Table 14. Results of ANOVAs examining effects of Season, Precipitation and Deposition on each of several common taxa, and for total number of taxa and total number of individuals. The variables *N. hartvigiana*, Polychaetes and the total number of individuals still showed significant heterogeneity after transformation (Cochran's test, $P < 0.05$), so results of these analyses should be interpreted with caution.

		Austrovenus stutchburyi			Nemerteans			*Nucula hartvigiana*			*Notomastus* sp.			*Prionospio* complex		
Source	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**	**MS**	**F**	**P**	**MS**	**F**	**P**	**MS**	**F**	**P**
Se	2	1.1676	3.22	0.0575	2.4301	5.61	**0.0100**	2.6788	2.86	0.0768	8.3509	4.97	**0.0156**	10.2801	7.91	**0.0023**
P	1	0.9738	1.98	0.1847	1.1040	2.31	0.1547	5.6750	9.58	**0.0093**	15.2259	11.23	**0.0058**	0.6862	0.72	0.4119
D	2	197.2102	18.10	**0.0002**	0.0483	0.04	0.9620	33.0611	1.09	0.3671	118.5256	5.48	**0.0204**	24.5624	0.65	0.5378
Si(D)	12	10.8984	26.63	**0.0000**	1.2424	3.26	**0.0002**	3.3109	47.60	**0.0000**	21.6381	38.91	**0.0000**	37.5889	58.66	**0.0000**
Se x P	2	0.3906	0.62	0.5489	5.0362	8.77	**0.0010**	1.5611	1.94	0.1651	13.4923	15.54	**0.0000**	13.4618	12.92	**0.0002**
Se x D	4	1.0313	2.85	**0.0460**	0.6839	1.58	0.2122	0.8651	0.92	0.4662	0.2932	0.71	0.9493	2.1251	1.64	0.1978
Se x Si(D)	24	0.3621	0.88	0.6238	0.4332	1.14	0.2979	0.9359	1.47	0.0717	1.6791	3.02	**0.0000**	1.2990	2.03	**0.0031**
P x De	2	0.7790	1.58	0.2452	0.5307	1.11	0.3614	2.1599	3.65	0.0579	1.3634	1.01	0.3946	0.3048	0.32	0.7314
P x Si (D)	12	0.4180	1.20	0.2788	0.4785	1.26	0.2420	0.5921	0.93	0.5166	1.3557	2.44	**0.0044**	0.9495	1.48	0.1274
Se x P x D	4	0.6268	0.99	0.4333	0.5321	0.93	0.4648	0.6256	0.78	0.5499	1.7538	2.02	0.1237	1.9419	1.86	0.1495
Se x P x Si(D)	24	0.6349	1.55	**0.0475**	0.5740	1.51	0.0596	0.8031	1.26	0.1846	0.8683	1.56	**0.0451**	1.0416	1.63	**0.0322**
Res	450	0.4092			0.3809			0.6368			0.5561			0.6408		

		Bivalves			Crustaceans			Polychaetes			Total # taxa			Total # individuals		
Source	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**	**MS**	**F**	**P**	**MS**	**F**	**P**	**MS**	**F**	**P**
Se	2	1.1680	2.53	0.1003	12.8933	15.57	**0.0000**	0.7135	0.85	0.4400	59.4389	4.55	**0.0211**	0.5181	1.46	0.2531
P	1	0.1559	0.29	0.6015	0.2971	0.30	0.5966	4.6813	5.79	**0.0332**	14.0167	1.83	0.2009	0.0465	0.12	0.7321
D	2	179.3018	12.29	**0.0012**	85.9232	9.97	**0.0028**	38.4995	1.62	0.2381	224.2889	0.65	0.5392	15.0211	1.48	0.2668
Si(D)	12	14.5944	37.80	**0.0000**	8.6223	18.53	**0.0000**	23.7496	49.89	**0.0000**	344.7565	39.53	**0.0000**	10.1618	46.63	**0.0000**
Se x P	2	0.5691	1.00	0.3832	3.7558	6.40	**0.0059**	8.2913	15.87	**0.0000**	71.7167	6.34	**0.0062**	2.8633	11.21	**0.0004**
Se x D	4	0.3333	0.72	0.5847	3.3442	4.04	**0.0121**	0.6788	0.81	0.5321	15.3861	1.18	0.3453	0.2484	0.70	0.6008
Se x Si(D)	24	0.4608	1.19	0.2418	0.8279	1.78	**0.0136**	0.8397	1.76	**0.0149**	13.0565	1.50	0.0626	0.3559	1.63	**0.0309**
P x De	2	0.1016	0.19	0.8315	2.9236	2.91	0.0932	0.4600	0.57	0.5808	0.4222	0.06	0.9466	0.2330	0.61	0.5570
P x Si (D)	12	0.5421	1.40	0.1603	1.0046	2.16	**0.0127**	0.8088	1.70	0.0641	7.6528	0.88	0.5701	0.3791	1.74	0.0561
Se x P x D	4	0.4224	0.74	0.5734	0.6289	1.07	0.3919	0.6973	1.33	0.2860	9.1472	0.81	0.5320	1.0783	4.22	**0.0100**
Se x P x Si(D)	24	0.5700	1.48	0.0695	0.5864	1.26	0.1853	0.5226	1.10	0.3418	11.3139	1.30	0.1586	0.2555	1.17	0.2622
Res	450	0.3861			0.4653			0.4760			8.7211			0.2179		

Notomastus sp.

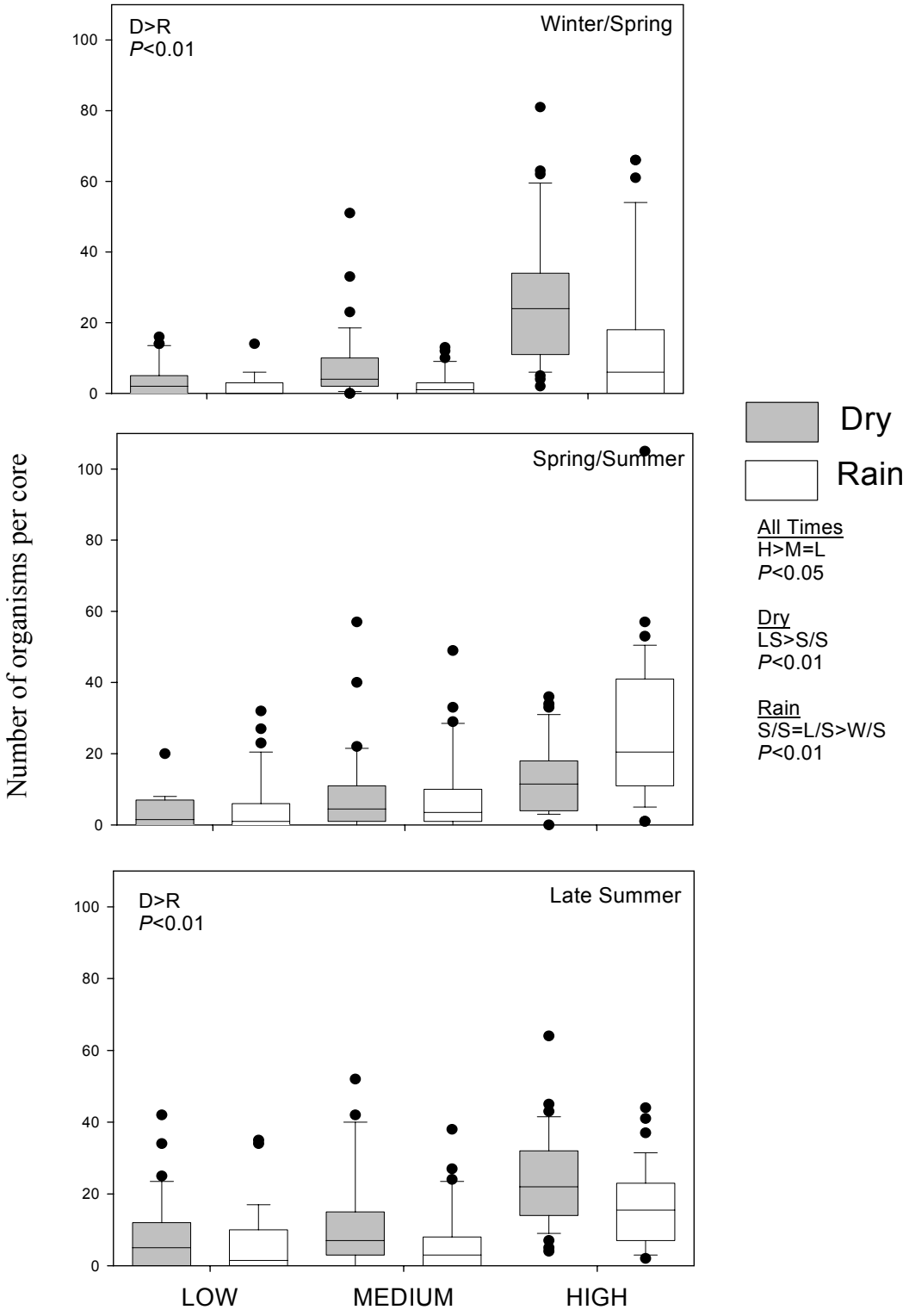

Fig. 17. Boxplots of counts of *Notomastus* sp. for each combination of Season, Deposition and Precipitation (6 cores x 5 sites = 30 observations per combination).

Austrovenus stutchburyi

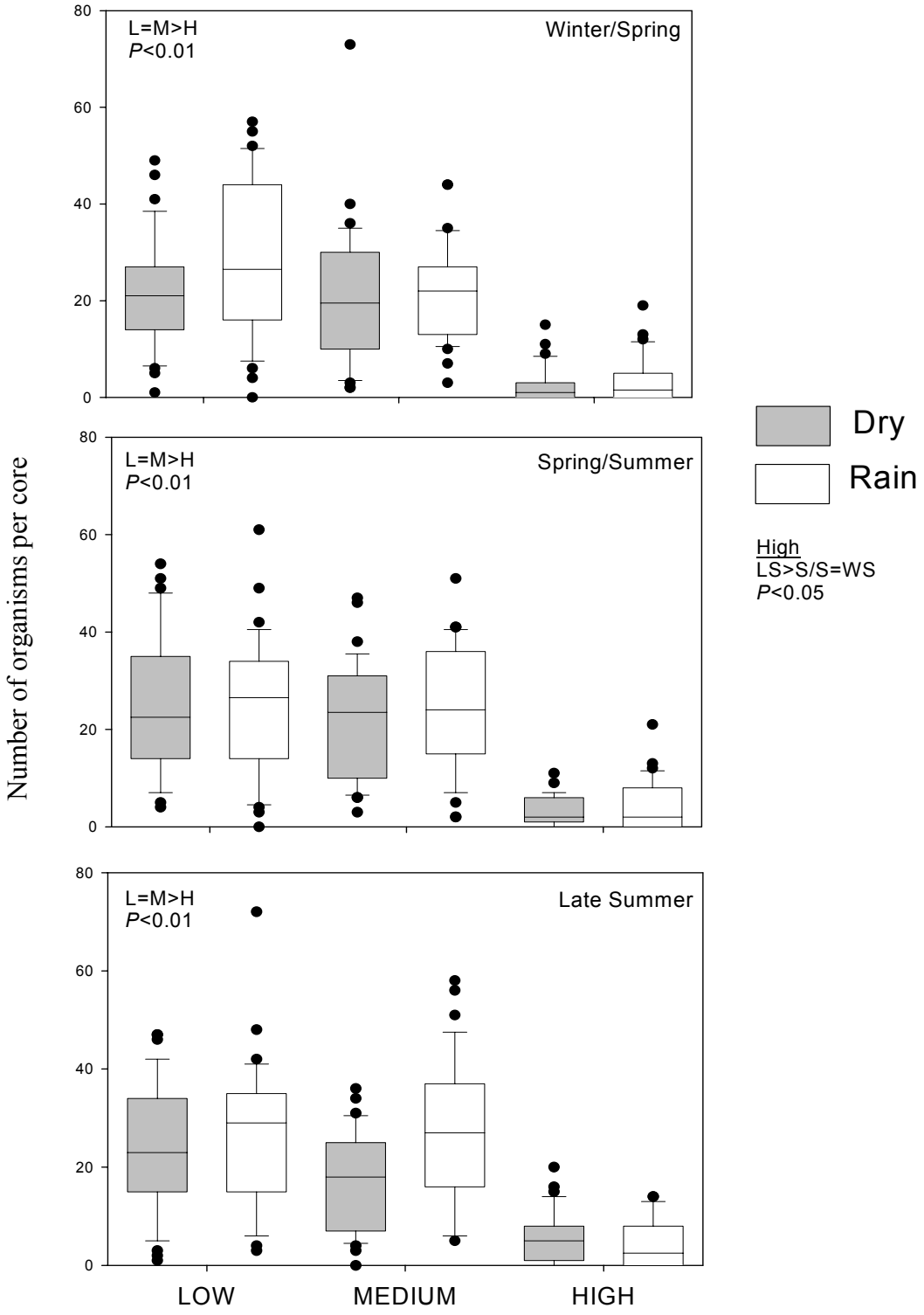

Fig. 18. Boxplots of counts of *Austrovenus stutchburyi* for each combination of Season, Deposition and Precipitation (6 cores x 5 sites = 30 observations per combination).

Bivalves

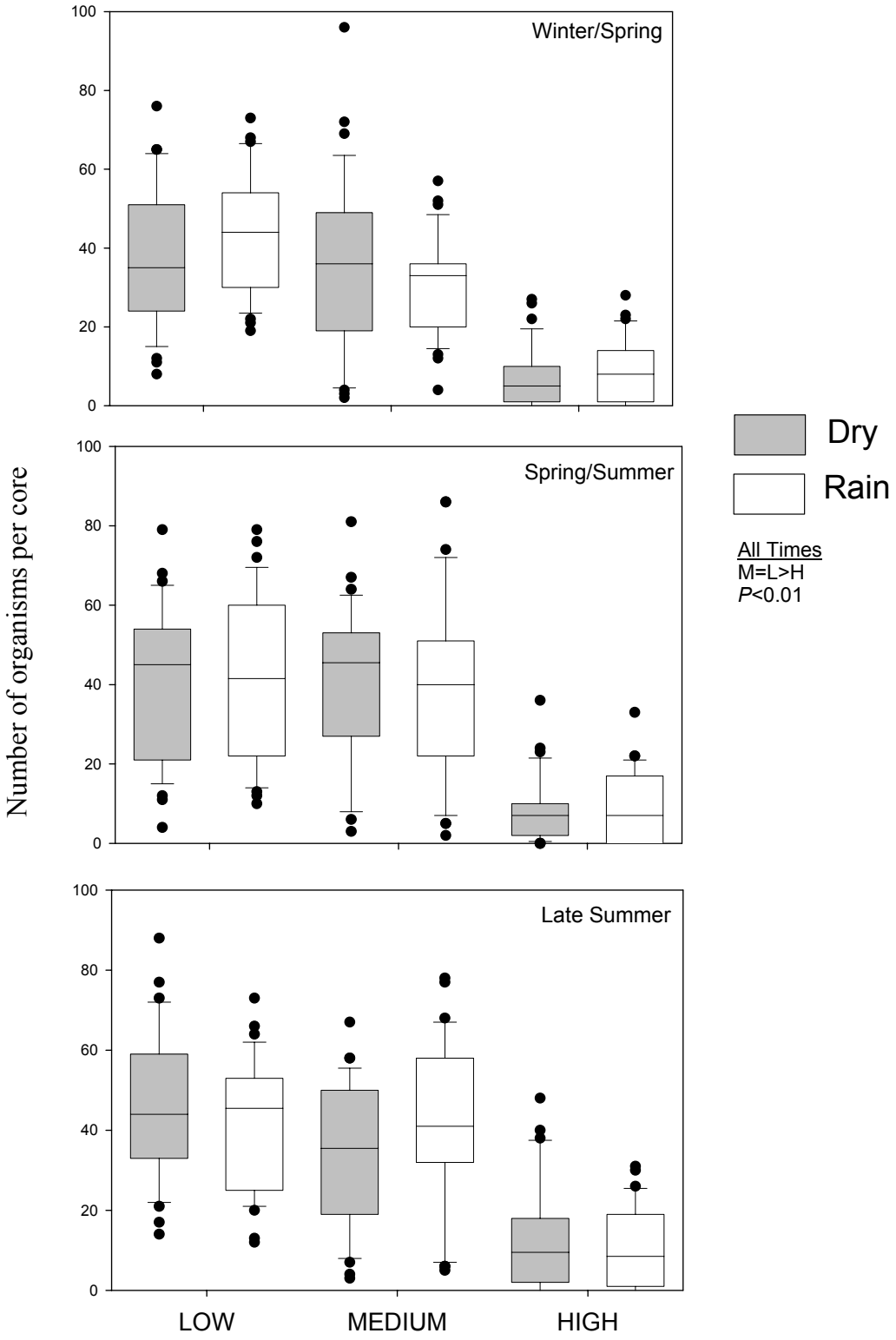

Fig. 19. Boxplots of counts of Bivalves for each combination of Season, Deposition and Precipitation (6 cores x 5 sites = 30 observations per combination).

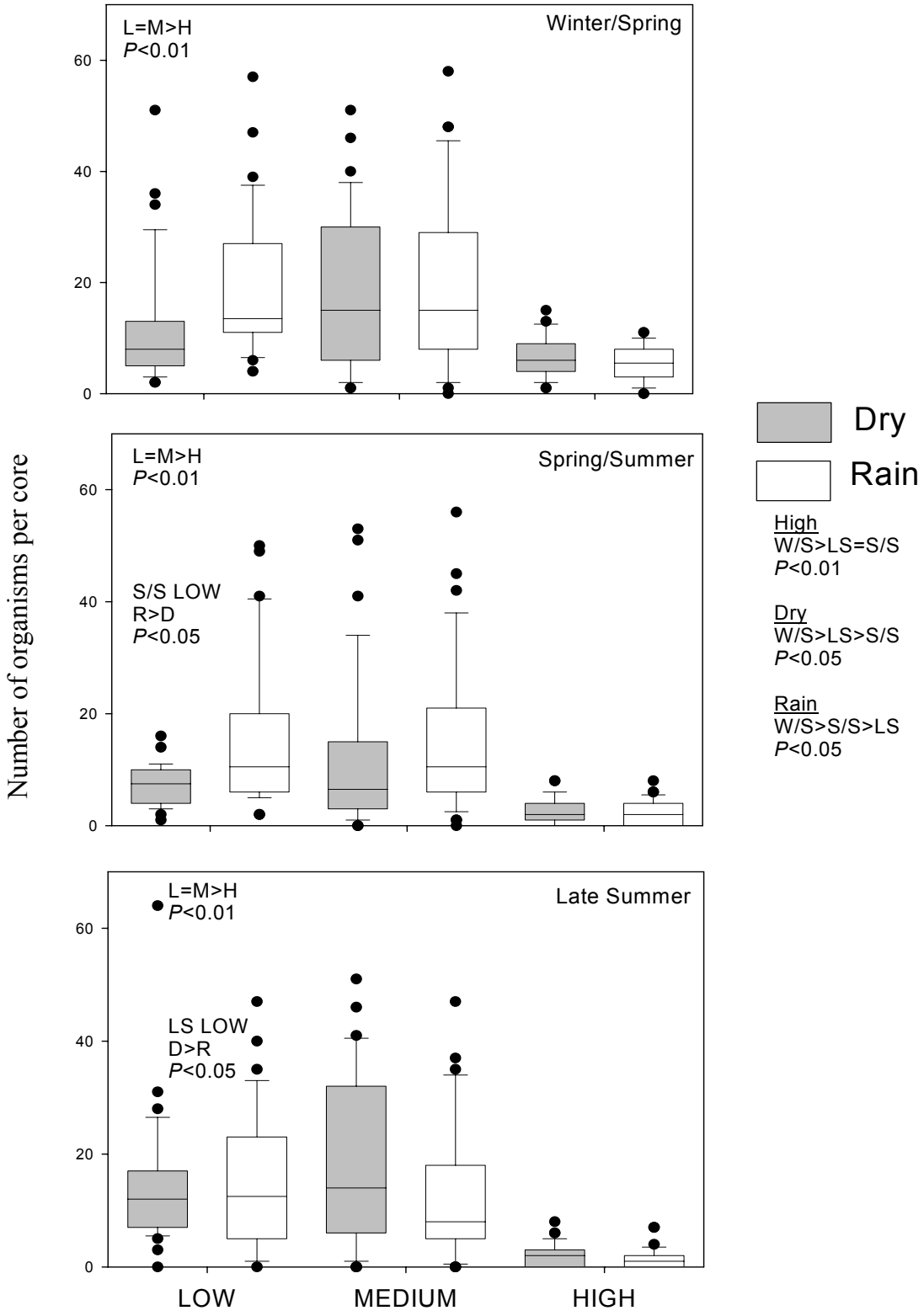

Fig. 20. Boxplots of counts of Crustaceans for each combination of Season, Deposition and Precipitation (6 cores x 5 sites = 30 observations per combination).

Total number of individuals

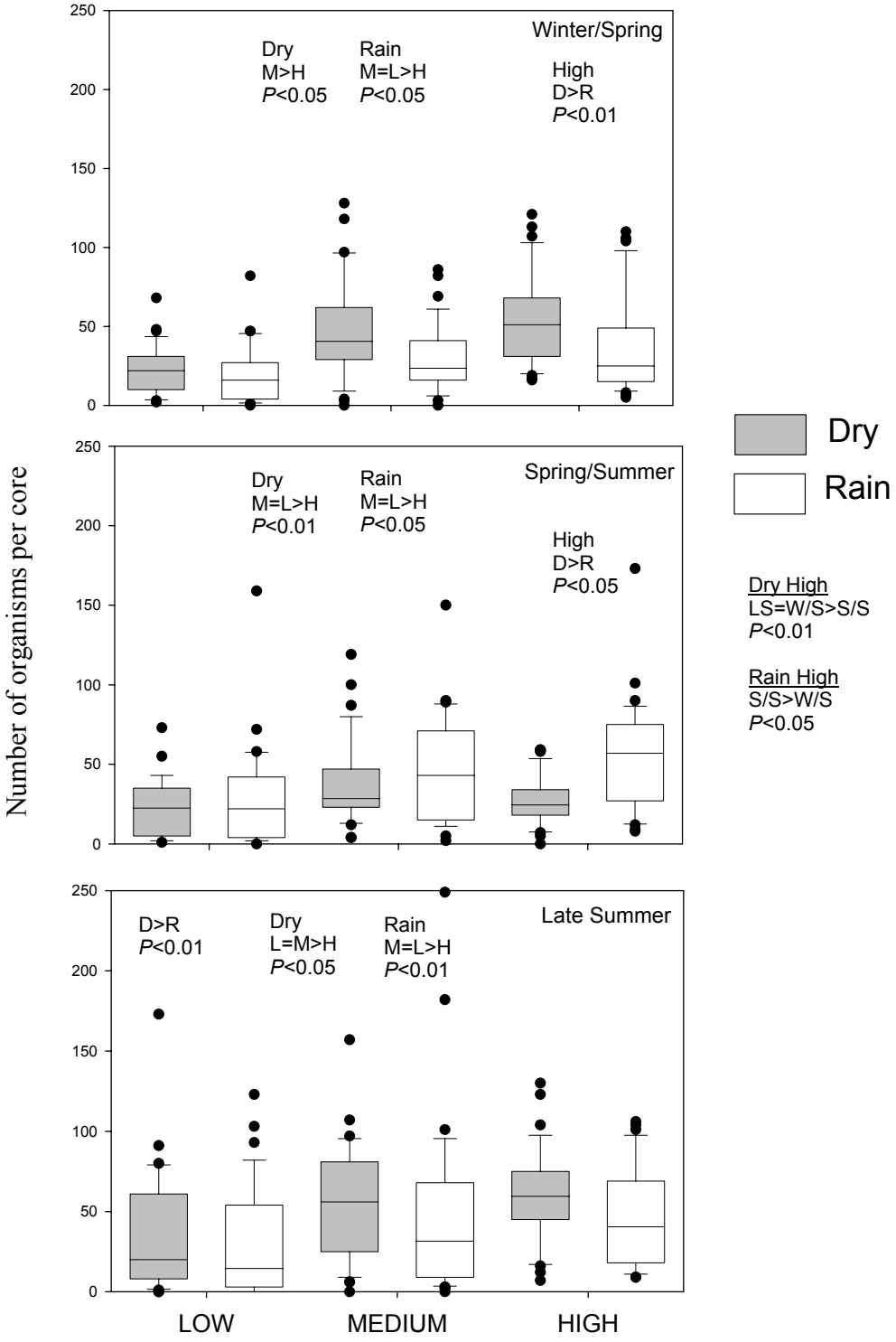

Fig. 21. Boxplots of counts of total number of individuals for each combination of Season, Deposition and Precipitation (6 cores x 5 sites = 30 observations per combination).

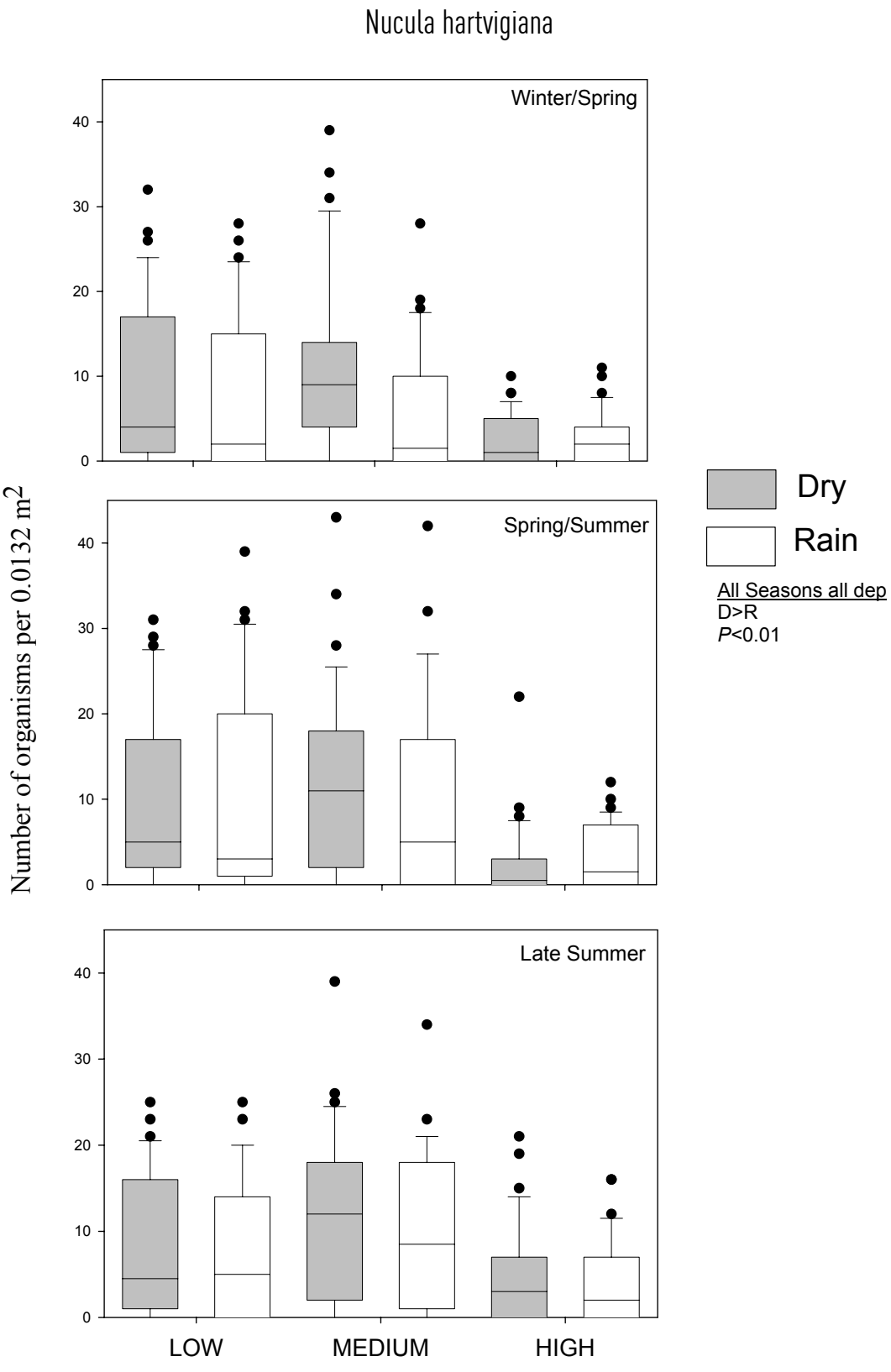

Fig. 22. Boxplots of counts of *Nucula hartvigiana* for each combination of Season, Deposition and Precipitation (6 cores x 5 sites = 30 observations per combination).

Prionospio complex

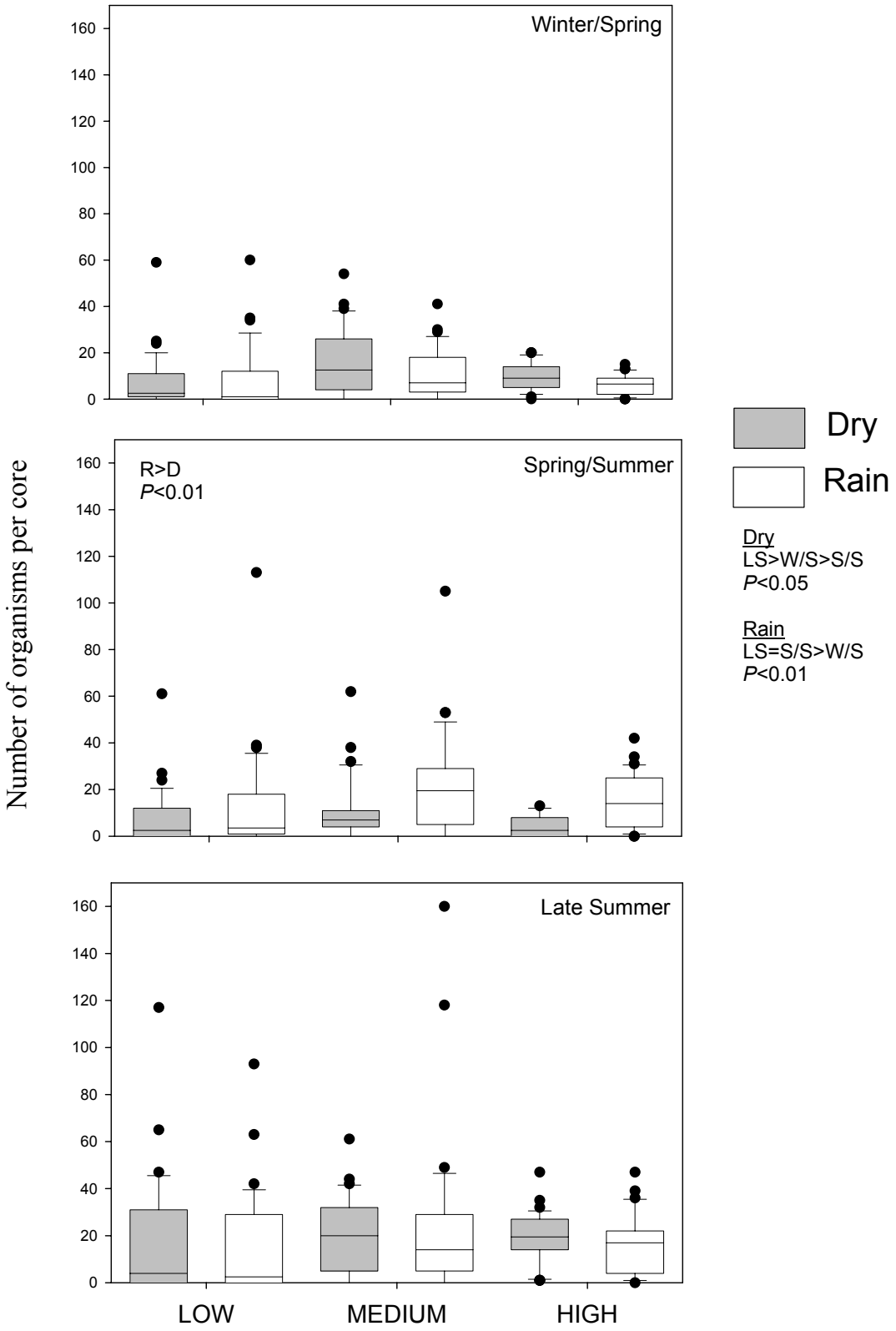

Fig. 23. Boxplots of counts of *Prionospio* complex for each combination of Season, Deposition and Precipitation (6 cores x 5 sites = 30 observations per combination).

Total number of taxa (richness)

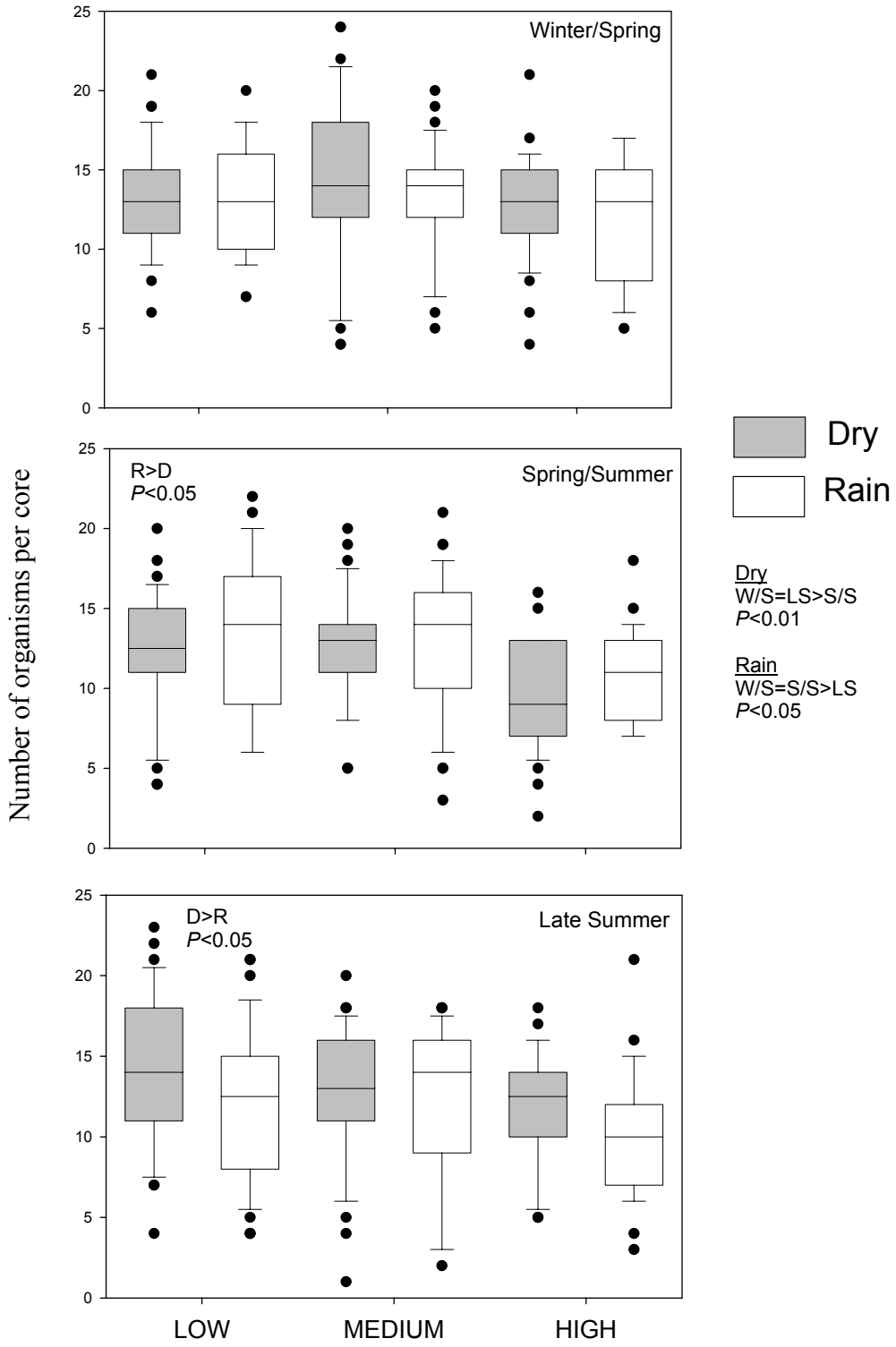

Fig. 24. Boxplots of counts of the total number of taxa (richness) for each combination of Season, Deposition and Precipitation (6 cores x 5 sites = 30 observations per combination).

Nemerteans

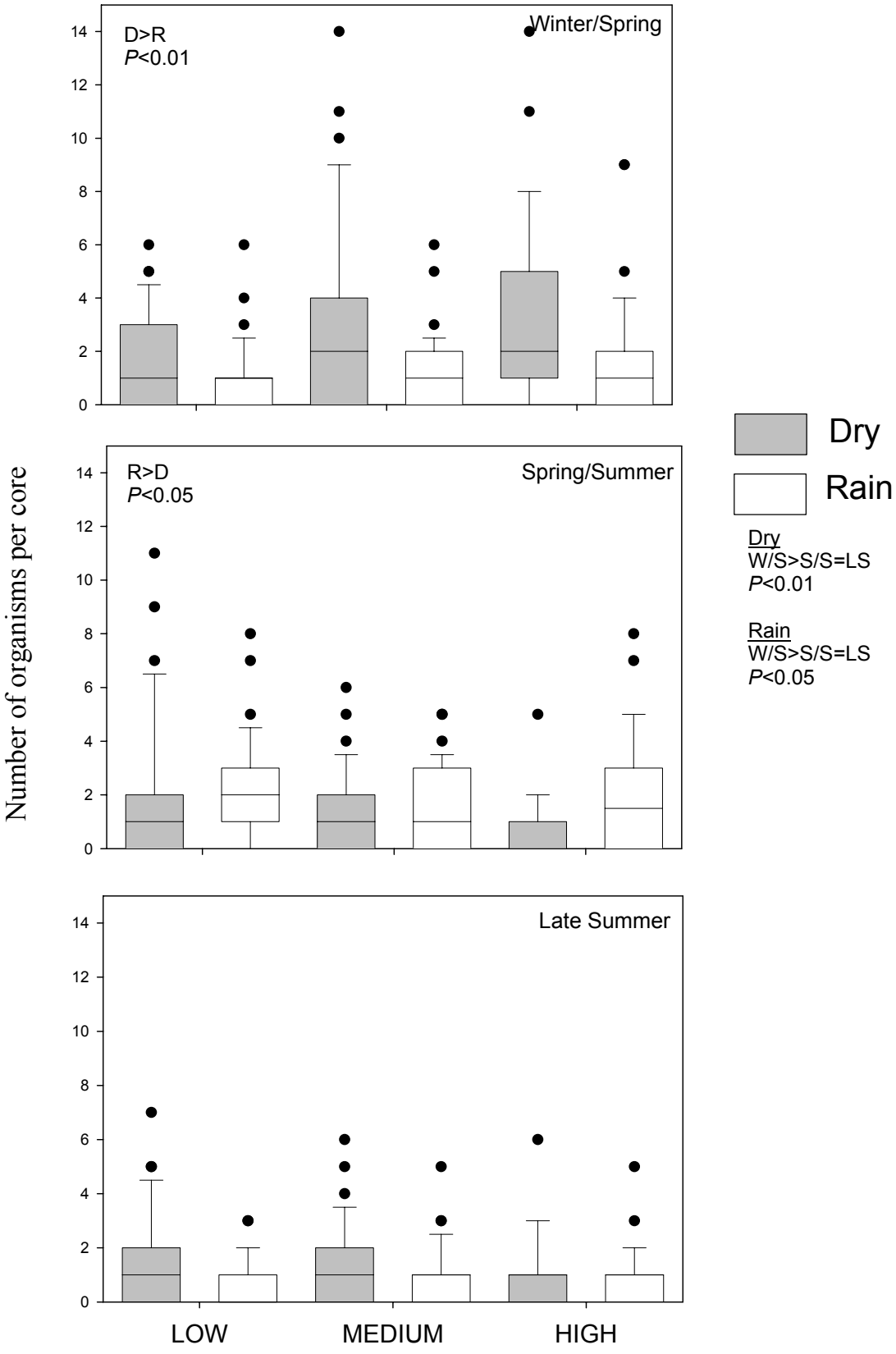

Fig. 25. Boxplots of counts of Nemerteans for each combination of Season, Deposition and Precipitation (6 cores x 5 sites = 30 observations per combination).

Polychaetes

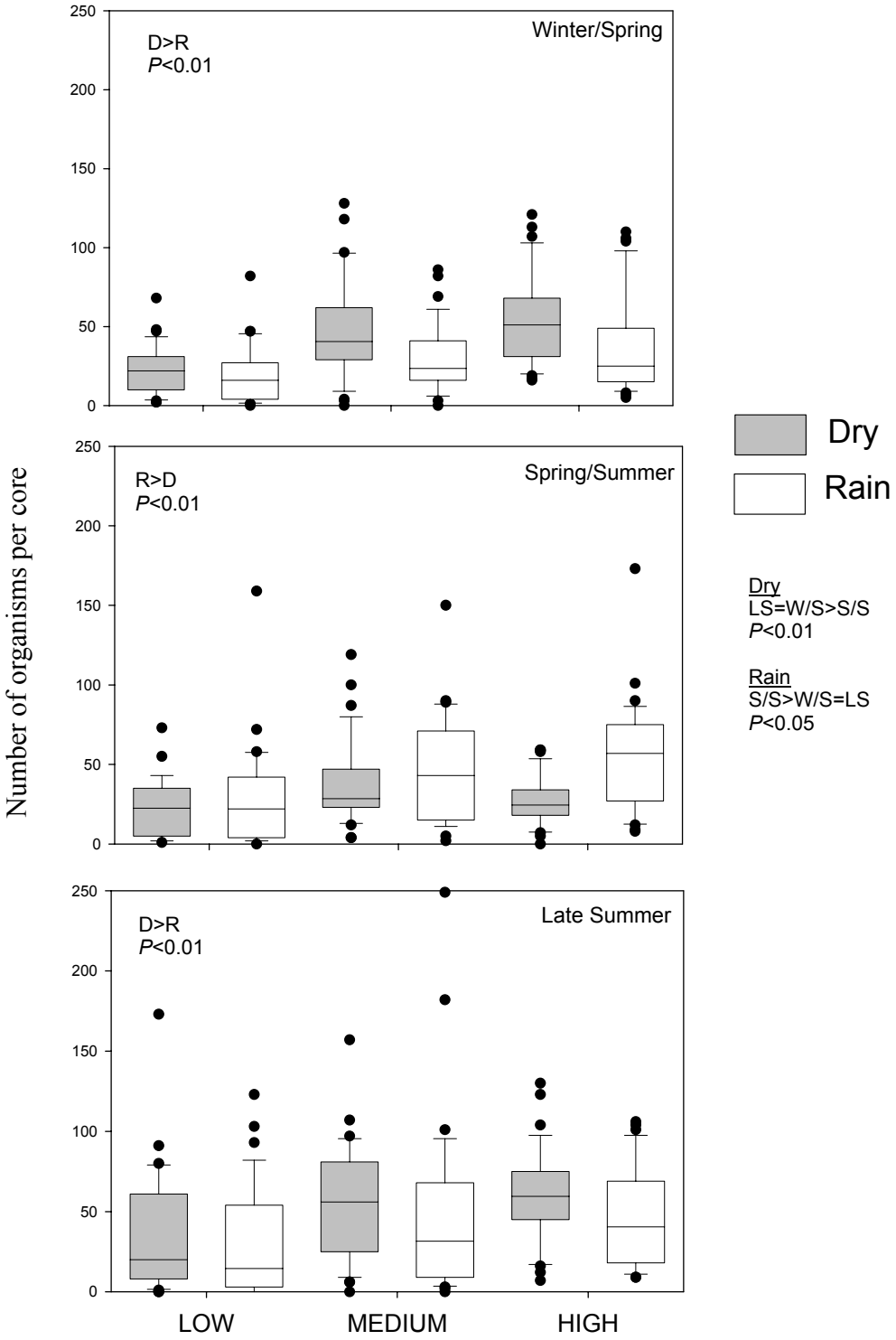

Fig. 26. Boxplots of counts of Polychaetes for each combination of Season, Deposition and Precipitation (6 cores x 5 sites = 30 observations per combination).

Table 15. ANOVA Results for different size classes of *Austrovenus stutchburyi*.

		Junveniles (< 4 mm)			Medium-sized (4-15 mm)			Large (> 15 mm)		
Source	**df**	**MS**	***F***	***P***	**MS**	***F***	***P***	**MS**	***F***	***P***
Se	2	2.6289	6.55	**0.0054**	1.4143	2.79	0.0814	0.4677	0.80	0.4616
P	1	0.1419	0.58	0.4589	2.2572	3.47	0.0871	0.8779	1.70	0.2173
D	2	18.7763	5.54	**0.0198**	192.3919	25.85	**0.0000**	69.6518	10.34	**0.0025**
Si(D)	12	3.3896	10.08	**0.0000**	7.4429	13.50	**0.0000**	6.7389	15.54	**0.0000**
Se x P	2	0.5196	0.62	0.5459	0.0607	0.07	0.9324	0.8466	5.63	**0.0099**
Se x D	4	0.0752	0.19	0.9428	0.2994	0.59	0.6727	1.3441	2.30	0.0886
Se x Si(D)	24	0.4017	1.19	0.2414	0.5070	0.92	0.5747	0.5856	1.35	0.1257
P x De	2	0.1895	0.78	0.4808	0.3937	0.61	0.5617	0.7217	1.39	0.2856
P x Si (D)	12	0.2433	0.72	0.7292	0.6504	1.18	0.2945	0.5178	1.19	0.2844
Se x P x D	4	0.7226	0.86	0.4999	0.6135	0.71	0.5931	0.8757	5.82	**0.0020**
Se x P x Si(D)	24	0.8368	2.49	**0.0001**	0.8641	1.57	**0.0437**	0.1505	0.35	0.9986
Res	450	0.3368			0.5511			0.4337		

Juvenile and Medium-sized *A. stutchburyi*

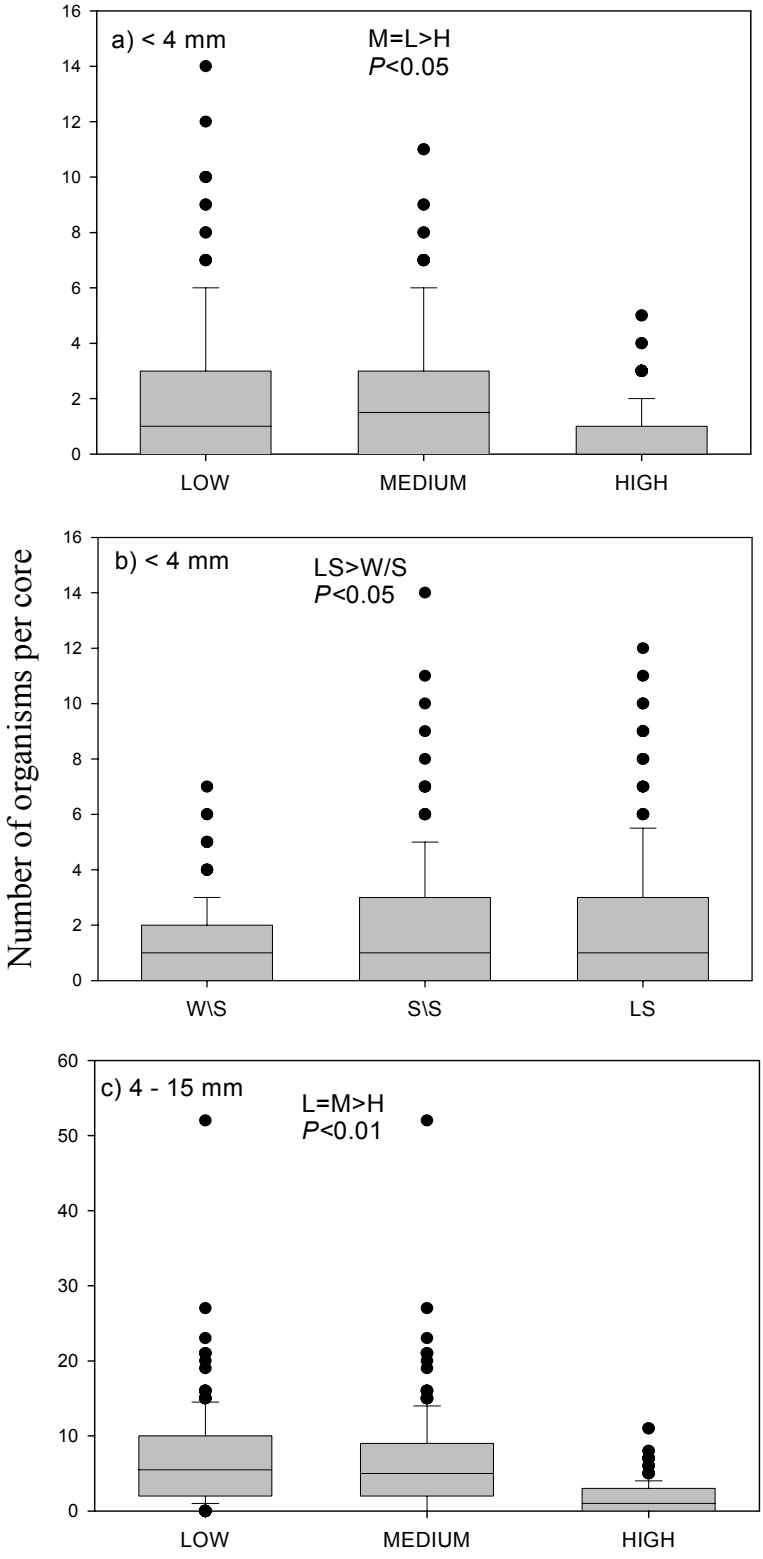

Fig. 27. Boxplots of counts of size classes of *Austrovenus stutchburyi* a) < 4 mm for each Deposition, b) < 4 mm for each Season, c) 4 - 15 mm for each Deposition.

Large *A. stutchburyi*

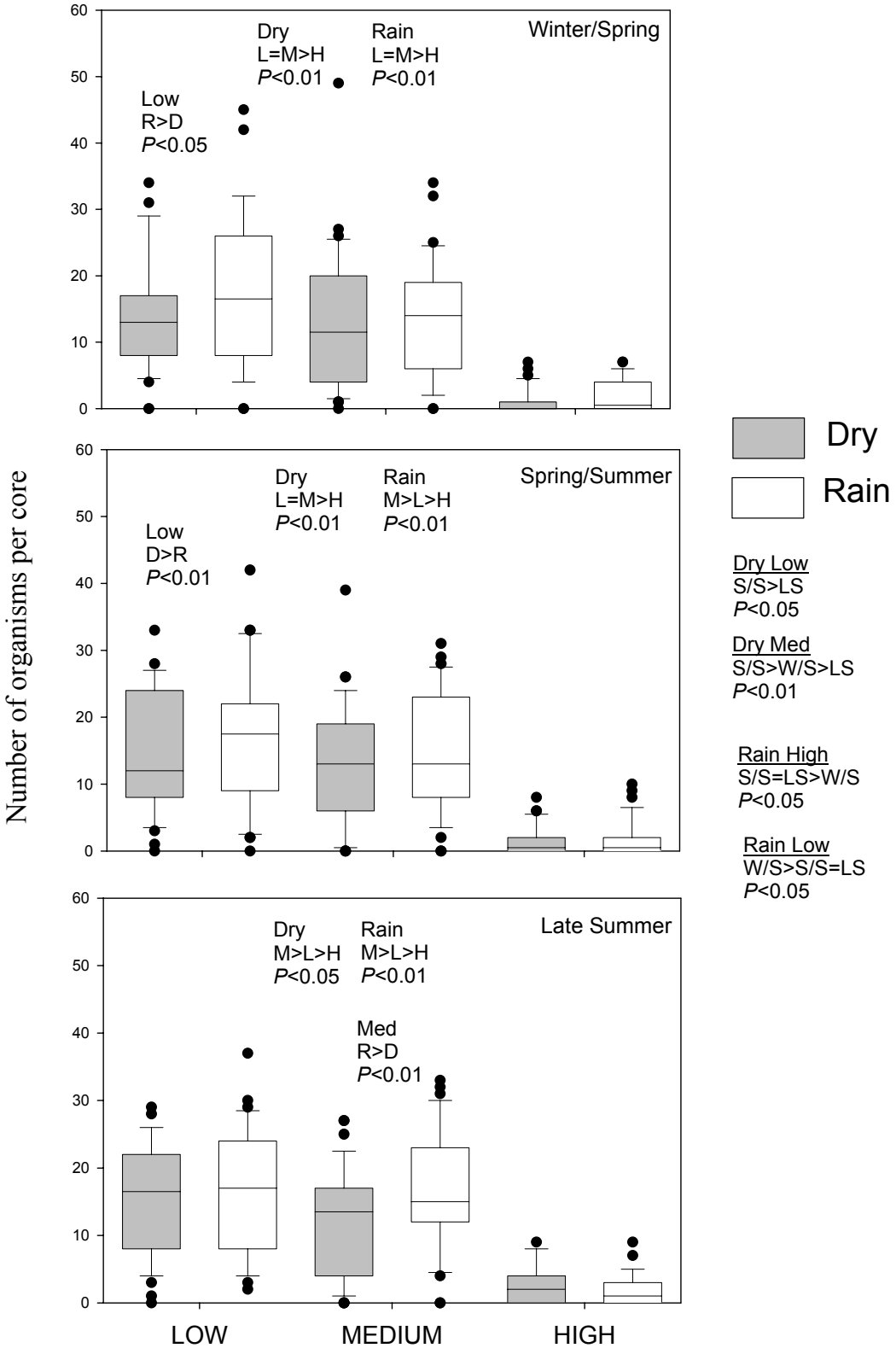

Fig. 28. Boxplots of counts of *Austrovenus stutchburyi* (> 15 mm) for each combination of Season, Deposition and Precipitation (6 cores x 5 sites = 30 observations per combination).

Discussion

Seventy-one percent of the variation in assemblages in the Okura estuary can be explained using the 16 environmental sediment variables measured. This is an impressive model and suggests an extremely strong link between sediment characteristics and the biology of estuaries. Previous models have explained up to 70% of biological variation using physical and biological variables, but only for two species at one time (Legendre *et.al.*, 1997).

The strongest effect upon assemblages in the Okura estuary was that of site, with all 15 sites being significantly different from one other. This difference was driven mainly by sediment characteristics, with ambient sediment grain-size fractions explaining 46% of the variation in assemblages, and short-term sediment deposition explaining an additional 12%. The depositional environment (H, M, L) and rank distance from the mouth of the estuary had the next strongest effects, explaining approximately 4.5% of remaining variation in assemblages each. The erosion/accretion measurements explained an additional 2% of the variation in assemblages. Additional site characteristics (organics and chlorophyll *a*) each explained less than an additional 1% of the assemblage variation.

Assemblages in High depositional sites were extremely distinct from those in the Low or Medium depositional sites. *Notomastus* sp. was the only common taxon to show higher densities in High depositional sites. This is a member of the family Capitellidae, which are small worms that are generally considered to be opportunistic (Grassle and Grassle, 1974; Beukema *et. al.* 1999). *Helice/Macrophthalmus* complex, Crab zoea and the polychaetes Pectinarids, *Magelona dakini,* and Other Orbinids were less abundant species that were associated with High depositional environments. Low and Medium depositional sites were characterised by higher median abundances of the common cockle *Austrovenus stutchburyi* compared to High depositional sites. These results are consistent with previous results. Last year (Anderson *et. al.* 2001b), Capitellid polychaetes and the crab *Macrophthalmus hirtipes* (which has since been reclassified as *Helice/Macrophthalmus* complex) were more abundant in High depositional areas and *Austrovenus stutchburyi* was more common in Medium and Low depositional areas. In contrast, there was little ecological difference between the Medium and Low depositional environments, which were difficult to distinguish or characterise separately using either multivariate or univariate statistical methods.

The effect of Season was significant on assemblages, although seasonal effects were not as strong as the effects of Deposition. Seasonal effects were most apparent in High Depositional areas, where increased abundances of *Armandia* sp., Oligochaetes, *Psuedopolydora* sp. and *Colorustylis lemurum* were seen in Late Summer. This influx of taxa is likely to be the settlement of recruits. Crab zoea and Orbinids were more abundant in the Winter/Spring season. More study is required to determine why certain taxa apparently recruit only to certain areas of the estuary.

The effects of Precipitation were significant, but varied seasonally and were much weaker than the effects of Site, Deposition or Season. Rain had a significant effect upon

assemblages in the Winter/Spring and Spring/Summer but not in the Late Summer. This does not correlate with any environmental differences observed, and is counter-intuitive as it might be expected that the impact of rain would be most apparent in Late Summer, when there are new recruits in the population. The reasons for this lack of any significant effect of rainfall in Late Summer are still therefore unclear.

It appeared that assemblages in Okura were changing directionally through time (Fig. 12). This could be an indication that some estuary-wide "press" disturbance may be occurring. Perhaps there are ongoing changes in the estuarine fauna through time. On the other hand, this temporal change through the year could have been due simply to seasonal effects. Only continued sampling will provide more information as to whether the apparently directional change is due simply to a seasonal change, or rather is due to ongoing changes occurring in the estuary. Seasonal changes would be indicated by cyclical patterns on MDS plots through time, while long-term directional change would be indicated by continuous linear trends on the plots.

Recommendations

Future sampling that incorporates additional estuaries should disregard sampling of chlorophyll *a* and sediment organics. These environmental characteristics are costly in terms of sampling and processing time and explain less than one percent each of the biological variation at Okura estuary.

Models showing gradients of sites' physical characteristics proved useful in Okura estuary to explain variation in ecological faunal assemblages. Models of depositional environments also proved useful to explain additional ecological variation. These models should therefore be developed for future use across all estuaries to explain biological variation in the future. The physical characteristics of existing sediments and sediment deposition at sites should be used to create a physical gradient model of all sites including Okura. This will allow generalisations to be made across sites in all estuaries. These physical variables should also be used to classify sites in new estuaries into High, Medium or Low depositional environments.

Future sampling for Okura estuary should be combined with data from 2001-2002 to examine the direction of temporal change. Linear change over time may indicate response to a 'press' impact from a factor that is constantly present over time. Erratic but brief changes to trajectories of assemblages through time may indicate a 'pulse' impact from a factor that is present only briefly. Natural seasonal changes, however, would result in cyclical patterns of variation over time.

To interpret the results from Okura in a wider regional context similar sampling designs should be employed in comparable estuaries. This will allow us to determine whether observed patterns are estuary-specific or regional. It will also enable us to detect significant

impacts on any of these comparable estuaries over time. In particular, differential impacts within an estuary will be discernable from natural variation. For example, if increased sediment deposition were to affect High depositional environments in Okura, we would be able to discriminate this from natural variation at High depositional sites, based on concurrent information from other estuaries.

In addition, data on existing sediment characteristics and sediment deposition are needed from Okura and other estuaries through time into the future to explicitly link biological changes with potential sediment influxes.

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Appendix 1. Guide to Statistical Methods

Multivariate Methods

When a number of organisms of different species are sampled simultaneously in response to a particular sampling program or experimental design, multivariate statistical methods are required to analyse the data. In particular, each species or taxonomic group (e.g. *Austrovenus stutchburyi*) is considered a separate variable and these variables are inter-related (i.e. they are not independent). Each variable is also generally considered a dimension. We have, in this study, obtained counts of several such variables at once from a single core of sediment. This we refer to as an assemblage or community. In the present study, we wished to know how the entire suite of variables has responded (a) to different depositional environments (H, M or L), (b) to different seasons (Winter/Spring, Spring/Summer or Late Summer) and (c) to precipitation (Rain or Dry). In addition, we wished to examine the effects of several different quantitative environmental variables (such as percentage of fine sediments, total deposition of sediments, etc.) on the assemblages.

To do this, several methods of multivariate analysis were required. These included: (a) *cluster analysis* (to examine potential group structure versus gradual changes across sites and to generate models), (b) *ordination* (to visualize patterns and reduce dimensionality), and (c) *hypothesis-testing methods* (to rigorously test explicit models and ideas). In general, all of the multivariate methods we used here begin with the calculation of a measure of distance or dissimilarity between every pair of cores (or between every pair of sites, where the information from n = 6 cores was combined for a single site) on the basis of the composition and relative abundance of the species that were found within them.

Distance and Dissimilarity Measures

The distance between any two observations (e.g. cores or sites) can be calculated simply as the straight-line distance in Euclidean space, as follows:

$$d_{12} = \sqrt{\sum_{k=1}^{p} (y_{1k} - y_{2k})^2}$$

where d_{12} is the Euclidean distance between cores (or sites) 1 and 2, y_{ik} is the measure for variable k in core (or site) i, and there are k = 1,…, p variables in the data matrix. This distance measure is generally appropriate to use with quantitative environmental data (such as grain sizes of sediments). It is, however, sensitive to differences in scale or units among the variables. Thus, before calculating the Euclidean distance, one generally standardizes each variable to z-scores (also called normalisation), as follows:

$$y'_{ik} = \frac{y_{ik} - \bar{y}_k}{\sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(y_{ik} - \bar{y}_k)^2}} = \frac{y_{ik} - mean(y)_k}{sd(y)_k}$$

where $\bar{y}_k = mean(y)_k = \frac{1}{N}\sum_{i=1}^{N} y_{ik}$ is the mean of variable k (the average of a total of N cores) and $sd(y)_k = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(y_{ik} - \bar{y}_k)^2}$ is the standard deviation of variable k.

Ecologists generally do not use the Euclidean distance, however, for counts of species abundances (e.g. Clarke 1993). One reason for this is that it treats the value of zero like any other value on the number line. As a consequence, Euclidean distance will have a tendency to make two cores that both lack some species to be more similar to one another than if they both had that species, just in different relative abundances. This is not ecologically very meaningful. For species data, a value of zero is more appropriately thought of, in general, as a lack of any information. A measure that reflects differences in composition as well as differences in relative abundances of species (or taxa) is more commonly used for species data. Currently, the most commonly used measure for this is the Bray-Curtis measure of dissimilarity (Bray and Curtis 1957), which is defined as:

$$d_{12} = \frac{\sum_{k=1}^{p}|y_{1k} - y_{2k}|}{\sum_{k=1}^{p}(y_{1k} + y_{2k})}$$

The Bray-Curtis measure varies between 0 and 1.0. The closer to 1.0 the measure is, the more dissimilar those two cores (or sites) are in terms of their composition and relative abundance of species. This measure, when multiplied by 100, is also referred to as the "percentage difference" between two communities. Although this measure treats zeros in an ecologically meaningful way, it is like the Euclidean distance measure in that it is sensitive to differences in scale among the variables. If one or more of the species is extremely abundant, it will tend to dominate the measure. Thus, the data are generally transformed before calculating the Bray-Curtis measure, in order to even up the relative importance (contribution) of different species. A transformation to $\ln(y + 1)$ or to fourth roots is generally appropriate (Clarke and Green 1988, Clarke 1993). For this investigation, we transformed the species data to $\ln(y + 1)$ and then calculated Bray-Curtis dissimilarities among all pairs of observations (either cores or sites) as a starting point for multivariate analyses of the species data.

For more information on measures of distance and dissimilarity, see Faith et al. (1987) and Legendre and Legendre (1998).

Cluster Analysis and Dendrograms

Cluster analysis is a method that can be used to explore and build potential models and hypotheses for multivariate data. In general, cluster analysis places objects together into groups if they are "close together" in multivariate space. That is, if the dissimilarity or distance among several sites is relatively small, then the two sites will be grouped or "clustered" together.

We used hierarchical agglomerative group-average clustering for the cluster analysis of sites on the basis of Euclidean distances calculated on standardised environmental variables. Agglomerative clustering means that one starts with all individual sites being their own "group", one then gradually puts sites together into groups on the basis of their dissimilarities (pairs with small dissimilarities are put together first, and so on), until all sites are in a single large group. Group-average clustering means that one or more other sites will join a group when their average dissimilarities match. Hierarchical clustering means that once two sites or groups of sites fuse, they remain together for the entire clustering procedure.

The results of a cluster analysis are usually shown in what is called a "dendrogram." This diagram shows how the fusion of sites (or groups of sites) occurred at particular levels of dissimilarity. One way in which this is useful is that it can be used to visually assess whether the sites appear to occur in several discrete groups, or whether, instead, the sites seem to occur along a gradual gradient (with no obvious discontinuities), in terms of the underlying variables. Fig. A1.1 shows the patterns that one would expect in a dendrogram for either of these situations.

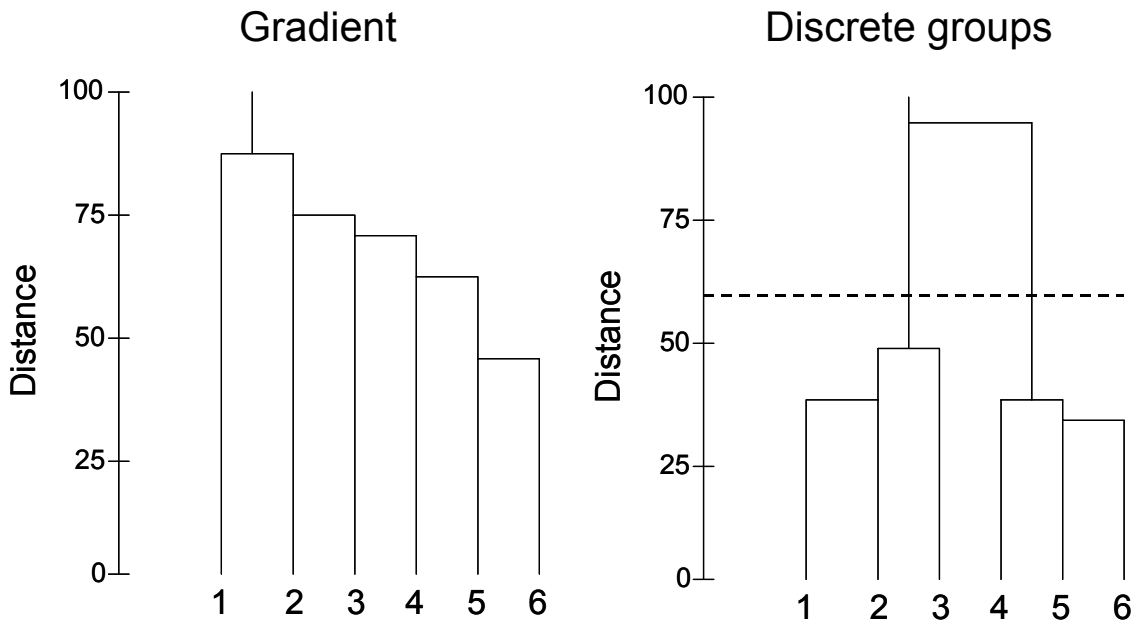

Fig. A1.1. Examples of dendrograms from hypothetical cluster analyses of six sites. The dendrogram on the left shows a pattern of gradual differences (a gradient relationship) among the sites. The dendrogram on the right shows a pattern of discrete groups. The dotted line corresponds to a distance of 60, which in this case separates the sites into two distinct groups: sites 1, 2 and 3 in one group and sites 4, 5 and 6 in another group).

For the environmental variables investigated here, the shape of the dendrogram resulting from the cluster analysis suggested a gradient model for the sites on the basis of the sediment characteristics would be more reasonable than a model involving arbitrary groups (see Fig. 7). For more details on cluster analysis, see Gordon (1994).

Principal Component Analysis (PCA)

Principal component analysis (PCA) is an ordination method that is useful for reducing the number of variables (and thus the number of dimensions) in a multivariate system. To explain how PCA works, consider a system with two variables, as shown in Figure A1.2. Imagine that we wish to reduce the dimensionality from 2 dimensions down to 1 dimension. For every site, we have two values, one along each dimension, which places the site as a point in the two-dimensional multivariate (in this case bivariate) space.

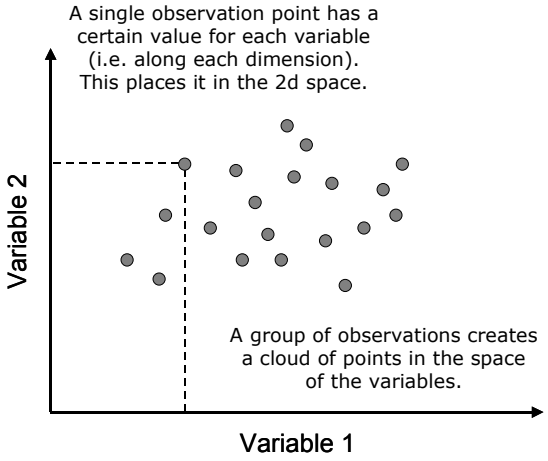

Fig. A1.2. A set of observations (e.g. sites) as points in bivariate space.

Next, draw an axis through the cloud of points in such a way as to maximise the variation of points along it (Fig. A1.3). This is exactly the same as drawing an axis in such a way so as to minimise the sum of squared Euclidean distances from the points to the new axis. The axis is called the first principal component and the values along the axis for the points are called principal component scores (PC scores).

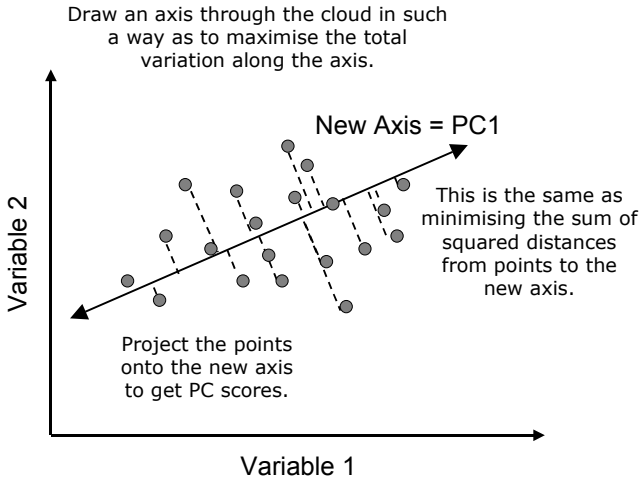

Fig. A1.3. Drawing of the first principal component axis through a cloud of points in bivariate space. The two variables have a positive correlation in this hypothetical example, so the PC axis will explain a reasonably large proportion of the total variation.

We can repeat this procedure to obtain more PC axes, where in each case we are looking for an axis that maximises variation through the cloud, but subsequent axes are constrained to be completely uncorrelated with previous PC axes. Thus, different components of variation (different directions and therefore different aspects of the data cloud) are described by

different individual PC axes. There will be the same number of PC axes as there were original variables in the analysis. Thus, to be useful for reducing dimensions, a large proportion of the variation in the original data needs to be described well by just the first few PC axes. This happens (i.e. the PCA is most successful for reducing dimensionality) when there is a reasonable amount of correlation among the original variables.

How can the PC axes be interpreted? Well, the PC scores are new variables that are linear combinations of the original variables that can be plotted in an ordination diagram or used for subsequent analyses. For example, to get the score for site one along PC axis one, one would calculate:

$$Score_1 = \beta_1 y'_{11} + \beta_2 y'_{12} + ... + \beta_k y'_{1k} + ... + \beta_p y'_{1p}$$

where y'_{11}, y'_{12}, …, y'_{1k}, …, y'_{1p} are the normalized values for variables 1 through *p* at the original site 1 and β_1, β_2, …, β_k, …, β_p are the weights for variables 1 through *p* for principal component axis 1. When the variables are normalized like this for the analysis, the relative sizes of the weights can be used to determine the relative importance of the original variables in the description of the PC axis (e.g. Table 3).

PCA intrinsically preserves Euclidean distances among the points and, therefore, is commonly used for analysis of environmental data (as opposed to species data). It was used in the present investigation to analyse sediment characteristics. For more details on PCA, see Mardia et al. (1979), Seber (1984) and Rao (1964).

Non-metric Multi-dimensional Scaling (MDS)

Non-metric multi-dimensional scaling is an extremely robust method of ordination that can be done on the basis of any measure of dissimilarity (including the Bray-Curtis measure, as was used in the present investigation). The algorithm essentially attempts to plot the points (e.g. sites or cores) on the basis of the relative dissimilarities between them in an arbitrary number of Euclidean dimensions. That is, one chooses, for example, *a priori*, to see an ordination or "map" of the sites in, say, two dimensions in Euclidean space. The algorithm starts by placing the points in a random orientation. It then iteratively moves or "jitters' the points around relative to one another so as to minimize the discrepancy between the inter-point Euclidean distances on the 2-d plot and their original Bray-Curtis dissimilarities. A measure of this discrepancy is called "stress" and the algorithm works to find a solution that minimises stress. Several random starts are usually needed in order to obtain a global (as opposed to a local) minimum in the value of stress.

Unlike PCA, the axes produced in non-metric MDS are arbitrary and bear no known relationship to the original variables. This is why these plots do not have any labels on their axes. It also means that the axes can be rotated, inverted, expanded or contracted, without altering their meaning. Each MDS plot in the text reports a measure of stress, because stress indicates how accurately the MDS plot reflects the original relative Bray Curtis (or other) dissimilarities among the points. As a general rule of thumb, stress values less than 0.2 provide a good representation of the original dissimilarities among the points. MDS plots with stress values of 0.2 or greater are suspect in terms of their interpretability.

When viewing an MDS plot, the relative distances between points indicate their relative similarity with respect to the composition and abundance of assemblages. In general, the points on the plot are labeled according to their membership in groups. For example, individual sites belong to High, Medium or Low depositional environments, and in this study are given labels for H, M or L, respectively, in MDS plots. Of interest is to see whether the sites belonging to the same group are clustered together on the plot and are cleanly separated from other sites belonging to other groups (e.g. Fig. A1.4). This would suggest that groups differ in their communities of organisms. On the other hand, if labels of different types are well-mixed in the diagram, this would suggest no clear differences in assemblages from different groups.

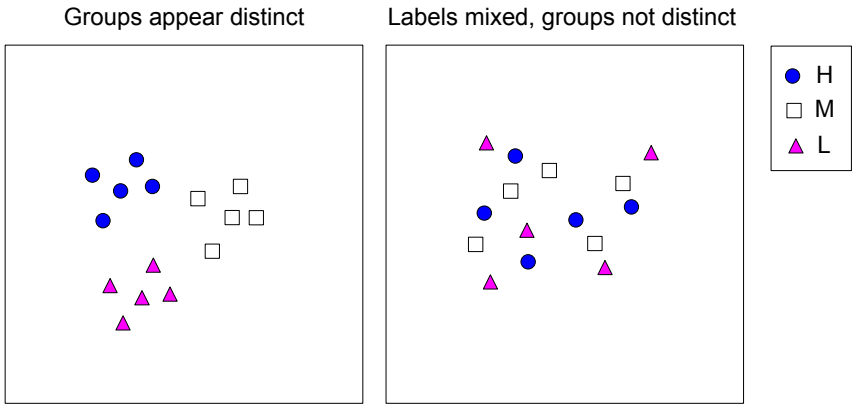

Fig. A1.4. Examples of patterns in non-metric MDS plots that indicate either differences among assemblages (left: similar symbols are grouped together), or no clear differences (right: symbols are mixed and do not form distinct groups).

For more details on MDS, see Shepard (1962), Gower (1966), Kruskal and Wish (1978) and Clarke (1993).

Constrained Ordination

There are some situations where there are statistically significant differences in assemblages that are, nevertheless, not visible in patterns on the MDS plot. Some methods of ordination are designed to view the cloud of multivariate data in such a way that *any* differences in the assemblages that might be apparent in multivariate space can be viewed in a lower-dimensional diagram. Such methods are called "constrained" ordinations, because they use the hypothesis of interest as part of the criterion for finding an axis through the multivariate cloud for ordination. Note that PCA and non-metric MDS are both ordination methods that are "unconstrained." That is, these methods do not use any hypothesis at all, but instead use very general and "hypothesis-free" criteria (e.g. maximizing the variance of the entire data cloud along a new PC axis, or minimizing stress in the case of MDS). Such unconstrained methods may be thought of as "letting the data speak for themselves" (Clarke and Ainsworth 1993).

One method of constrained ordination is Canonical Discriminant Analysis (CDA). This method finds an axis through the cloud of points that maximizes differences between groups, where the group membership is provided by an *a priori* hypothesis. To see how CDA differs from PCA, we can consider how each of these methods would treat with the same set of two-dimensional data for which we wish to obtain a one-dimensional ordination (Fig. A1.5).

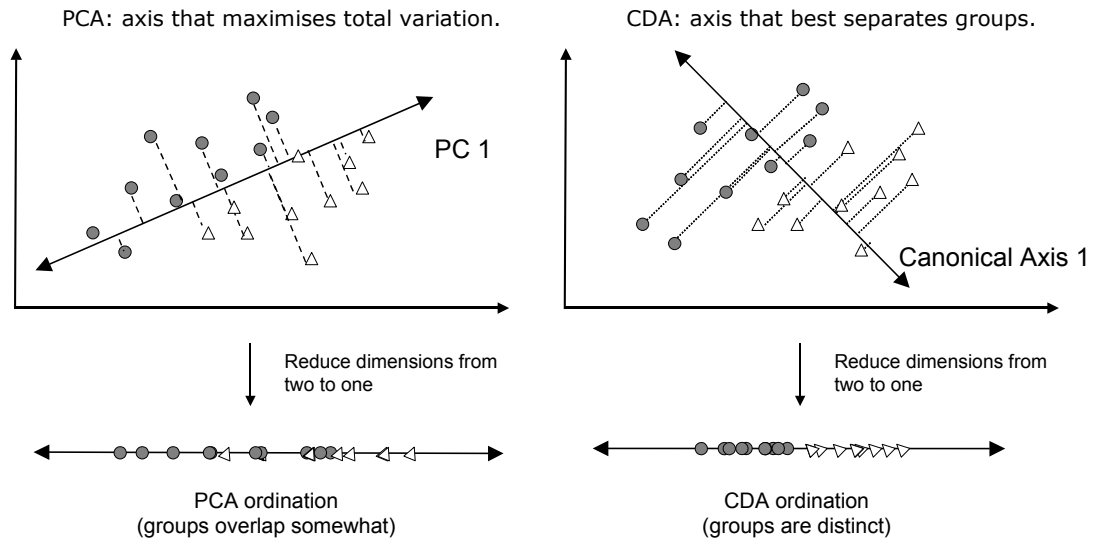

Fig. A1.5. Contrast between an unconstrained PCA ordination and a constrained CDA ordination of the same data set. The differences arise from the fact that the PCA does not use the group membership of points to draw the axis, whereas the CDA searches for an axis that maximises group differences.

If the direction of group differences is similar to the direction of greatest total variation, then PCA and CDA will give quite similar-looking ordination plots. This will happen, for example, if

the differences among groups occur in the most abundant and variable species or taxa. If, however, the direction of group differences in multivariate space is different to the direction of greatest total variation (i.e. Figure A1.5), then the CDA may uncover differences among groups that are not seen in a PCA plot. This might happen, for example, when group differences are caused by changes in the less abundant and less prominent species or taxa. An important further point is that a constrained ordination is not useful, however, for determining potential differences in *dispersion* among groups, which can generally be discerned, however, in an unconstrained plot.

Clearly, both an unconstrained and a constrained ordination will be useful for discovering patterns in multivariate data, in any particular situation. They just give different views of the same data cloud. For more details on CDA, see Mardia et al. (1979), Seber (1984) and Williams (1983). CDA was not used in the present investigation, but has been described here to clarify what is meant by a constrained ordination. A more flexible and robust method of constrained ordination was used, called CAP, which stands for *Canonical Analysis of Principal Coordinates*.

CAP plots: Canonical Analysis of Principal Coordinates

We have seen, above, how non-metric MDS is an unconstrained ordination method that has the added advantage (over PCA) that any measure of dissimilarity can be used as the basis for the analysis. It is a particularly robust and flexible method (Minchin 1987). A constrained ordination method that can be done on the basis of any measure of dissimilarity has recently been developed and is called *Canonical Analysis of Principal Coordinates*, or CAP (Anderson and Willis, in press). It is essentially a two-step procedure that involves calculation of principal coordinates from Bray-Curtis (or some other) dissimilarities, followed by CDA on these principal coordinates. Further details are found elsewhere (Anderson and Willis, in press, Anderson and Robinson, in review).

The essential point is that CAP provides a constrained ordination of the data on the basis of any measure of dissimilarity, a kind of constrained version of MDS, if you like. In other words, CAP is to MDS what CDA is to PCA.

Allocation Success

When viewing the results of a CAP ordination, several things are reported, each with specific meaning. First, for each axis of the ordination, one is given the *squared canonical correlation* (symbolized by δ^2). This value goes from 0 to 1 and is the correlation between the group structure and the species data. The closer the value is to 1, the greater is the strength of the group effects.

Second, in the canonical ordination, one is looking for clear separation of groups of similar symbols, (as described for MDS plots, Fig. A1.4 above). A measure of the distinctness of the groups is given by what is called the "allocation success," which is a percentage out of 100. What is allocation success? It is a measure of the probability that a new observation, when placed into the canonical ordination, will get placed into its correct group. How is allocation success determined? The method used here is called "leave-one-out classification" and proceeds as follows (e.g. Lachenbruch and Mickey 1968):

1. Remove one of the points and do the CAP analysis without it.
2. Place the point that was "left out" into the canonical space, based on its dissimilarities with all other points in the diagram.
3. Determine the group whose centroid (central location) is the closest to the point and allocate the point to this group.
4. The "true" group to which the point belongs is known: was the allocation of the point correct?
5. Repeat steps 1-4 for all of the points in the diagram and determine the proportion of the points that were correctly allocated.

If 100% of the points were correctly allocated, then the groups are extremely distinct. If, on the other hand, there are, say, three groups, then an allocation success of 30% would be no better than random. An analogous measure for determining the distinctness of the groups, called "misclassification error," is simply 100 minus the allocation success. For more information concerning methods of calculating misclassification error, see Seber (1984).

Correlations of Species with Canonical Axes

Although CAP is a very robust procedure, it has the same slight drawback that MDS has in that the axes it produces for the ordination have no known relationship to the original variables. A natural question to ask is, "Which of the original variables contribute to group differences?" In the case of PCA, one can use the weights to determine the importance of the original variables directly (i.e. Table 3). However, in CAP, one can get at this question by calculating, after the fact, the simple correlation of each original variable with the canonical axes. For example, consider the CDA diagram on the left-hand side of Fig. A1.5 and imagine that the triangles represent, say, "Dry" and the circles represent, say, "Rain". A species that has a strong positive correlation with the first canonical axis would, therefore, be associated with "Dry" situations, while a species that has a strong negative correlation would be associated with situations of "Rain." In the present investigation, we have used the sizes of correlations of individual species with canonical axes as a way of deciding which species to examine more closely in univariate analyses.

Experimental Design

The experimental design used in this investigation was fairly complex. It consisted of the following factors and levels:

Factor 1 = Season, a fixed factor with *a* = 3 levels: Winter/Spring, Spring/Summer and Late Summer.
Factor 2 = Precipitation, a fixed factor with *b* = 2 levels: Rain and Dry.
Factor 3 = Deposition, a fixed factor with c = 3 levels: High, Medium and Low.
Factor 4 = Site, a random factor with *d* = 5 levels, nested within each level of Deposition.

Replication at the lowest level was provided by *n* = 6 cores within each of the $a \times b \times c \times d = 90$ combinations of the above factors.

Analysis of variance (ANOVA) is an extremely useful method for testing hypotheses for complex experimental designs. We know that natural systems are extremely variable. As scientists, we wish to examine, explain and model the variability in the systems we are studying. More particularly, we would like to measure the proportion of the natural variation (in one or more response variables) that is attributable to particular factors in an experimental design. ANOVA is an extremely important tool for doing this, because it partitions the total variation we have measured in a single variable into pieces that correspond to the various contributing sources (factors) and their interactions. ANOVA allows us to (i) test for which factors are contributing significantly to the variability in the response variable and (ii) measure the size of the variation explained by significant factors.

ANOVA allows us to do this for one single variable. To partition the variability and test for significant effects for multivariate data, we need to use multivariate analysis of variance (MANOVA). Unfortunately, the statistical assumptions required for the traditional MANOVA tests are too stringent for the vast majority of ecological data sets. As a consequence, a new robust method has been developed which, like MDS, is based on dissimilarities among assemblages. It is called non-parametric multivariate analysis of variance (NPMANOVA, Anderson 2001a), and allows test of hypotheses which are (i) flexible (since any distance or dissimilarity measure can be used) and (ii) robust (since no specific assumptions about the distributions of variables are made – *P*-values are obtained using permutations).

The linear model corresponding to the experimental design used for the present investigation was as follows:

$$y_{ijklm} = \mu + Se_i + P_j + D_k + Si(D)_{l(k)} + SeP_{ij} + SeD_{ik} + SeSi(D)_{il(k)} + PD_{jk} + PSi(D)_{jl(k)} + SePD_{ijk} + SePSi(D)_{ijl(k)} + \varepsilon_{ijklm}$$

where Se_i is the effect of the *i*th level of the factor "Season" (*i* = 1, 2, 3), P_j is the effect of the *j*th level of the factor "Precipitation" (*j* = 1, 2), D_k is the effect of the *k*th level of the factor "Deposition" (*k* = 1, 2, 3), $Si(D)_{l(k)}$ is the effect of the *l*th level of the factor "Site" (*l* = 1, …, 5) within the *k*th level of "Deposition" and ε_{ijklm} is the individual error associated with

the mth observation of the response variable y_{ijklm} (m = 1, …, 6). All other terms in the model are terms corresponding to the interactions of these main effects.

Table A1.1. Sources of variation in the ANOVA model for the present investigation. Random effects' variance components are denoted by σ^2, while sources of variation due to fixed effects are denoted by K^2. For example, $K_A^2 = \frac{1}{a-1}\sum_{i=1}^{a} A_i^2$, where *a* is the number of levels of factor A and we rely on the summation restriction for fixed effects, i.e. that $\sum_{i=1}^{a} A_i = 0$.

Source	***Component of Variation***
Season = Se	K_{Se}^2
Precipitation = P	K_P^2
Deposition = D	K_D^2
Site(Deposition) = Si(D)	$\sigma_{Si(D)}^2$
Se x P	K_{SeP}^2
Se x D	K_{SeD}^2
Se x Si(D)	$\sigma_{SeSi(D)}^2$
P x D	K_{PD}^2
P x Si(D)	$\sigma_{PSi(D)}^2$
Se x P x D	K_{SePD}^2
Se x P x Si(D)	$\sigma_{SePSi(D)}^2$
Residual	σ_{ε}^2

Every term in the model contributes a source of variation, shown in Table A1.1, each of which may be estimated. To determine the significance of individual sources of variation, one must first consider the expected values for mean squares calculated in the ANOVA. These expected mean squares will depend on the particular design, whether certain terms are fixed or random, and whether they are crossed with or nested in other terms. In turn, the *F*-ratio used to test for the significance of individual terms in the model (using either ANOVA for single variables or NPMANOVA for all response variables) will need to be constructed by reference to these expected mean squares (EMS) in order to isolate the test on the factor of interest. Details of the EMS's for each term in the model and the consequences for the construction of the *F*-ratios are shown in Table A1.2.

Table A1.2. Expected mean squares (EMS) and terms to be used as the denominator in the construction of the *F*-ratio for each term in the analysis.

Source	***EMS***	***Term whose MS is the Denominator of the F-ratio***
Season = Se	$\sigma_\varepsilon^2 + bn\sigma_{SeSi(D)}^2 + bcdnK_{Se}^2$	Se x Si(D)
Precipitation = P	$\sigma_\varepsilon^2 + an\sigma_{PSi(D)}^2 + acdnK_P^2$	P x Si(D)
Deposition = D	$\sigma_\varepsilon^2 + abn\sigma_{Si(D)}^2 + abdnK_D^2$	Si(D)
Site(Deposition) = Si(D)	$\sigma_\varepsilon^2 + abn\sigma_{Si(D)}^2$	Residual
Se x P	$\sigma_\varepsilon^2 + n\sigma_{SePSi(D)}^2 + cdnK_{SeP}^2$	Se x P x Si(D)
Se x D	$\sigma_\varepsilon^2 + bn\sigma_{SeSi(D)}^2 + bdnK_{SeD}^2$	Se x Si(D)
Se x Si(D)	$\sigma_\varepsilon^2 + bn\sigma_{SeSi(D)}^2$	Residual
P x D	$\sigma_\varepsilon^2 + an\sigma_{PSi(D)}^2 + adnK_{PD}^2$	P x Si(D)
P x Si(D)	$\sigma_\varepsilon^2 + an\sigma_{PSi(D)}^2$	Residual
Se x P x D	$\sigma_\varepsilon^2 + n\sigma_{SePSi(D)}^2 + dnK_{SePD}^2$	Se x P x Si(D)
Se x P x Si(D)	$\sigma_\varepsilon^2 + n\sigma_{SePSi(D)}^2$	Residual
Residual	σ_ε^2	

For more details about NPMANOVA, see Anderson (2001a) and McArdle and Anderson (2001). For more details about ANOVA in complex designs, see Underwood (1981, 1997). For more details about estimating variance components, see Searle et al. (1992). For more information on permutation tests, see Manly (1997) and Anderson (2001b).

Boxplots for Univariate Data

Boxplots provide a useful tool for viewing univariate data. They provide information concerning the location, relative spread and shape of a data set. A boxplot of a set of data shows the following pieces of information (see Fig. A1.6):

- *median* = The observation that occupies the middle of the data set. Half (50%) of the observations lie above and half of the observations lie below the median. If there is an even number of observations in the data set, the median is the average of the two middle observations.
- *lower quartile* = The bottom of the box, one quarter (25%) of the observations lie below this line.
- *upper quartile* = The top of the box, three quarters (75%) of the observations lie below this line.
- *inter-quartile range* = The difference between the upper and lower quartile, this is the "box" of the boxplot and it contains the range of the central half (50%) of the data.
- *whiskers* = The lines extending above and below the box, they extend to the 10^{th} and 90^{th} percentiles of the data. Therefore the length of a single whisker encompasses 15% of the observations, and 20% of the observations lie outside these whiskers.
- Note that values lying outside the extent of the whiskers are plotted as individual outlying points.

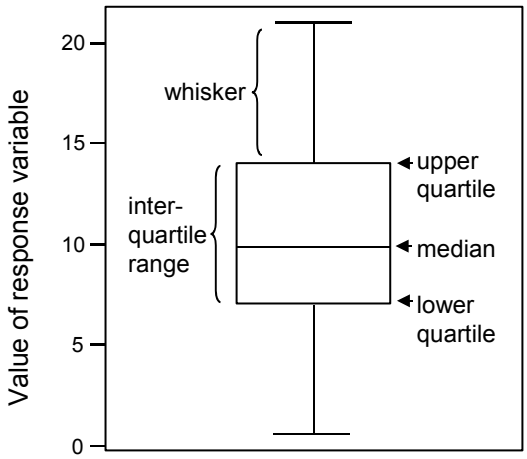

Fig. A1.6. Example of a boxplot, showing its salient features.

Side-by-side boxplots, as were used in this investigation, are useful for seeing differences among groups, such as differences in location (mean or median) or in spread (inter-quartile range or variance). They are also useful for identifying non-symmetric or non-normal distributions, such as right-skewed distributions, which are commonly encountered for counts of species variables. For examples of these patterns, see Fig. A1.7.

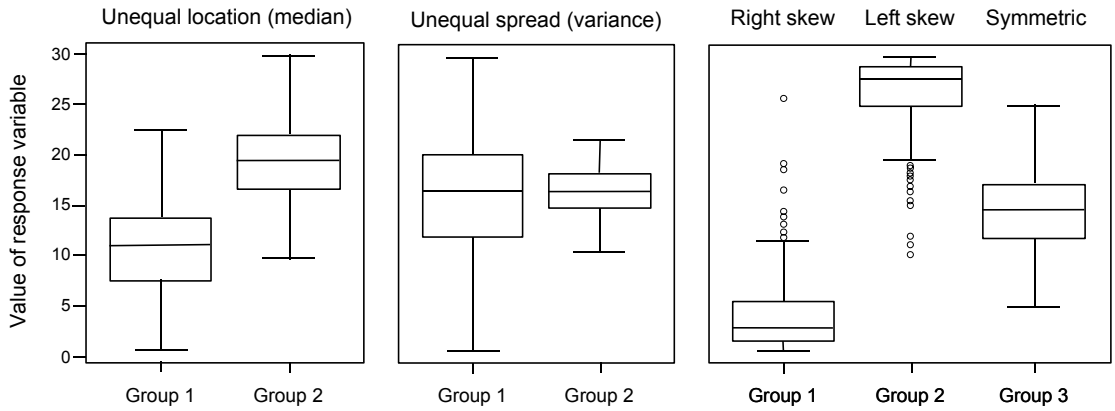

Fig. A1.7. Boxplots showing patterns of: (a) unequal location, where the median for group 1 is smaller than the median for group 2 (left-hand plot), (b) unequal spread, where the inter-quartile range and whiskers are broader for group 1 than for group 2 (middle plot) and (c) different distributions, with group1 being right skewed, group 2 being left skewed and group 3 being symmetric (right-hand plot).

Appendix 2. List of Taxa

Where possible, organisms were identified to the species level. Some specimens were unable to be unambiguously identified, and are grouped together at the lowest classification possible.

Table A2.1 Taxa and their corresponding taxonomic groups identified and recorded for this study.

Taxon	Group
MOLLUSCS	
Austrovenus stutchburyi	Bivalvia
Nucula hartvigiana	Bivalvia
Paphies australis	Bivalvia
Macomona liliana	Bivalvia
Arthritica bifurcata	Bivalvia
Corbula zelandica	Bivalvia
Notoacmea helmsii	Gastropoda
Sypharochiton pelliserpentis	Gastropoda
Cominella glandiformis	Gastropoda
Diloma subrostratum	Gastropoda
Cominella maculosa	Gastropoda
Cominella adspersa	Gastropoda
Turbo smaragdus	Gastropoda
Haminoea zelandiae	Opisthobranchia
Other Opistobranchs	Opisthobranchia
CRUSTACEANS	
Phoxocephalid sp.	Amphipoda
Parakalliope sp.	Amphipoda
Waitangi sp.	Amphipoda
Other Amphipods	Amphipoda
Elminius modestus	Cirripedia
Copepoda	Copepoda
Paracorophium sp.	Crustacean
Unidentified Crustaceans	Crustacean
Colorustylis lemurum	Cumacea
Helice/Macrophthalmus complex	Decapoda
Halicarcinus sp.	Decapoda
Crab zoea	Decapoda
Hemigrapsus crenualtus	Decapoda
Pinnotheres sp.	Decapoda
Pagurus sp.	Decapoda
Psuedosphaeroma sp.	Isopoda
Other Isopods	Isopoda
Cirolana sp.	Isopoda
Leptostracan	Leptostracan
Ostracods	Ostracoda

Taxon	Group
POLYCHAETES	
Notomastus sp.	Capitellidae
Capitella sp.	Capitellidae
Timarete anchylochaeta	Cirratulidae
Other Cirratulidae	Cirratulidae
Cossura coasta	Cossuridae
Diopatra sp.	Eunicea
Other Glycerids	Glyceridae
Glycera lamellipoda	Glyceridae
Glycera americana	Glyceridae
Magelona dakini	Magelonidae
Macroclymenella stewartensis	Maldanidae
Aglaophamus macroura	Nephtyidae
Nereid/Nicon complex	Nereidae
Oligochaetes	Oligochaeta
Armandia sp.	Opheliidae
Travisia sp.	Opheliidae
Scoloplos cylindifer	Orbiniidae
Orbinia papillosa	Orbiniidae
Other Orbinids	Orbiniidae
Owenia fusiformis	Oweniidae
Aricidea sp.	Paraonidae
Pectinarids.	Pectinariidae
Sabellid sp.	Sabellidae
Aonides spp.	Spionidae
Psuedopolydora spp.	Spionidae
Boccardia spp.	Spionidae
Polydora spp.	Spionidae
Other Spionids	Spionidae
Prionospio complex	Spionidae
Exogoninae	Syllidae
Other Syllids	Syllidae
MISCELLANEOUS	
Anthopleura spp.	Anthozoa
Other Anthozoa	Anthozoa
Insect larvae	Insecta
Nemerteans	Nemertea
Platyhelminth	Platyhelminth
Sipunculid	Sipuncula

Appendix 3. Tables of Correlations of Individual Taxa with Canonical Axes

Table A3.1. Correlations of individual taxa with canonical axes for effects of Deposition, within each Season. Taxa with positive correlations should have greater abundance and/or frequency in High depositional sites, while those with negative correlations should have greater abundance and/or frequency in Medium or Low depositional sites. Dashes indicate the taxon did not occur in that Season.

Taxon	Winter/ Spring	Spring/ Summer	Late Summer	Average
Positive correlation (High):				
Nereid/Nicon complex	0.7951	0.7809	0.8283	0.8014
Cossura coasta	0.7762	0.7901	0.7870	0.7844
Helice/*Macrophthalmus* complex	0.8206	0.5467	0.6401	0.6691
Notomastus sp.	0.6159	0.6553	0.5542	0.6085
Other Glycerids	0.5194	0.6335	0.4056	0.5195
Glycera lamellipoda	0.7278	0.3545	0.4359	0.5061
Timarete anchylochaeta	0.4720	0.6486	0.1959	0.4388
Crab zoea	0.2697	0.6243	0.4050	0.4330
Oligochaetes	0.3961	0.4051	0.4491	0.4168
Pectinarids	0.6484	0.6264	-0.0315	0.4144
Boccardia spp.	0.3618	0.0761	0.7526	0.3968
Sabellid sp.	---	---	0.3949	0.3949
Copepoda	---	0.1969	0.5865	0.3917
Paracorophium	0.3718	0.0921	0.5757	0.3465
Teleosts	---	---	0.2927	0.2927
Polydora spp.	0.5542	-0.1005	0.3794	0.2777
Unidentified Crustaceans	0.2601	0.2570	0.2995	0.2722
Arthritica bifurcata	---	0.2971	0.2355	0.2663
Other Cirratulidae	---	---	0.2355	0.2355
Negative correlation (Medium, Low):				
Austrovenus stutchburyi	-0.8156	-0.7881	-0.8483	-0.8173
Anthopleura spp.	-0.7964	-0.8509	-0.7767	-0.8080
Elimnius modestus	-0.7646	-0.7752	-0.7964	-0.7787
Colorustylis lemurum	-0.7106	-0.5527	-0.8309	-0.6981
Notoacmaea helmsii	-0.6854	-0.7769	-0.6192	-0.6938
Aonides spp.	-0.6566	-0.7695	-0.5995	-0.6752
Paphies australis	-0.5443	-0.6676	-0.4749	-0.5623
Sypharochiton pelliserpentis	-0.4476	-0.6071	-0.4630	-0.5059
Halicarcinus sp.	-0.6061	-0.4032	-0.4293	-0.4795
Phoxocephalid sp.	-0.4955	-0.4818	-0.4158	-0.4644
Cominella glandiformis	-0.376	-0.5152	-0.4038	-0.4317
Parakalliope sp.	-0.4935	-0.3643	-0.4059	-0.4212
Orbinia papillosa	-0.5842	-0.4685	-0.1549	-0.4025
Psuedosphaeroma sp.	-0.3253	-0.2839	-0.4157	-0.3416
Waitangi sp.	-0.3103	-0.4579	-0.2429	-0.3370
Nucula hartvigiana	-0.2348	-0.3655	-0.3015	-0.3006
Sipunculid	-0.2818	-0.2213	-0.2967	-0.2666
Other Syllids	-0.2042	-0.298	-0.2262	-0.2428
Diloma subrostratum	-0.2544	-0.129	-0.3438	-0.2424
Corbula zelandica	---	-0.1699	-0.3127	-0.2413
Armandia sp.	-0.3640	-0.1622	-0.1644	-0.2302
Aglaophamus macroura	-0.2406	-0.1870	---	-0.2138
Cominella maculosa	-0.2066	---	---	-0.2066
Diopatra sp.	---	-0.2063	---	-0.2063

Table A3.2. Correlations of individual taxa with canonical axes for effects of Season, within each depositional environment. Taxa with positive correlations should have greater abundance and/or frequency in Late Summer, while those with negative correlations should have greater abundance and/or frequency in Winter/Spring or Spring/Summer. Dashes indicate the taxon did not occur in that depositional environment.

Taxon	High	Medium	Low	Average
Positive correlation (LS):				
Armandia sp.	0.3248	0.5223	0.5700	0.4724
Oligochaetes	0.3204	0.5735	0.2964	0.3968
Psuedopolydora spp.	0.4852	0.1574	0.5167	0.3864
Colorustylis lemurum	0.2005	0.3620	0.5463	0.3696
Teleosts	0.3574	---	---	0.3574
Capitella sp.	0.2885	---	0.4075	0.3480
Other Cirratulidae	0.2516	---	---	0.2516
Sabellid sp.	0.2334	---	---	0.2334
Other Spionids	0.0822	0.0428	0.5673	0.2308
Boccardia spp.	0.5079	-0.0901	0.2605	0.2261
Pagurus sp.	---	---	0.2099	0.2099
Notomastus sp.	0.2091	0.1840	0.2309	0.2080
Cominella maculosa	---	0.1864	0.2187	0.2026
Negative correlation (W/S, S/S):				
Helice/Macrophthalmus complex	-0.7912	-0.5230	-0.4188	-0.5777
Corbula zelandica	---	---	-0.3924	-0.3924
Timarete anchylochaeta	-0.3566	---	---	-0.3566
Other Orbinids	-0.3591	-0.4962	-0.1705	-0.3419
Crab zoea	-0.4225	-0.3542	-0.2352	-0.3373
Magelona dakini	-0.2973	-0.2570	-0.4061	-0.3201
Other Anthozoa	---	-0.1703	-0.4539	-0.3121
Nemerteans	-0.2928	-0.3234	-0.2076	-0.2746
Aonides spp.	-0.5529	-0.1082	-0.0903	-0.2505
Orbinia papillosa	-0.4656	-0.4236	0.1486	-0.2469
Pectinarids	-0.5898	-0.2235	0.0849	-0.2428
Cominella glandiformis	-0.3494	-0.1577	-0.1693	-0.2255
Glycera lamellipoda	-0.5481	-0.1838	0.0654	-0.2222
Hemigrapsus crenualtus	-0.3202	-0.0909	-0.2282	-0.2131
Paracorophium	-0.1940	-0.2182	-0.2259	-0.2127

Table A3.3. Correlations of individual taxa with canonical axes for effects of Precipitation, within each Season. Late Summer is not included, as there were no effects of precipiation during that Season. Taxa with positive correlations should have greater abundance and/or frequency after Rain, while those with negative correlations should have greater abundance and/or frequency after a Dry period. Dashes indicate the taxon did not occur in that season.

Taxon	Winter/ Spring	Spring/ Summer	Average
Positive correlation (Rain):			
Other Opistobranchs	---	0.3916	0.3916
Orbinia papillosa	0.6466	0.0082	0.3274
Unidentified Crustaceans	-0.1022	0.6230	0.2604
Pinnotheres sp.	---	0.2381	0.2381
Negative correlation (Dry):			
Oligochaetes	-0.5167	-0.6647	-0.5907
Copepoda	---	-0.5639	-0.5639
Nemerteans	-0.5328	-0.4266	-0.4797
Paracorophium	-0.3266	-0.4455	-0.3861
Cirolana sp.	---	-0.3341	-0.3341
Prionospio complex	-0.2698	-0.3265	-0.2982
Notomastus sp.	-0.5516	0.0067	-0.2725
Other Orbinids	-0.3555	-0.1555	-0.2555
Exogoninae	-0.0905	-0.3969	-0.2437
Aglaophamus macroura	---	-0.2240	-0.2240
Crab zoea	-0.2691	-0.1642	-0.2167
Aricidea sp.	---	-0.2087	-0.2087

Appendix 4. Results of Chi-squared Analyses of Frequencies of Occurrences

Table A4.1: Results of chi-squared analyses on frequencies of occurrences in different depositional environments. Frequencies within each deposition are from a possible 180 cores (6 in each of 5 sites for 6 sampling occasions). NE = not estimated due to expected counts less than 4.

		Depositional Probability			
Taxon	**Group**	**High**	**Med**	**Low**	***P***
Cossura coasta	Cossuridae	42	41	38	0.8981
Nereid/Nicon complex	Nereidae	58	43	48	0.3090
Paphies australis	Bivalvia	59	55	49	0.6273
Colorustylis lemurum	Cumacea	70	48	87	**0.0037**
Other Glycerids	Glyceridae	59	74	58	0.2831
Prionospio complex	Spionidae	149	142	145	0.9186
Glycera lamellipoda	Glyceridae	73	52	51	0.0720
Helice/macrohpthalmus complex	Decapoda	95	70	33	**0.0000**
Oligochaetes	Oligochaeta	11	32	43	**0.0001**
Elminius modestus	Cirripedia	83	84	82	0.9880
Aonides spp.	Spionidae	104	95	78	0.1514
Notoacmea helmsii	Gastropoda	74	76	64	0.5602
Other Syllids	Syllidae	10	11	5	0.3035
Crab zoea	Decapoda	22	7	1	**0.0000**
Anthopleura spp.	Anthozoa	85	98	102	0.4354
Polydora spp.	Spionidae	31	8	12	**0.0001**
Waitangi sp.	Amphipod	16	11	8	0.2466
Parakalliope sp.	Amphipod	52	31	57	**0.0169**
Macomona liliana	Bivalvia	137	129	126	0.7808
Pectinarids	Pectinariidae	42	29	10	**0.0001**
Scoloplos cylindifer	Orbiniidae	62	69	42	**0.0332**
Aglaophamus macroura	Nephtyidae	0	3	4	NE
Other Spionids	Spionidae	3	5	12	**0.0351**
Psuedosphaeroma sp.	Isopoda	25	27	22	0.7736
Halicarcinus spp.	Decapoda	36	21	41	**0.0363**
Other Amphipods	Amphipoda	26	16	17	0.2139
Magelona dakini	Magelonidae	14	2	1	**0.0001**
Sypharochiton pelliserpentis	Gastropoda	25	32	25	0.5502
Other Orbinids	Orbiniidae	17	8	3	**0.0045**
Psuedopolydora sp.	Spionidae	45	16	72	**0.0000**
Boccardia spp.	Spionidae	42	31	69	**0.0003**
Insect larvae	Insecta	0	2	1	NE
Timarete anchylochaeta	Cirratulidae	9	9	4	0.3210
Unidentified Crustaceans	Crustacea	11	19	8	0.0779

Table A4.2: Results of chi-squared analyses on frequencies of occurrences for different Seasons Frequencies within each season are from a possible 180 cores (6 in each of 15 sites for 2 sampling occasions). NE = not estimated due to expected counts less than 4.

		Season			
Taxon	**Group**	**W/S**	**S/S**	**LS**	***P***
Paphies australis	Bivalvia	59	55	49	0.6273
Prionospio complex	Spionidae	149	142	145	0.9186
Anthopleura spp.	Anthozoa	85	98	102	0.4354
Other Syllids	Syllidae	10	11	5	0.3035
Parakalliope sp.	Amphipod	52	31	57	**0.0169**
Helice/Macrophthalmus complex	Decapoda	95	70	33	**0.0000**
Waitangi sp.	Amphipod	16	11	8	0.2466
Notoacmea helmsii	Gastropoda	74	76	64	0.5602
Halicarcinus spp.	Decapoda	36	21	41	**0.0363**
Exogoninae	Syllidae	13	12	26	**0.0276**
Scoloplos cylindifer	Orbiniidae	62	69	42	**0.0332**
Glycera lamellipoda	Glyceridae	73	52	51	0.0720
Elminius modestus	Cirripedia	83	84	82	0.9880
Other Orbinids	Orbiniidae	17	8	3	**0.0045**
Aglaophamus macroura	Nephtyidae	0	3	4	NE
Boccardia spp.	Spionidae	42	31	69	**0.0003**
Psuedopolydora spp.	Spionidae	45	16	72	**0.0000**
Aricidea sp.	Paraonidae	0	11	9	**0.0058**
Other Anthozoa	Anthozoa	6	1	0	**0.0119**
Sypharochiton pelliserpentis	Gastropoda	25	32	25	0.5502
Polydora spp.	Spionidae	31	8	12	**0.0001**
Magelona dakini	Maldanidae	14	2	1	**0.0001**
Phoxocephalid sp.	Amphipod	99	71	64	**0.0123**
Other Spionids	Spionidae	3	5	12	**0.0351**
Colorustylis lemurum	Cumacea	70	48	87	**0.0037**
Macroclymenella stewartensis	Maldanidae	23	37	32	0.1937
Unidentified Crustaceans	Crustacea	11	19	8	0.0779
Sipunculid	Sipuncula	7	5	2	0.2574

Table A4.3: Results of chi-squared analyses on frequencies of occurrences for Precipitation. Frequencies within each level of precipitation are from a possible 270 cores (6 in each of 15 sites for 6 sampling occasions). NE = not estimated due to expected counts less than 4.

Taxon	Group	Rain	Dry	*P*
Oligochaetes	Oligochaeta	40	46	0.5176
Prionospio complex	Spionidae	214	222	0.7016
Other Glycerids	Glyceridae	100	91	0.5149
Elminius modestus	Cirripedia	118	131	0.4100
Colorustylis lemurum	Cumacea	85	120	**0.0145**
Phoxocephalid sp.	Amphipod	112	122	0.5133
Unidentified Crustaceans	Crustacea	29	9	**0.0012**
Helice/Macrophthalmus complex	Decapoda	108	90	0.2008
Crab zoea	Decapoda	17	13	0.4652
Glycera lamellipoda	Glyceridae	81	95	0.2913
Orbinia papillosa	Orbiniidae	39	45	0.5127
Waitangi sp.	Amphipod	24	11	**0.0280**
Paphies australis	Bivalvia	74	89	0.2400
Macroclymenella stewartensis	Maldanidae	45	47	0.8348
Boccardia sp.	Spionidae	70	72	0.8667
Scoloplos cylindifer	Orbiniidae	93	80	0.3230
Exogoninae	Syllidae	17	34	**0.0173**
Paracorophium sp.	Crustacean	7	8	0.7963
Parakalliope sp.	Amphipod	61	79	0.1282
Other Syllids	Syllidae	12	14	0.6949
Cossura coasta	Cossuridae	63	58	0.6494
Other Amphipods	Amphipoda	33	26	0.3621
Aglaophamus macroura	Nephtyidae	3	4	NE
Psuedopolydora spp.	Spionidae	66	67	0.9309
Arthritica bifurcata	Bivalvia	8	1	**0.0196**
Aonides spp.	Spionidae	137	140	0.8570
Travisia sp.	Opheliidae	3	0	NE
Copepoda	Copepoda	2	8	**0.0578**
Cominella glandiformis	Gastropoda	0	1	NE
Hemigrapsus crenualtus	Decapoda	9	1	**0.0114**
Haminoea zelandiae	Opisthobranchia	6	5	0.7630
Anthopleura spp.	Anthozoa	140	145	0.7671
Polydora spp.	Spionidae	25	26	0.8886
Platyhelminth	Platyhelminth	0	2	NE
Macomona liliana	Bivalvia	202	190	0.5445
Sypharochiton pelliserpentis	Gastropoda	47	35	0.1851
Sipunculid	Sipuncula	5	9	0.2850

Table A4.4 Results of chi-squared analyses on frequencies of occurrences of different size classes of bivalves in each Depositional environment. Frequencies within each deposition are from a possible 180 cores (6 in each of 5 sites for 6 sampling occasions).

Taxa and size class	High	Medium	Low	*P*
Macomona liliana < 4 mm	47	32	46	0.1866
Macomona liliana 4-15 mm	63	56	73	**0.0004**
Macomona liliana > 15 mm	72	124	118	0.3196
Paphies australis < 4 mm	5	18	10	**0.0201**
Paphies australis 4-15 mm	7	82	38	**0.0000**
Paphies australis > 15 mm	2	63	34	**0.0000**

Appendix 5. Data Summaries

Table A5.1. The total number of organisms of each individual taxon recorded over the entire study in each depositional environment (listed in decreasing order of total numerical abundance).

		Depositional Envronment		
Taxon	**Group**	**High**	**Med**	**Low**
Austrovenus stutchburyi	Bivalvia	722	4492	4043
Prionospio complex	Spionidae	2138	2051	3114
Notomastus sp.	Capitellidae	3672	858	1432
Nucula hartvigiana	Bivalvia	592	1547	1839
Aonides spp.	Spionidae	53	1271	2289
Elminius modestus	Cirripedia	12	926	1732
Anthopleura spp.	Anthozoa	18	1207	858
Paphies australis	Bivalvia	16	1093	275
Macomona liliana	Bivalvia	367	374	461
Notoacmea helmsii	Gastropoda	13	353	579
Phoxocephalid sp.	Amphipod	144	435	306
Colorustylis lemurum	Cumacea	14	390	462
Cossura coasta	Cossuridae	849	3	4
Nemerteans	Nemertea	278	271	263
Scoloplos cylindifer	Orbiniidae	245	79	460
Parakalliope sp.	Amphipod	35	470	94
Helice/Macrophthalmus complex	Decapoda	283	51	108
Psuedopolydora spp.	Spionidae	265	94	46
Other Glycerids	Glyceridae	225	48	92
Glycera lamellipoda	Glyceridae	169	43	89
Boccardia spp.	Spionidae	174	69	50
Oligochaetes	Oligochaeta	162	49	53
Nereid/Nicon complex	Nereidae	199	10	35
Pectinarids.	Pectinariidae	187	12	30
Exogoninae	Syllidae	6	23	128
Orbinia papillosa	Orbiniidae	29	34	76
Macroclymenella stewartensis	Maldanidae	33	65	31
Halicarcinus sp.	Decapoda	9	61	51
Sypharochiton pelliserpentis	Gastropoda	0	49	67
Psuedosphaeroma sp.	Isopoda	17	44	46
Waitangi sp.	Amphipod	3	80	10
Other Amphipods	Amphipoda	30	39	20
Polydora spp.	Spionidae	51	15	19
Timarete anchylochaeta	Cirratulidae	55	0	0
Other Syllids	Syllidae	0	52	3
Armandia sp.	Opheliidae	2	18	26
Unidentified Crustaceans	Crustacea	26	12	7
Cominella glandiformis	Gastropoda	3	24	17
Other Orbinids	Orbiniidae	14	16	13
Crab zoea	Decapoda	21	5	6
Paracorophium sp.	Crustacean	11	1	13

Aricidea sp.	Paraonidae	6	16	3
Other Spionids	Spionidae	2	18	4
Sipunculid	Sipuncula	0	21	2
Diloma subrostratum	Gastropoda	0	8	14
Magelona dakini	Magelonidae	3	13	2
Hemigrapsus crenualtus	Decapoda	5	5	5
Arthritica bifurcata	Bivalvia	10	1	3
Other Isopods	Isopoda	0	13	0
Haminoea zelandiae	Opisthobranchia	2	5	4
Copepoda	Copepoda	8	2	0
Leptostracan	Leptostracan	6	0	3
Other Anthozoa	Anthozoa	0	5	3
Ostracods	Ostracoda	4	3	0
Aglaophamus macroura	Nephtyidae	0	3	4
Corbula zelandica	Bivalvia	0	5	0
Cirolana sp.	Isopoda	1	2	0
Insect larvae	Insecta	1	0	2
Platyhelminth	Platyhelminth	2	0	1
Capitella sp.	Capitellidae	1	2	0
Diopatra sp.	Eunicea	0	2	1
Travisia sp.	Opheliidae	1	1	1
Teleosts	Teleosts	3	0	0
Pinnotheres sp.	Decapoda	0	2	0
Cominella maculosa	Gastropoda	0	1	1
Other Opistobranchs	Opisthobranchia	1	0	1
Other Cirratulidae	Cirratulidae	2	0	0
Pagurus sp.	Decapoda	0	1	0
Cominella adspersa	Gastropoda	0	0	1
Turbo smaragdus	Gastropoda	0	0	1
Glycera americana	Glyceridae	0	0	1
Owenia fusiformis	Oweniidae	0	0	1
Sabellid sp.	Sabellidae	1	0	0

Table A5.2. Total number of organisms of each individual taxon recorded over the entire study in each time of sampling (listed in decreasing order of numerical abundance).

Taxon	Group	W/S Dry Sep 01	W/S Rain Oct 01	S/S Dry Nov 01	S/S Rain Dec 01	LS Dry Feb 02	LS Rain Mar 02
Austrovenus stutchburyi	Bivalvia	1357	1664	1520	1608	1426	1717
Prionospio complex	Spionidae	1005	801	680	1521	1692	1657
Notomastus sp.	Capitellidae	1164	587	748	1236	1371	879
Nucula hartvigiana	Bivalvia	686	475	727	725	750	638
Aonides spp.	Spionidae	730	518	631	551	663	521
Elminius modestus	Cirripedia	345	636	382	599	362	359
Anthopleura spp.	Anthozoa	300	262	350	361	379	441
Paphies australis	Bivalvia	152	193	155	215	409	260
Macomona liliana	Bivalvia	198	223	219	181	216	172
Notoacmea helmsii	Gastropoda	186	169	204	208	83	99
Phoxocephalid sp.	Amphipod	209	231	94	154	120	77
Colorustylis lemurum	Cumacea	130	86	16	97	330	210
Cossura coasta	Cossuridae	169	110	123	154	147	153
Nemerteans	Nemertea	229	113	114	168	118	72
Scoloplos cylindifer	Orbiniidae	246	108	121	115	87	109
Parakalliope sp.	Amphipod	72	187	24	51	143	122
Helice/Macrophthalmus complex	Decapoda	148	138	69	47	27	13
Psuedopolydora spp.	Spionidae	42	32	11	8	206	106
Other Glycerids	Glyceridae	75	59	58	84	55	35
Glycera lamellipoda	Glyceridae	70	83	31	54	33	30
Boccardia spp.	Spionidae	34	50	25	18	110	56
Oligochaetes	Oligochaeta	33	1	8	111	56	56
Nereid/Nicon complex	Nereidae	49	48	32	33	33	49
Pectinarids.	Pectinariidae	56	112	33	16	6	6

Exogoninae	Syllidae	13	17	1	29	52	52
Orbinia papillosa	Orbiniidae	24	57	18	12	18	10
Macroclymenella stewartensis	Maldanidae	15	17	30	25	23	19
Halicarcinus sp.	Decapoda	31	18	14	16	23	21
Sypharochiton pelliserpentis	Gastropoda	15	20	28	17	22	16
Psuedosphaeroma sp.	Isopoda	25	25	19	14	14	12
Waitangi sp.	Amphipod	47	11	7	13	5	10
Other Amphipods	Amphipoda	33	13	11	9	6	17
Polydora spp.	Spionidae	25	25	7	2	17	9
Timarete anchylochaeta	Cirratulidae	16	19	8	8	4	0
Other Syllids	Syllidae	7	15	7	15	4	7
Armandia sp.	Opheliidae	0	2	2	0	15	27
Unidentified Crustaceans	Crustacea	6	5	23	1	7	3
Cominella glandiformis	Gastropoda	8	9	8	13	2	5
Other Orbinids	Orbiniidae	21	7	4	6	3	2
Crab zoea	Decapoda	16	8	3	4	0	1
Paracorophium sp.	Crustacean	8	2	0	13	1	1
Aricidea sp.	Paraonidae	0	0	5	7	13	0
Other Spionids	Spionidae	1	2	0	5	10	6
Sipunculid	Sipuncula	3	5	1	11	2	1
Diloma subrostratum	Gastropoda	9	6	0	2	4	1
Magelona dakini	Magelonidae	3	12	0	2	0	1
Hemigrapsus crenualtus	Decapoda	12	1	1	0	1	0
Arthritica bifurcata	Bivalvia	0	0	13	0	0	1
Other Isopods	Isopoda	1	0	0	0	0	12
Haminoea zelandiae	Opisthobranchia	5	1	0	1	1	3
Copepoda	Copepoda	0	0	0	5	2	3
Leptostracan	Leptostracan	4	0	0	0	0	5
Other Anthozoa	Anthozoa	3	3	2	0	0	0
Ostracods	Ostracoda	1	0	1	1	3	1

Aglaophamus macroura	Nephtyidae	0	0	0	3	3	1
Corbula zelandica	Bivalvia	2	2	0	1	0	0
Cirolana sp.	Isopoda	0	0	0	1	2	0
Insect larvae	Insecta	0	0	1	1	0	1
Platyhelminth	Platyhelminth	0	0	0	3	0	0
Capitella sp.	Capitellidae	0	0	0	0	0	3
Diopatra sp.	Eunicea	0	0	1	2	0	0
Travisia sp.	Opheliidae	0	0	2	0	1	0
Teleosts	Teleosts	0	0	0	0	0	3
Pinnotheres sp.	Decapoda	0	0	0	2	0	0
Cominella maculosa	Gastropoda	0	0	0	0	1	1
Other Opistobranchs	Opisthobranchia	0	0	1	0	0	1
Other Cirratulidae	Cirratulidae	0	0	0	0	0	2
Pagurus sp.	Decapoda	0	0	0	0	1	0
Cominella adspersa	Gastropoda	0	0	0	0	0	1
Turbo smaragdus	Gastropoda	0	0	0	1	0	0
Glycera americana	Glyceridae	0	0	0	0	0	1
Owenia fusiformis	Oweniidae	0	0	1	0	0	0
Sabellid sp.	Sabellidae	0	0	0	0	1	0