spp.	Decapoda	1047
Phoxocephalid	Amphipoda	343
Mysid shrimp	Cumacea	294
Cirolana sp.	Isopoda	280
Psuedosphaeroma sp.	Isopoda	115
Halicarcinus spp.	Decapoda	112
Amphipod other	Amphipoda	66
Crab juvenile	Decapoda	66
Shrimp	Decapoda	49
Isopod other	Isopoda	41
Ostracod sp.	Ostracoda	23
Mantis shrimp	Stomatopoda	12
Leptostracean	Leptostraca	10
Alpheus sp.	Decapoda	7
Decapod unknown	Decapoda	1

Macroclymenella stewartensis	Malanidae	24
Paraonid sp.	Paraonidae	16
Polychaete unknown		6
Aglaophamus macroura	Nephtyidae	5
Scalibregmatidae	Scalibregmatidae	5
Spionid other	Spionidae	5
Aphroditidae	Aphroditidae	4
Diopatra sp.	Eunicae	4
Pectinaria other	Pectinariidae	4
Sphaerodoridae	Sphaerodoridae	4
Hesionidae	Hesionidae	3
Cirratulidae other	Cirratulidae	2
Nephtyidae other	Nephtyidae	2
Asychis sp.	Malanidae	1
Owenia fusiformis	Oweniidae	1

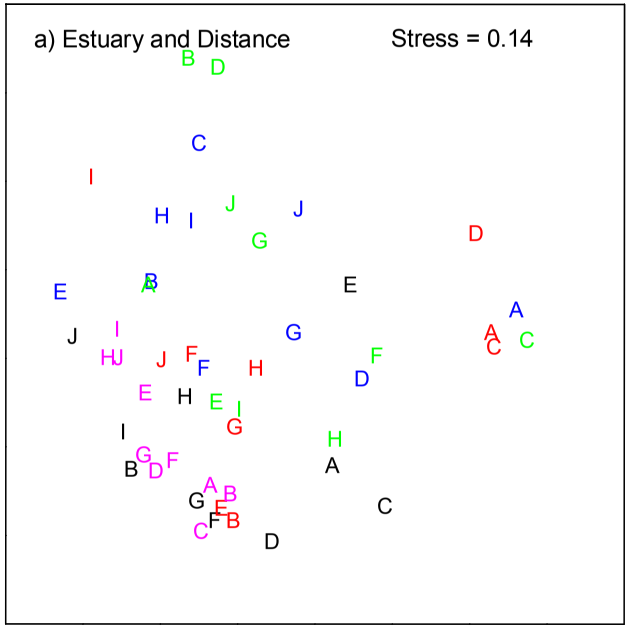
MISCELLANEOUS	**Group**	**Total**
Capitella sp. & Oligochaete	Capitellidae and Oligochaete	8358
Anthopleura spp.	Anthozoa	2159
Nemertean	Nemertea	1007
Nematode	Nematoda	179
Sipunculid	Nonsegmented coelomate worm	43
Larvae (fly)	Insecta	25
Platyhelminth	Platyhelminth	11
Anemone (free living)	Anthozoa	9
Fish	Pisces	5
Chaetognath	Chaetognatha	3
mite	Insecta	3
Larvae (fish)	Pisces	2
Priapulid	Nonsegmented coelomate worm	1

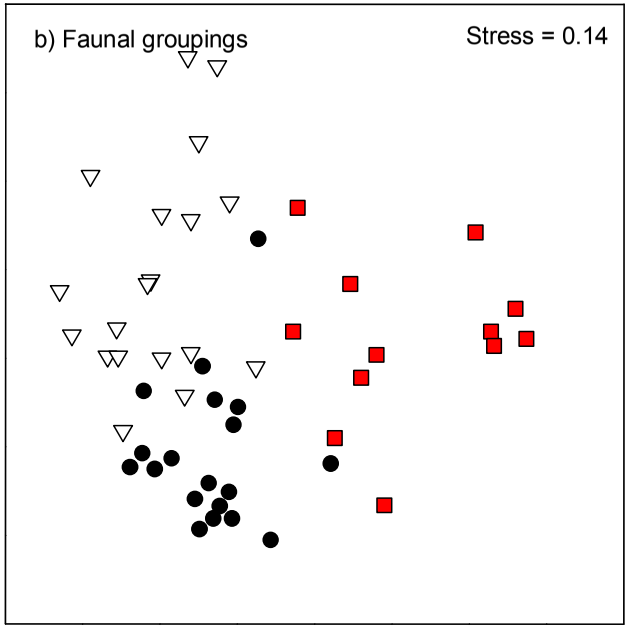
Appendix. C. Mean percentage of ambient sediments of different grain sizes for April 2003



Appendix. C. Mean (+S.E., *n*=6) percentage of ambient sediments of different grain sizes for the April 2003 sampling of all sites in all estuaries.

Appendix D. MDS plots of assemblage data from October 2002, March 2003 and April 2003

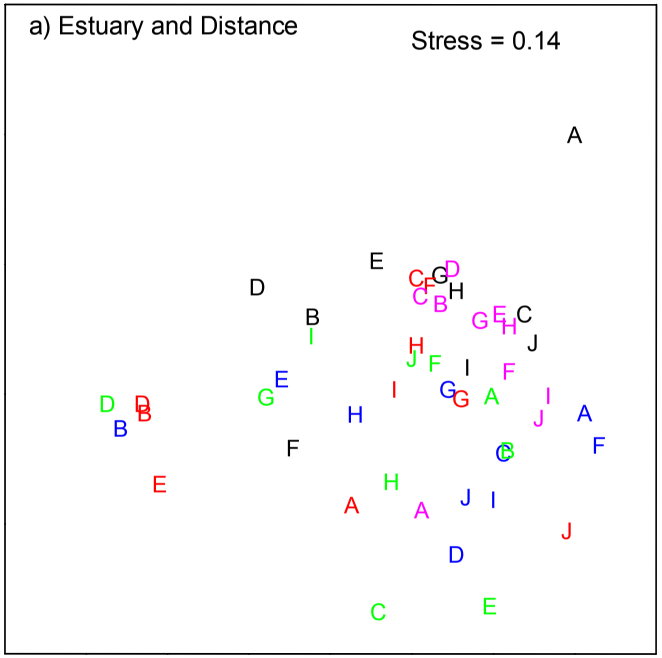


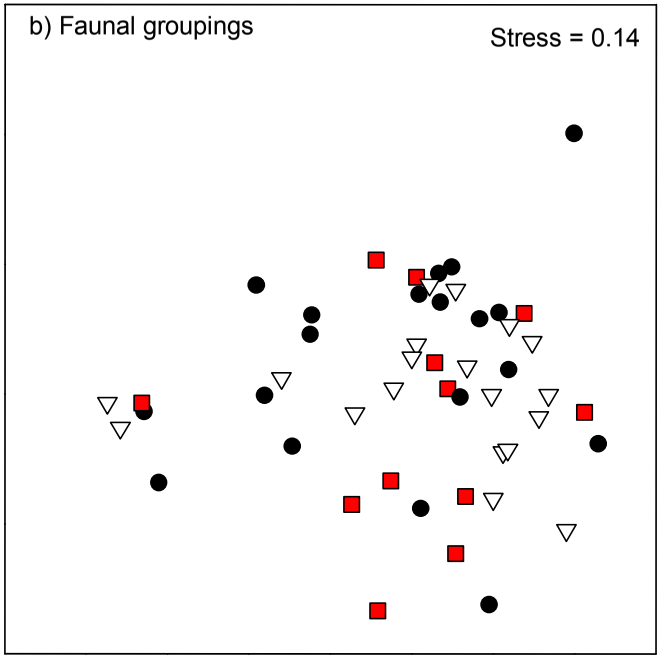


Blue = Puhoi sites A-J
Black = Okura sites A-J
Red = Orewa sites A-J
Pink = Maungamaungaroa sites A-J
Green = Waiwera sites A-J

White triangles = Group 1
Black circles = Group 2
Red squares = Group 3

Appendix D1. MDS plot of assemblage data from October 2002 showing a) estuary and distance information, b) faunal groupings. The analyses were based on the Bray-Curtis dissimilarity measure calculated from $ln(y+1)$-transformed species data. Observations were pooled at the site level (n=5).

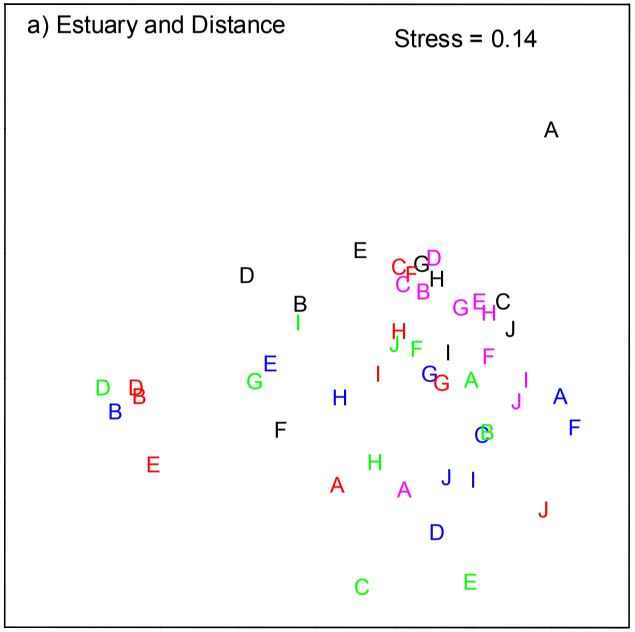


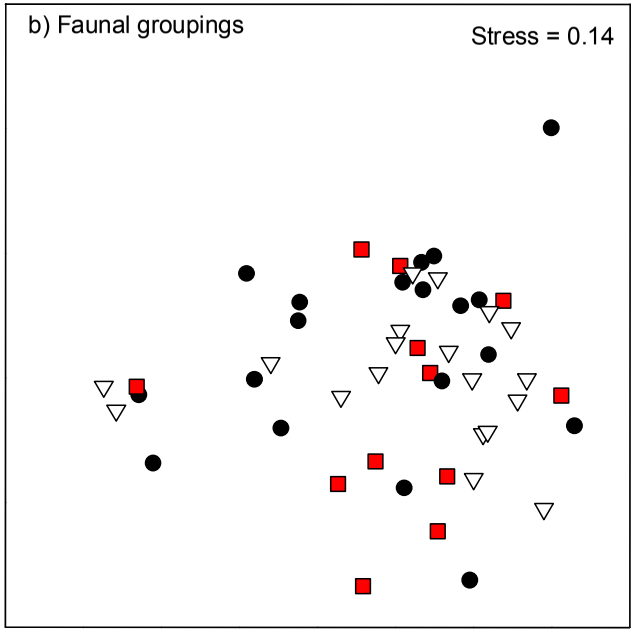


Blue = Puhoi sites A-J
Black = Okura sites A-J
Red = Orewa sites A-J
Pink = Maungamaungaroa sites A-J
Green = Waiwera sites A-J

White triangles = Group 1
Black circles = Group 2
Red squares = Group 3

Appendix D2. MDS plot of assemblage data from March 2003 showing a) estuary and distance information, b) faunal groupings. The analyses were based on the Bray-Curtis dissimilarity measure calculated from $ln(y+1)$-transformed species data. Observations were pooled at the site level (n=5).



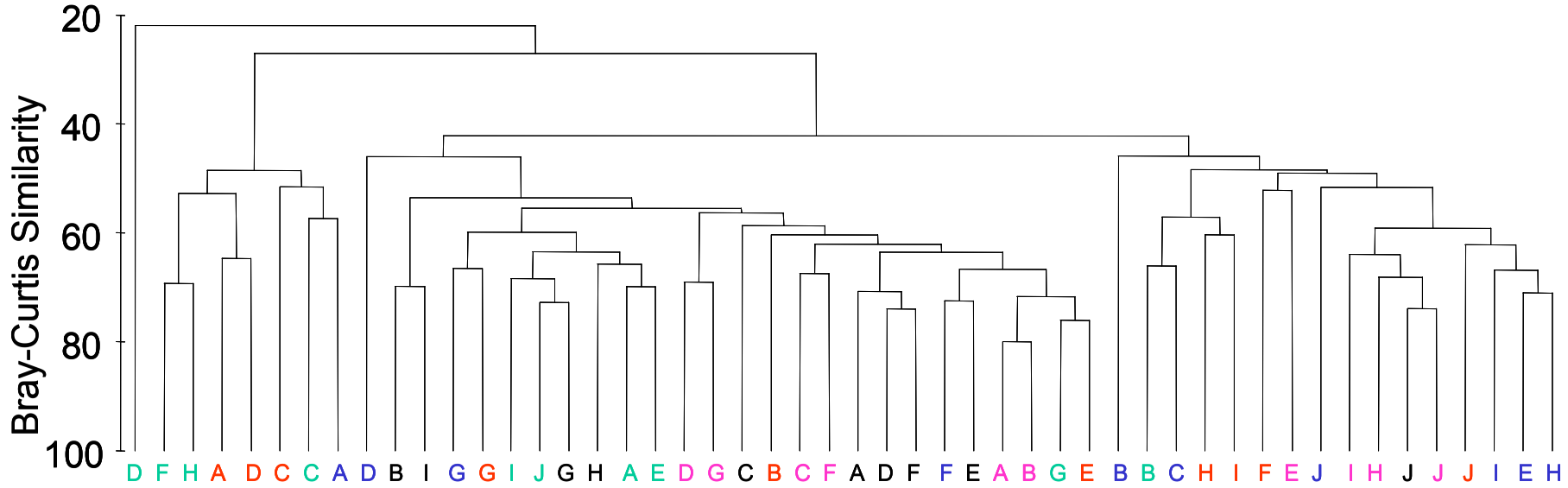


Blue = Puhoi sites A-J
Black = Okura sites A-J
Red = Orewa sites A-J
Pink = Maungamaungaroa sites A-J
Green = Waiwera sites A-J

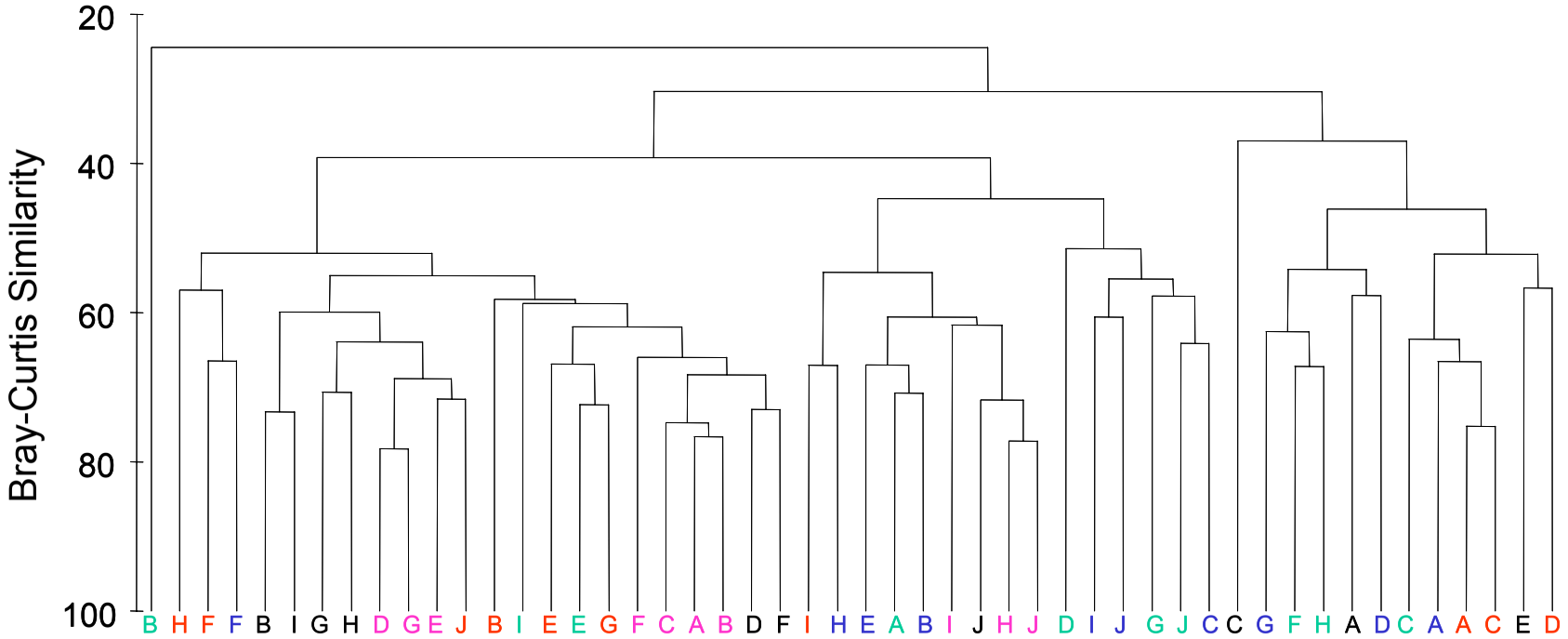
White triangles = Group 1
Black circles = Group 2
Red squares = Group 3

Appendix D3. MDS plot of assemblage data from April 2003 showing a) estuary and distance information, b) faunal groupings. The analyses were based on the Bray-Curtis dissimilarity measure calculated from *ln* (y + 1)-transformed species data. Observations were pooled at the site level (n=5).

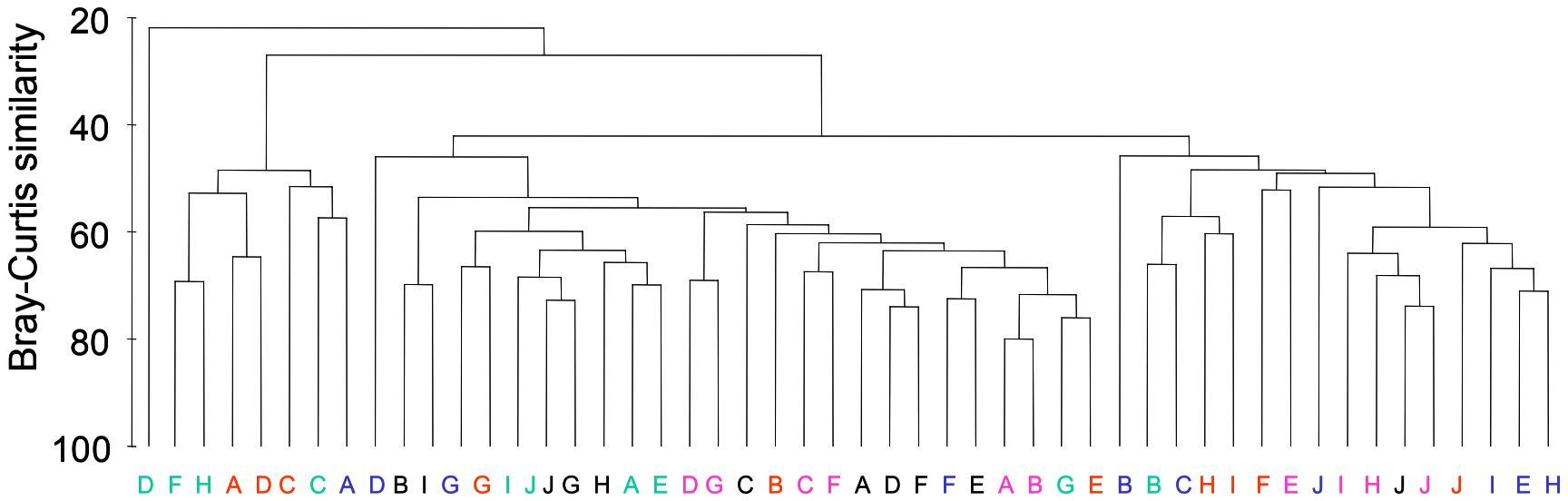
Appendix E. Dendrograms for assemblage data from October 2002, March 2003 and April 2003



Appendix E1. Dendrogram for assemblage data from October 2002 of all sites in all estuaries. The analyses were based on the Bray-Curtisdissimilarity measure calculated from *ln* (*y* + 1)-transformed species data. Observations were pooled at the site level. Sites are indicated by a coloured letter, the letter indicates the site within an estuary (A-J), the colour represents an estuary Blue = Puhoi, Green = Waiwera,Red = Orewa, Black = Okura and Pink = Maunagamaungaroa



Appendix E2. Dendrogram for assemblage data from March 2003 of all sites in all estuaries. The analyses were based on the Bray-Curtisdissimilarity measure calculated from $ln(y + 1)$-transformed species data. Observations were pooled at the site level. Sites are indicated by acoloured letter, the letter indicates the site within an estuary (A-J), the colour represents an estuary Blue = Puhoi, Green = Waiwera,Red = Orewa, Black = Okura and Pink = Maunagamaungaroa



Appendix E3. Dendrogram for assemblage data from April 2003 of all sites in all estuaries. The analyses were based on the Bray-Curtisdissimilarity measure calculated from $ln(y+1)$-transformed species data. Observations were pooled at the site level. Sites are indicated by acoloured letter, the letter indicates the site within an estuary (A-J), the colour represents an estuary Blue = Puhoi, Green = Waiwera,Red = Orewa, Black = Okura and Pink = Maunagamaungaroa

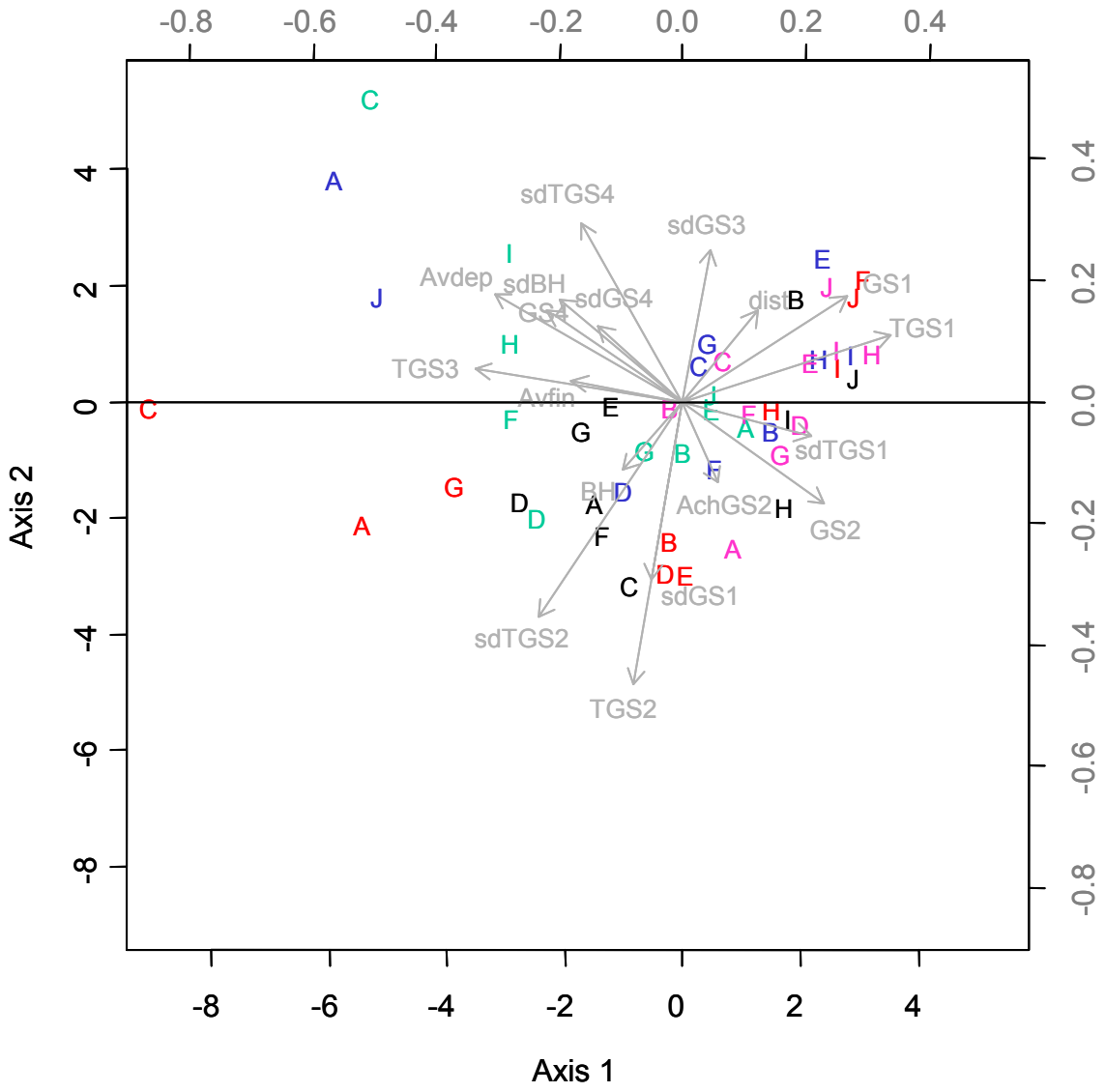
Appendix F. SIMPER Analysis results for assemblage groups from all times

Appendix F.a Similarity scores for individual groups. Analyses were based on Bray-Curtis similarities of taxa transformed to ln(y + 1).Av. Abund. = Average abundance of the taxa in the specified group, Contrib. = Percentage contribution of that taxa to the similarity within that group, Cumm. Contrib. = Cummulative percentage contribution of all taxa up to that point to the similarity within that group.

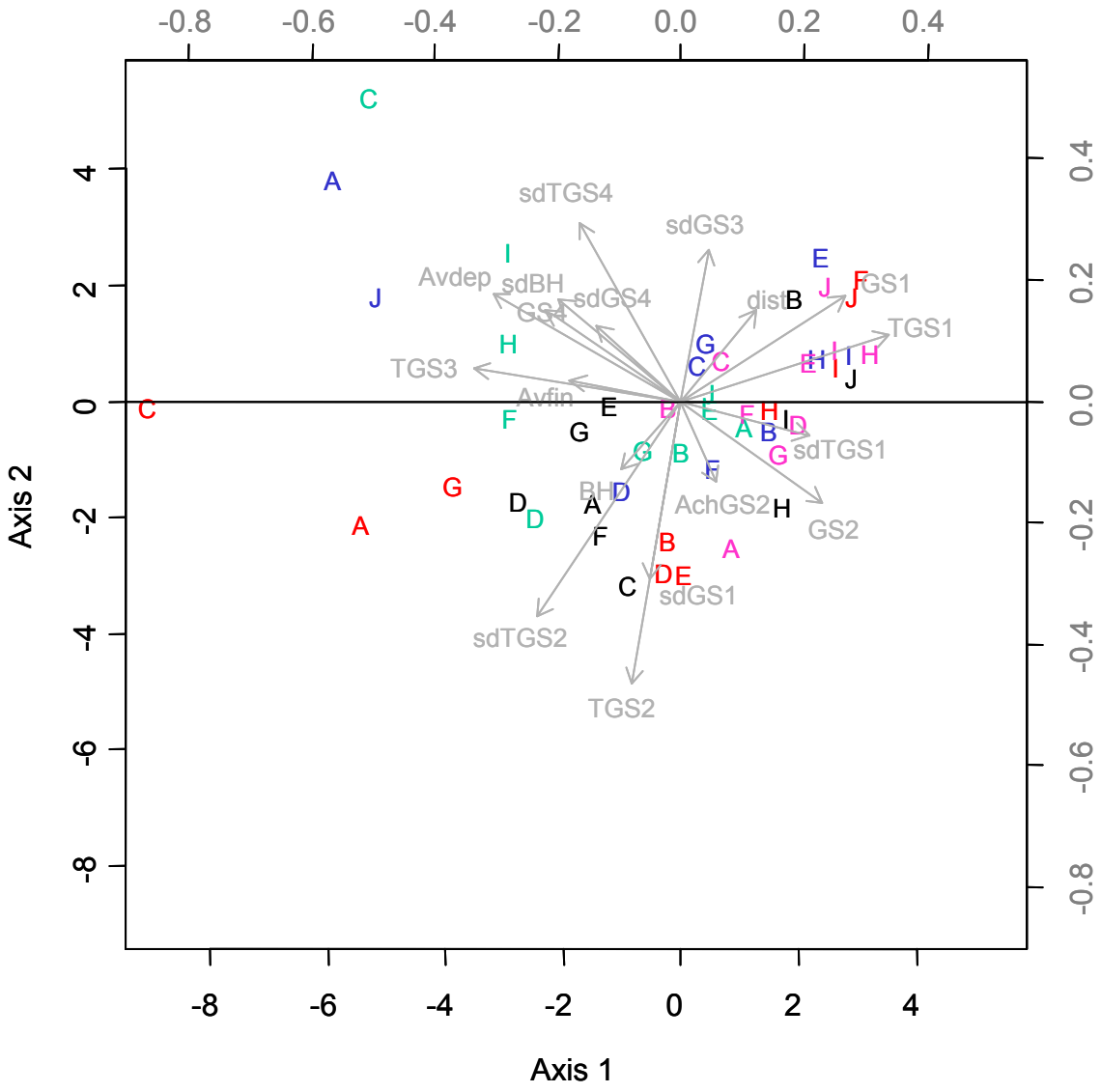
Group	Similarity	Taxa	Av. Abund.	Contrib.	Cumm. Contrib.
1	32.75	*Capitella* sp. + Oligochaetes	17.01	24.73	24.73
		Prionospio complex	8.63	13.90	38.63
		Nereid/Nicon complex	3.75	10.45	49.08
2	41.61	*Austrovenus stutchburyi*	22.32	25.03	25.03
		Prionospio complex	16.08	15.42	40.45
		Notomastus sp.	8.23	8.91	49.36
3	37.55	*Paphies australis*	46.74	28.15	28.15
		Waitangi sp.	18.02	19.59	47.74
		Colorustylis lemurum	11.72	17.64	65.38

Appendix F.b Dissimilarity scores between groups. Analyses were based on Bray-Curtis similarities of taxa transformed to ln(y + 1)Av. Abund. = Average abundance of the taxa in the specified group, Contrib. = Percentage contribution of that taxa to the dissimilarity between groups, Cumm. Contrib. = Cummulative percentage contribution of all taxa up to that point to the dissimilarity between groups.

Groups		Dissimilarity	Taxa	Av. Abund.		Contrib.	Cumm. Contrib.
A	B			A	B		
1	2	73.03	*Austrovenus stutchburyi*	3.20	22.32	8.79	8.79
			Prionospio complex	8.63	16.08	6.71	15.51
			Capitella sp. + Oligochaetes	17.01	3.82	6.70	22.21
			Notomastus sp.	6.99	8.23	5.99	28.20
1	3	85.30	*Paphies australis*	0.10	46.74	11.28	11.28
			Waitangi sp.	0.04	18.02	8.65	19.93
			Colorustylis lemurum	0.46	11.72	7.20	27.13
			Capitella sp. + Oligochaetes	17.01	1.85	6.97	34.10
			Austrovenus stutchburyi	3.20	9.79	5.79	39.89
			Prionospio complex	8.63	1.60	5.56	45.46
2	3		*Paphies australis*	1.89	47.64	8.83	8.83
			Waitangi sp.	0.61	18.02	7.06	15.89
			Prionospio complex	16.08	1.60	6.70	22.59
			Austrovenus stutchburyi	22.32	9.79	6.54	29.12
			Colorustylis lemurum	4.04	11.72	5.51	34.63
			Notomastus sp.	8.23	0.82	5.07	39.70



Appendix G1. Distance-based RDA ordination relating the environmental variables to the 77 taxonomic variables for the October 2002 sampling. The analysis was done on principal coordinate axes obtained from Bray-Curtis dissimilarities of ln(y + 1) transformed species counts, with correction method 1 for negative eigenvalues (see Legendre and Anderson 1999). Observations were pooled at the site level. Sites within estuaries are indicated by a coloured letter as in revious plots. Names of variables are given in Table 5. The environmental variables sddep, GS3, TGS4, and sdTGS3 were not shown on the plot as they were highly correlated (correlation coefficient >0.8) with the variables Avdep, TGS3, sdTGS4, and sdTGS2 respectively. The axes values in grey relate to the bipolt arrows (also in grey).



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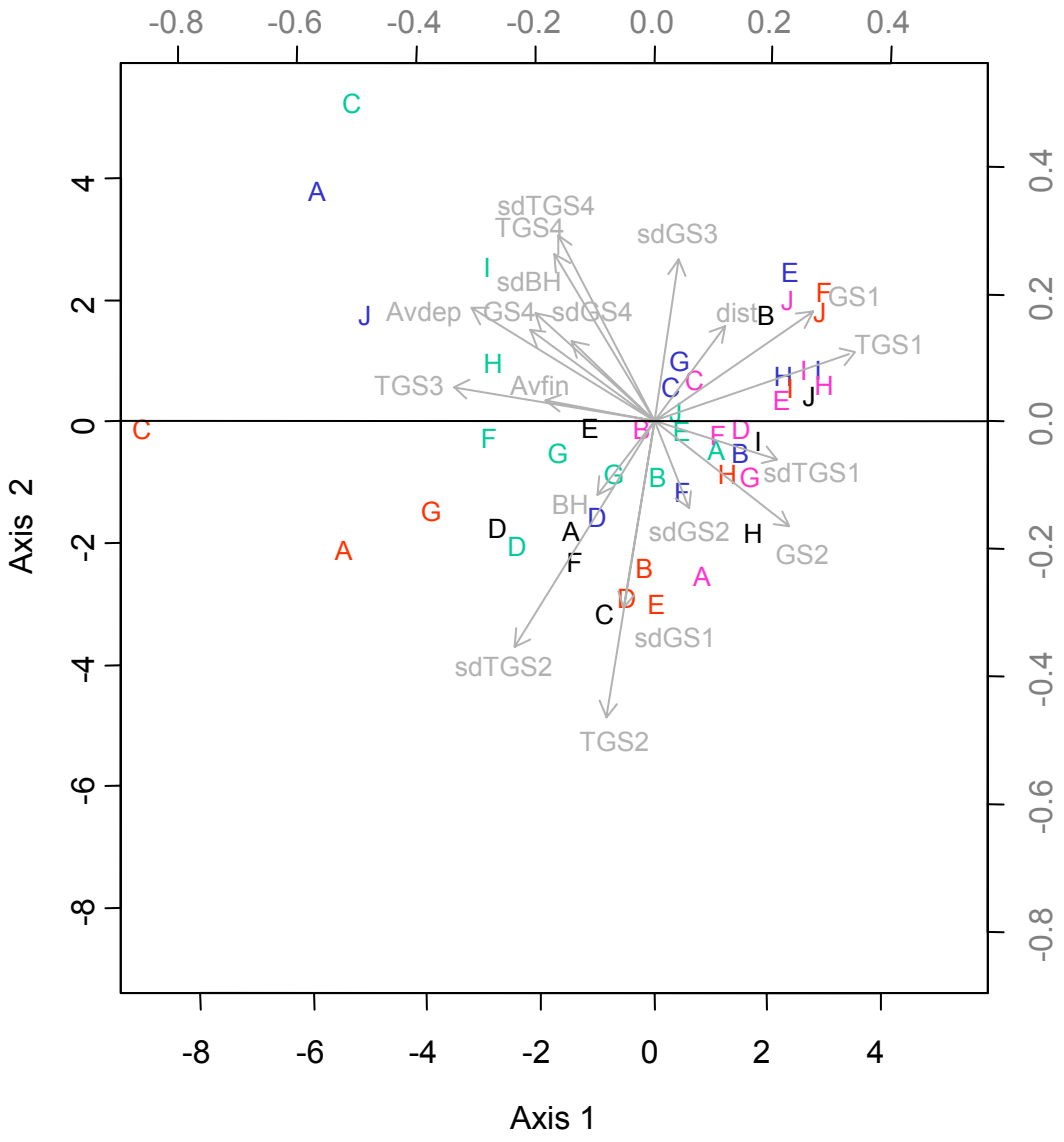

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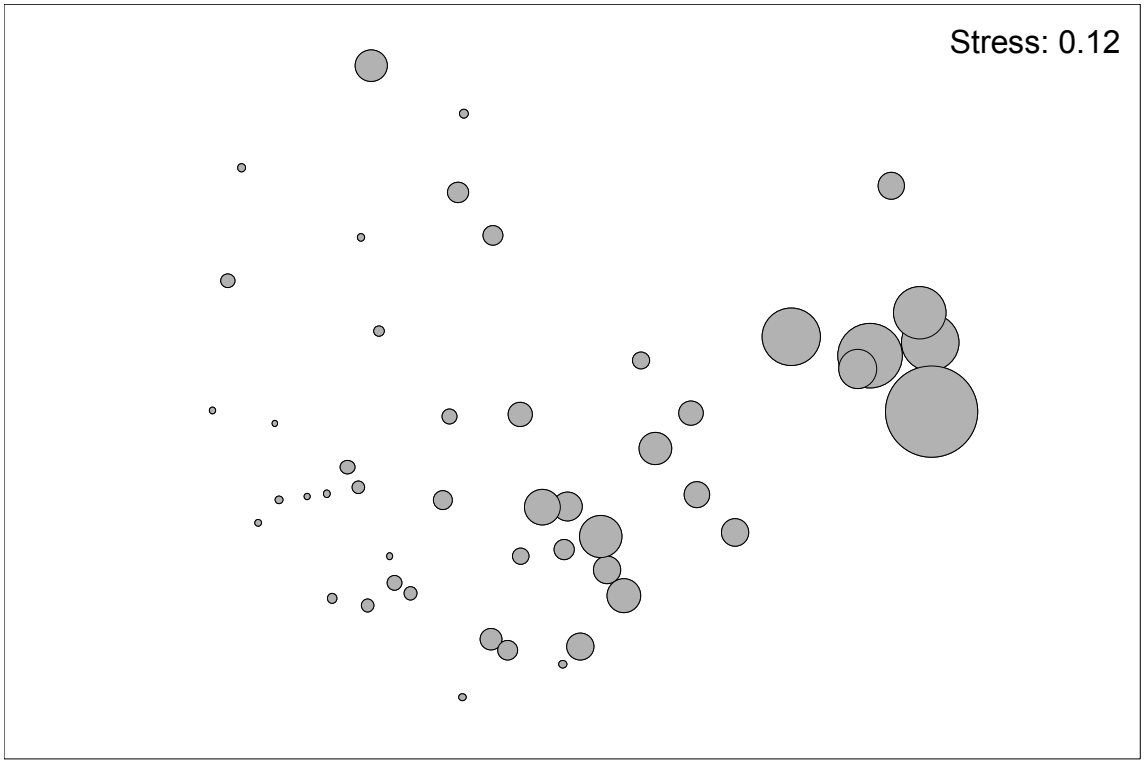
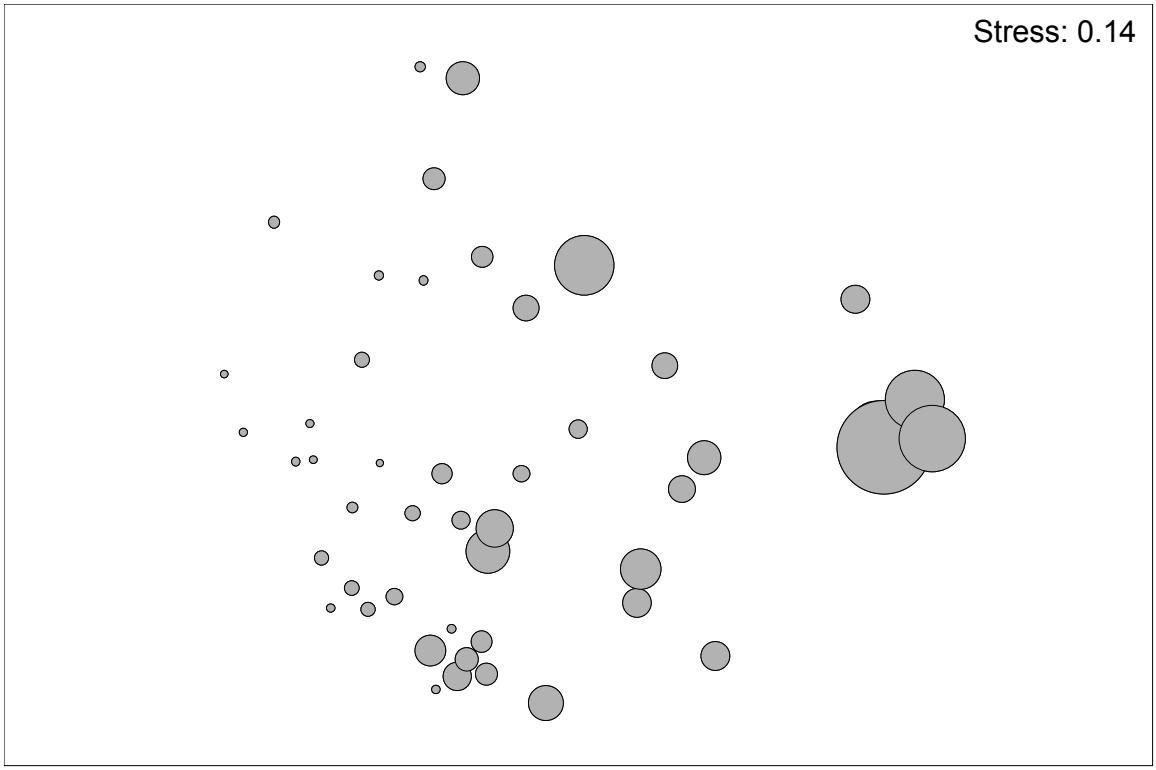
Appendix H. Bubble plots for October 2002, March 2003 and April 2003.



Appendix H1. Bubble plots showing the correlation of PCA axis 1 from Figure 13 (environmental data) with the biological datafrom October 2002. The analysis was done on principal coordinate axes obtained from Normalised Euclidean environmental data, withcorrection method 1 for negative eigenvalues (see Legendre and Anderson 1999). Environmental data was normalized thenunderwent a Euclidean dissimilarity measure. Small bubbles to the left of the plot and large bubbles to the right indicate a strongcorrelation between the environmental and biological data



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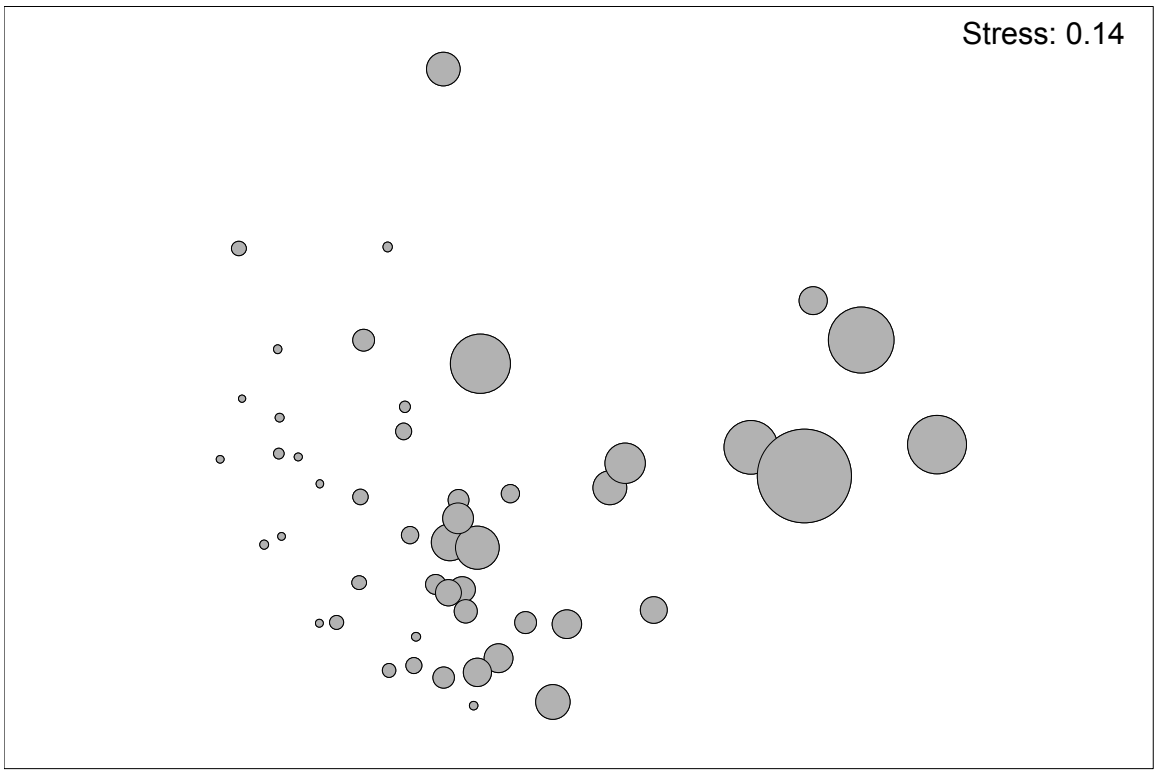

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