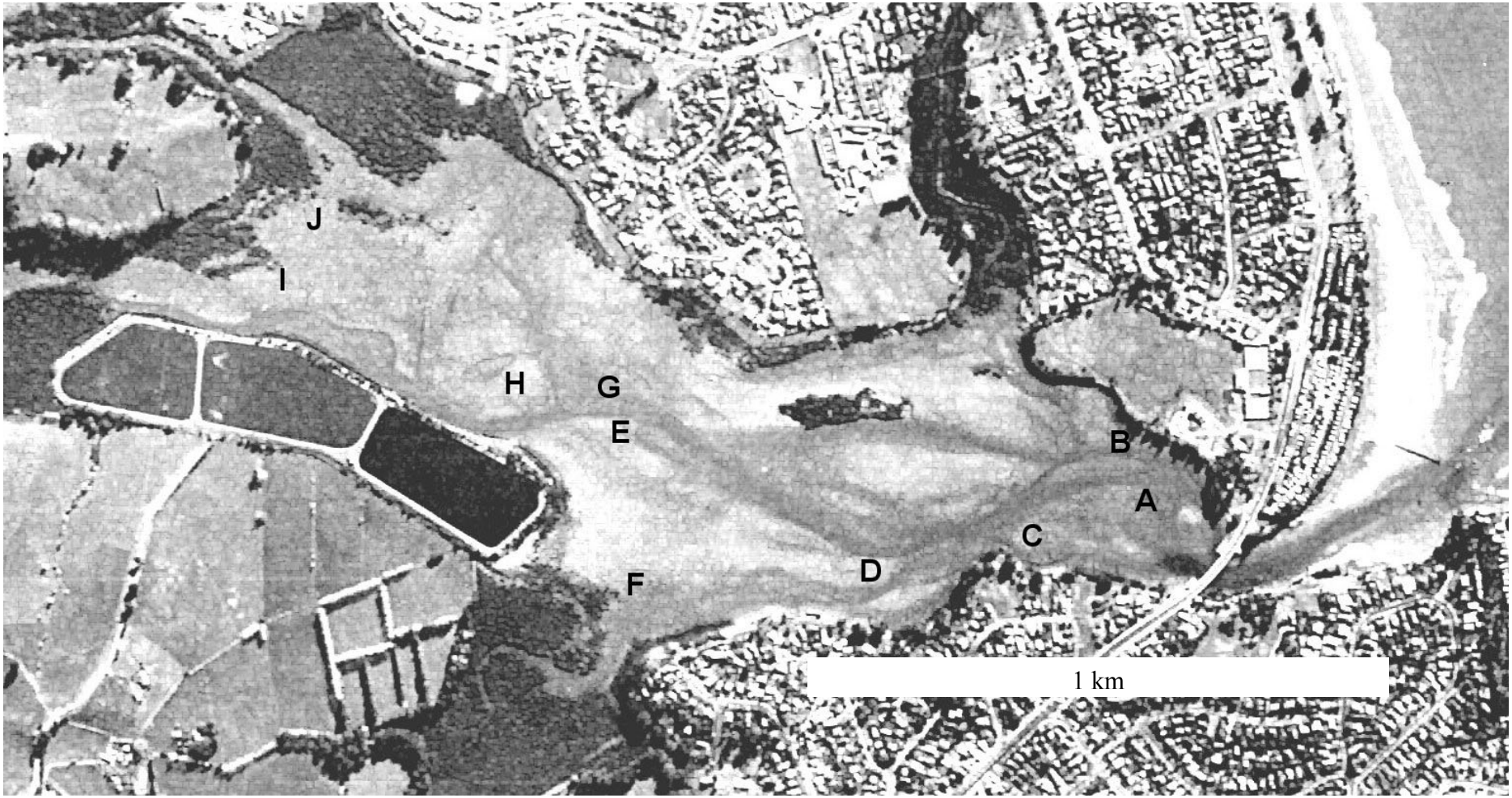

Fig. 5. Map of sampling sites within the Orewa estuary. Sites are labeled alphabetically and sequentially from the estuary mouth (A) to the inner reaches of the estuary (J). The spatial extent of a site (50m x25m) is approximately as tall as each letter and twice as wide

Fig. 6. Map of sampling sites within the Maunagamaungaroa estuary. Sites are labeled alphabetically and sequentially from the estuary mouth (A) to the inner reaches of the estuary (J). The spatial extent of a site (50m x25m) is approximately as tall as each letter and twice as wide.

2.1.b. Timing of Sampling

Sampling occurred within 2 discrete 3-month blocks (hereafter referred to as seasons): August - October 2002 (Winter/Spring (W/S) and February - April 2003 (Late Summer (LS)). The Spring/Summer (S/S) season was eliminated from the previous design due to difficulties in processing all the samples collected. This season was chosen to be eliminated because recent research indicates that only two seasons may be applicable for northern New Zealand marine soft-sediment benthic infauna: (i) a recruitment period when juveniles are present in high numbers (January to July), and (ii) a mature period when communities do not have high numbers of juveniles (August to December) (J. Hewitt, pers. comm.). The Spring/Summer (S/S) season was deleted from the design as it spanned the recruitment and mature periods, while the other two seasons fell clearly into either the mature (W/S) or recruitment (LS) periods. Within each season, sampling was event-driven and occurred twice: (i) once 7-10 days after a rainfall event, defined as ≥ 15mm of rainfall in a 24-hour period ('Rain') and (ii) once when such a rainfall event had not occurred in ≥ 10 days ('Dry'). Examination of seventeen years of data from the Leigh Marine Laboratory meteorological records showed that a rainfall event of 15 mm was an event that could be reliably expected to occur at least twice in every season. Rainfall was gauged from the Glenfield weather station, which is a site central to all estuaries. Data from the weather station was available from the following website: http://homepages.paradise.net.nz/tmcgavin/current_nzweather.html. All estuaries were sampled within a period of 7 days at each of the four times of sampling (Table 1).

Table 1. Sampling dates for 2002-2003.

Sampling Period	Estuary	'Rain' Sampling	'Dry' Sampling
Winter/Spring 2002	Waiwera	27th Oct 2002	23rd Aug 2002
	Puhoi	26th Oct 2002	19th Aug 2002
	Orewa	23rd Oct 2002	21st Aug 2002
	Okura	25th Oct 2002	20th Aug 2002
	Maunagamaungaora	24th Oct 2002	22nd Aug 2002
Late Summer 2003	Waiwera	11th March 2003	17th April 2003
	Puhoi	12th March 2003	14th April 2003
	Orewa	13th March 2003	11th April 2003
	Okura	14th March 2003	15th April 2003
	Maunagamaungaora	15th March 2003	16th April 2003

2.1.c. Field Sampling of Fauna

At each site the corner closest to the channel of an area measuring 50 m parallel to the shore (the x-axis) and 25 m perpendicular to the shore (the y-axis) was marked with a permanent flag. There were $n = 5$ cores obtained from random positions within each area by choosing a random number between 0 and 49 and between 0 and 24 for the x and y-axes, respectively. Cores were circular in shape, measuring 130 mm in diameter and 15 cm deep. Each core was sieved in the field using 0.5 mm mesh. Material retained on the sieve was brought back

to the laboratory for sorting and taxonomic identification. All organisms retained were preserved in 10% formalin with 0.01% rose bengal and later transferred to 70% ethanol.

Where possible, organisms were identified to the species level. Some specimens were unable to be unambiguously identified, and are grouped together. All organisms were identified to the lowest level of taxonomic resolution possible. This varied, depending on the particular group. For example, Oligochaete worms were grouped together, while Bivalves were identified to species. Some Polychaetes could be identified to species level, while others could only be identified to the genus or family level (see Appendix B).

2.1.d. Field Sampling of Environmental Variables

One core (38 mm diameter x 15 cm deep) was obtained to sample ambient grain sizes of sediments adjacent to each faunal core. Samples were analysed from the first and last sampling times only (August 2002 and April 2003). This was because grain size fractions are unlikely to change quickly (Ford *et al.* 2003) and sample processing was expensive. Samples were sub-sampled to obtain a representative known weight of dry material (~50 g). Subsamples were then deflocculated for at least 12 hours and wet sieved on a stack of sieves (500, 250, 125 and 63μm) and each fraction (>500, 250-499, 125-249, 63-124 and <63μm) was dried, weighed and calculated as a percentage of the total weight. The fraction less than 63 μm was calculated by subtraction of all other dry weights from the initial dry weight due to the inherent difficulties in settling and drying these fine sediments.

2.1.e. Measurement of Sedimentation and Rainfall

Sedimentation was characterised at each site by a combination of a sediment trap and a depth of disturbance rod. A sediment trap (36 mm diameter by 50 cm deep) was placed at the lowest point of each site so that the opening was 20-25 cm above the sediment surface. These traps collected sediment settling from the water column. Depths of disturbance rods (Clifton 1969, Greenwood and Hale 1980) were adapted from previous designs (Anderson *et al.* 2002) due to safety concerns and problems of sample reclamation. Marker poles with sediment traps attached were used to gauge relative change in the height of the bed. Measurements were taken between the top of the sediment trap holder and the ambient sediment surface at least once a month. The height of the top of the sediment trap holder above the sediment surface measured the net erosion or accretion at a site. Due to scour at the base of the marker poles the height of the top of the holder was estimated in relation to the ambient bed height at the pole independent of any scouring using a ruler.

Sediment traps were deployed at each site in the field for a period of approximately one month at a time, such that a continuous record was gained from July 24, 2002 (except for sediment traps lost). At deployment and collection, measurements were also taken of the depth of disturbance rods. Sediment at certain sites occasionally accumulated to a depth of greater than 35 cm within the tube. This compromised the preferable aspect ratio of the

sediment traps (5:1), therefore resuspension may have occurred (White 1990). These large measurements of sediment deposition (as seen for sites PA, RC and WC, see Results section, Fig. 8) are therefore acknowledged as being conservative estimates of sediment deposition. Sediment collected from traps was filtered (mesh size ~ 2 μm), dried and weighed. These sediments were then sub-sampled, deflocculated and wet-sieved as for ambient sediments to characterize their grain-size fractions (see section 2.1.d.).

Table 2 contains a summary of all the environmental variables measured and used in subsequent analyses and models.

Table 2. List and description of environmental variables used in analyses.

Group	Variable Name (abbreviation)	Description
Ambient Grain Size (AmbGS)	GS1 – GS5	Five variables expressing the average percentage of grain sizes of ambient sediments falling into particular size classes:
	GS1	< 62.5 microns
	GS2	62.5 - 124.9 microns
	GS3	125 - 249.9 microns
	GS4	250 - 499.9 microns
	GS5	> 499.9 microns
Ambient standard deviation in Grain Size (AmbsdGS)	sdGS1 – sdGS5	Five variables expressing the standard deviation in percentage of grain sizes of ambient sediments falling into particular size classes:
	sdGS1	< 62.5 microns
	sdGS2	62.5 - 124.9 microns
	sdGS3	125 - 249.9 microns
	sdGS4	250 - 499.9 microns
	sdGS5	> 499.9 microns
Trapped Total (TrapTot)	Avdep	Average total sediment deposition obtained in traps ($g.cm^{-2}.day^{-1}$)
	sddep	Standard deviation in total sediment deposition obtained in traps ($g.cm^{-2}.day^{-1}$)
	Avfin	The average weight of trapped sediments < 62.5 microns (g)
Trapped Grain Size (TGS)	TGS1 – TGS5	Five variables expressing the average percentage of grain sizes of trapped sediments falling into particular size classes:
	TGS1	< 62.5 microns
	TGS3	125 - 249.9 microns
	TGS4	250 - 499.9 microns
	TGS5	> 499.9 microns
Trapped standard deviation in Grain Size (AmbsdGS)	sdTGS1 – sdTGS5	Five variables expressing the standard deviation in percentage of grain sizes of trapped sediments falling into particular size classes:
	sdTGS1	< 62.5 microns
	sdTGS2	62.5 - 124.9 microns
	sdTGS3	125 - 249.9 microns
	sdTGS4	250 - 499.9 microns
	sdTGS5	> 499.9 microns
Distance (D)	D	Rank distance of site from the mouth of the estuary (1-10)
	D2	Rank distance squared (D^2)
Erosion	BH	Average change in bed height (erosion/accretion) ($cm.day^{-1}$)
	sdBH	Standard deviation of change in bed height ($cm.day^{-1}$)

2.2. Statistical Analyses

2.2.a. Large-scale spatial patterns: Characterization of sites

When sampling began in Okura estuary, there were existing hydrodynamic models of the estuary and surrounding catchment. No such models were available for the other estuaries included in this investigation. As such, it was necessary to attempt to characterize the sites we sampled in terms of (a) the environmental data and (b) the biological data collected. To characterize the sites, we used hierarchical agglomerative group-average clustering (UPGMA) (e.g. Legendre and Legendre 1998). This method was chosen because of its relative robustness in identifying genuine clusters, as shown by simulation studies (Belbin and McDonald 1993, Milligan 1996). In addition to the agglomerative method, a divisive method of finding groups was also used, called k-means partitioning (MacQueen 1967, Legendre and Legendre 1998). This method requires the user to specify the number of groups to be identified *a priori*. The method then partitions the individual observations into the specified number of groups in such a way as to minimize the sum of squared Euclidean distances from observations to their group centroid. In our case, for each of the environmental and biological data sets (analysed separately), we chose to find the best partition into three groups, based on patterns seen in the UPGMA dendrograms.

To visualize patterns, non-metric multi-dimensional scaling (MDS, Kruskal and Wish 1978) was used as a robust ordination method (e.g. Clarke 1993). Labels were superimposed on the MDS plots to identify (i) the specific estuary and site and then (ii) the groupings obtained from k-means partitioning. This was helpful to assess whether clusters of sites identified by k-means were indeed clearly separated or identifiable in ordination space. To identify the individual taxa that characterized particular faunal groups, the SIMPER routine ("similarity percentages", Clarke 1993) was used.

All multivariate analyses of environmental data (alone) were done on the basis of Euclidean distances. Environmental data were pooled at the site level through time because not all variables were measured at each time. Data were then standardized to *z*-scores (i.e. each variable was transformed by subtracting its mean and dividing by its standard deviation, also called normalisation), to put all variables on the same scale of importance. In addition, plots (boxplots and plots of means and standard errors) of several individual environmental variables were made for all sites for all estuaries. This was particularly useful to determine the nature of the variation in these variables at other estuaries compared to the values observed for sites at Okura.

Multivariate analyses of spatial patterns (cluster analyses, non-metric MDS plots and k-means partitioning) were done separately for each time of sampling for the biological data. All of these analyses were done on the basis of the Bray-Curtis dissimilarity measure calculated between every pair of sites using $\ln(y + 1)$ transformed species abundances. This put species variables onto a similar scale and ensured that communities were distinguished largely on

compositional differences (Clarke 1993). To achieve a k-means partitioning based on a non-Euclidan distance measure (namely, Bray-Curtis), principal coordinates were used (e.g. Anderson and Clements 2000).

To further assist in the spatial classification of sites, a two-factor non-parametric multivariate analysis of variance (NPMANOVA, Anderson 2001a) was done, based on Bray-Curtis dissimilarities of ln(y + 1) transformed species abundances, with the factors Estuary (5 levels, fixed) and Distance class (10 levels: A-J, fixed). These tests and appropriate pair-wise comparisons, as required (see results), were done using 4999 permutations of the raw data (Anderson 2001b).

2.2.b. Relationships of fauna with environmental variables

Direct models of the faunal data versus the environmental data were constructed using non-parametric multivariate multiple regression (McArdle and Anderson 2001). These were obtained by forward selection of (i) individual environmental variables and (ii) logical sets of environmental variables, as outlined in Table 2 above. Analyses were based on the Bray-Curtis dissimilarity matrix calculated from ln(y + 1) transformed species abundances. P-values were obtained using 4999 permutations of raw data (for marginal tests) or permutations of residuals under a reduced model (for sequential tests), as required (Anderson 2001b).

To visualize relationships among variables and to determine which environmental variables might be driving ecological patterns, distance-based redundancy analysis was done. Once again, the Bray-Curtis measure on ln(y + 1) transformed data formed the backbone of the analysis, and correction method 1 for negative eigenvalues was used to obtain principal coordinates before running the RDA (see Legendre and Anderson 1999 for details). The RDA axes are constrained to be a linear combination of the environmental variables that have the strongest possible relationship with patterns of variation in the biological data. The length and direction of arrows in the dbRDA biplot indicates the relative strength and direction of the relationships between individual environmental variables and the RDA axes. Drawing a constrained ordination diagram like this is sometimes referred to as "direct gradient analysis" (ter Braak 1995), as it displays directly the relationship between two sets of variables.

More generally, we would hope that the most important gradients that describe biological changes in a landscape will also be well represented by gradients in the environmental variables working together in concert. This will occur if we have chosen to measure environmental variables that are important to the organisms under investigation.

Another approach to displaying relationships between two sets of multivariate data is called "indirect gradient analysis" (ter Braak 1995). In this case, we consider separate (and unconstrained) ordinations of the environmental data and biological data. We then (after letting each set of data "speak for itself", as it were) attempt to relate the two pictures in

some way. The approach we used here was to 1) obtain a single measure of the most important environmental gradient among all sites in all estuaries as the first principal component from the analysis of the environmental data alone, 2) obtain a map of the most important changes in biological communities, using non-metric MDS on Bray-Curtis dissimilarities of the (transformed) biological data alone and then 3) superimpose the relative values of sites along the first PC from the environmental data onto the MDS plot of the biological communities as "bubbles" (i.e. large values = large bubbles, etc.). If the environmental gradient (as defined by the first PC) is good at determining the ecological structure of biological communities, then we should see obvious patterns of gradation in the bubbles superimposed on the MDS plots.

2.2.c. Estuary-specific effects

Although our approach above was purely to use the environmental data alone to characterize the important spatial influences on the organisms, it is also possible that other environmental factors not measured, which are specific to each estuary, could influence community structure. We can test the extent to which this may be happening by testing the effect of different estuaries on the fauna, given the environmental data that were collected. This was done using non-parametric multivariate analysis of covariance. We first fit the model of the data with the environmental variables and then, given that these were already in the model (as covariables), tested whether adding the factor of "Estuaries" to the model would significantly increase our ability to explain variation in the biological assemblage data. This analysis was based on Bray-Curtis dissimilarities of log-transformed abundances and a *P*-value was obtained using 4999 permutations of residuals under the reduced model.

2.2.d. Temporal patterns across all estuaries

Once three separate groups of sites had been identified (using k-means) on the basis of their biological variables, each of these groups of sites were tested for their variability through time. This was achieved by doing three separate NPMANOVA analyses (one for each group of sites) investigating Season (2 levels: W/S and LS, fixed), Precipitation (2 levels: Rain vs. Dry, fixed) and their interaction. These analyses were based on Bray-Curtis dissimilarities of $\ln(y + 1)$ transformed species abundance data, with *P*-values obtained using 4999 permutations of the raw data. Terms found to be significant were then investigated more fully by doing appropriate pair-wise comparisons and by examining several ordinations to visualize patterns using (a) non-metric MDS (an unconstrained ordination method) and (b) canonical analysis of principal coordinates (CAP, a constrained ordination method, Anderson and Willis 2003, Anderson and Robinson 2003). The constrained ordination method considers patterns in the multivariate data with respect to some a priori hypothesis, whereas the unconstrained method does not use the hypothesis in any way to draw the diagram. A further description of these methods can be found in Appendix 1 of Anderson *et al.* (2002).

Species showing high correlations with the canonical axes from the CAP plots were then examined more explicitly with univariate plots.

2.2.e. Temporal and spatial effects within Okura estuary

The monitoring data for Okura estuary now goes back some three years, with reasonably consistent sampling protocols and consistency in the choice of many of the sites sampled. It was therefore possible to examine a larger balanced sampling design with respect to several factors for the Okura estuary data set alone. The experimental design consisted of the following factors:

Year (2 levels: 2001-2002 and 2002-2003, random)

Season (2 levels: W/S versus LS, fixed)

Precipitation (2 levels: Rain versus dry, fixed)

Deposition (3 levels: High, Medium and Low depositional areas, fixed)

Sites (2 levels, nested within Deposition, random)

n = 5 cores per combination of factors

The full design, including all interaction terms, was analysed using NPMANOVA, based on Bray-Curtis dissimilarities of $\ln(y + 1)$ transformed species abundance data and using 4999 permutations of appropriate units. It was possible to include 44 taxa in the analyses, which were enumerated consistently across all sampling times from the two years of investigation. For such a complex design (5 factors including nested terms and random effects), some care needs to be taken when creating appropriate permutation tests (Anderson and ter Braak 2003). In some cases the number of permutable units was not enough to obtain a reasonable *P*-value using permutations. In these cases, a Monte Carlo sample from the asymptotic permutation distribution was used to obtain an appropriate *P*-value for the term of interest (see Anderson and Robinson 2003 for details).

Terms that were found to be statistically significant by NPMANOVA were examined in greater detail using appropriate multivariate pairwise comparisons and by examining several ordinations (unconstrained MDS plots and constrained CAP plots) to elucidate patterns.

2.2.f. Long-term monitoring of Okura

There have now been effectively 14 separate times of sampling of several sites consistently over a period of 36 months (from April 2000 to April 2003) within the Okura estuary by researchers from the University of Auckland. A further goal of this study is to examine whether recognizable temporal trends are becoming evident now that the time-line of this investigation spans several years. More particularly, we should wish for a monitoring program to be able to detect, as soon as possible, when a particular site may be going "awry" by reference to the natural variability we have observed (i) at other similar sites and (ii) at that site for all previous times. Indeed, one statistical tool that is available to us to investigate this is more generally known in the quality control (engineering) literature as "control charts" (e.g., Shewart 1931, Wald 1947, Wetherill 1975, Montgomery 1996) These charts essentially plot the progress of a particular process through time and "sound an alarm bell" if the measured value of the process goes outside of the bounds of what would be expected given previous observations. For example, one can plot the deviation of a value from its mean or "target" value through time. It should bounce around zero if the system is "in control".

These control chart methods have, traditionally, only been available for univariate time series data that are reasonably "well-behaved" (i.e. "normal"). Recently, Anderson and Thompson (in review) have extended the idea of control charts to allow for monitoring of multivariate species abundance data. More particularly, the criterion they suggested is the dissimilarity (deviation) of a new observation at a site at time t, from the centroid (average) of the previous observations at that site up to and including time $(t - 1)$. If the system is "in control", each new observation for the assemblage should "bounce around" some "target" centroid for that site through time. However, if there is an impact that dramatically alters the assemblage, then we can expect this dissimilarity to be large relative to the values we have seen for it (and for other similar sites) in the past.

Thus, the basic idea is to plot the Bray-Curtis dissimilarity of a site at time t from the centroid of the observations (based on all previous times) and examine if it is large relative to other such values across the spatial array of sites. We can use bootstrapping of the observations through time within a site (under the null hypothesis that the system is "in control") to put a 95% upper confidence bound on this value (Efron and Tibshirani 1993, Davison and Hinkley 1997). For further details, see Anderson and Thompson (in review). This sort of criterion will likely pick up on sudden dramatic changes at a site. However if the changes are more gradual, then a different criterion can be used, such as the distance from the new observation at time t from a centroid based on the first b (baseline) observations in the series. We have found that a baseline of only 1 or 2 observations actually works quite well for picking up gradual trends (Anderson and Thompson, in review).

In the present case, it was possible to generate multivariate control charts for each of 8 different sites (3 from High, 2 from Medium and 3 from Low depositional areas). Sites from different depositional areas were kept separate for these analyses. Although the spatial array

was therefore a bit small, we were still able to generate an upper 95% bootstrap confidence bound by using the replication through time.

Anderson and Thompson (in review) have applied this methodology in the context of monitoring fish assemblages across the entire Great Barrier Reef (47 different reefs). As we anticipate that a wider spatial array of sites throughout the region will be monitored from now onwards, (i.e. those included in the present study), this approach will likely prove to be extremely useful for determining particular instances of future impacts at particular sites.

2.2.g. Computer programs

Non-metric MDS plots, bubble plots, UPGMA dendrograms and SIMPER analyses were obtained using the computer program PRIMER v. 5 (Clarke and Gorley 2001). K-means partitioning was achieved using the program Kmeans.exe written by P. Legendre. Principal coordinates with correction for negative eigenvalues were obtained using the program DistPCoA.exe (written by M. Anderson and P. Legendre). Kmeans.exe and DistPCoA.exe are available from the following website:

http://www.fas.umontreal.ca/BIOL/Casgrain/en/labo/index.html.

Distance-based RDA was done using the MultivEcol computer package (by B. McArdle and M. Anderson) written for use with the R computer language (Ihaka and Gentleman 1996). Non-parametric MANOVA, MANCOVA, multivariate multiple regression and CAP analyses were performed using the programs NPMANOVA.exe, DISTLM.exe, DISTLM-forward.exe and CAP.exe, respectively, written by M. Anderson and available from the following website:

http://www.stat.auckland.ac.nz/people/~mja.

The program Monitor.exe (written by M. Anderson) was used to calculate the dissimilarities required for control charts and to do the bootstrapping to calculate the upper 95% confidence bounds. Univariate plots were generated using SigmaPlot™ 2000, version 6.10.

3. RESULTS

3.1. Large-scale spatial patterns

3.1.a. Characterization of sites based on environmental data

Overall, the environmental parameters measured for Okura fell within the range of values for these parameters that were measured for the four other estuaries included in the study. Thus, the choice of estuaries and sites included in the study did indeed span the range of environmental characteristics found within Okura. As such, these estuaries will provide a proper large-scale regional baseline for understanding any possible environmentally-driven estuary-wide changes in Okura over time.

In general, ambient sediments become finer the greater the distance from the mouth of the estuary (Fig 7, Appendix C), but there were exceptions to this trend in every estuary: e.g., sites WB, ZC, PB, PE, PJ, OB, RF. These exceptions tended to occur where streams enter the estuary and flow near sites, depositing fine sediments (WB, PB, PE, OB, RF) or where the main channel scours the site taking fine sediments away (ZC, PJ). The sites with the finest ambient grain size composition (>40% of sediments <63 μm diameter) were found at Puhoi, Orewa and Maungamaungaroa estuaries. The sites with the coarsest ambient grain size composition (> 40% of sediments > 500 μm diameter) were found at Maungamaungaroa estuary. Okura estuary showed ambient grain sizes of sediments intermediate to these extremes.

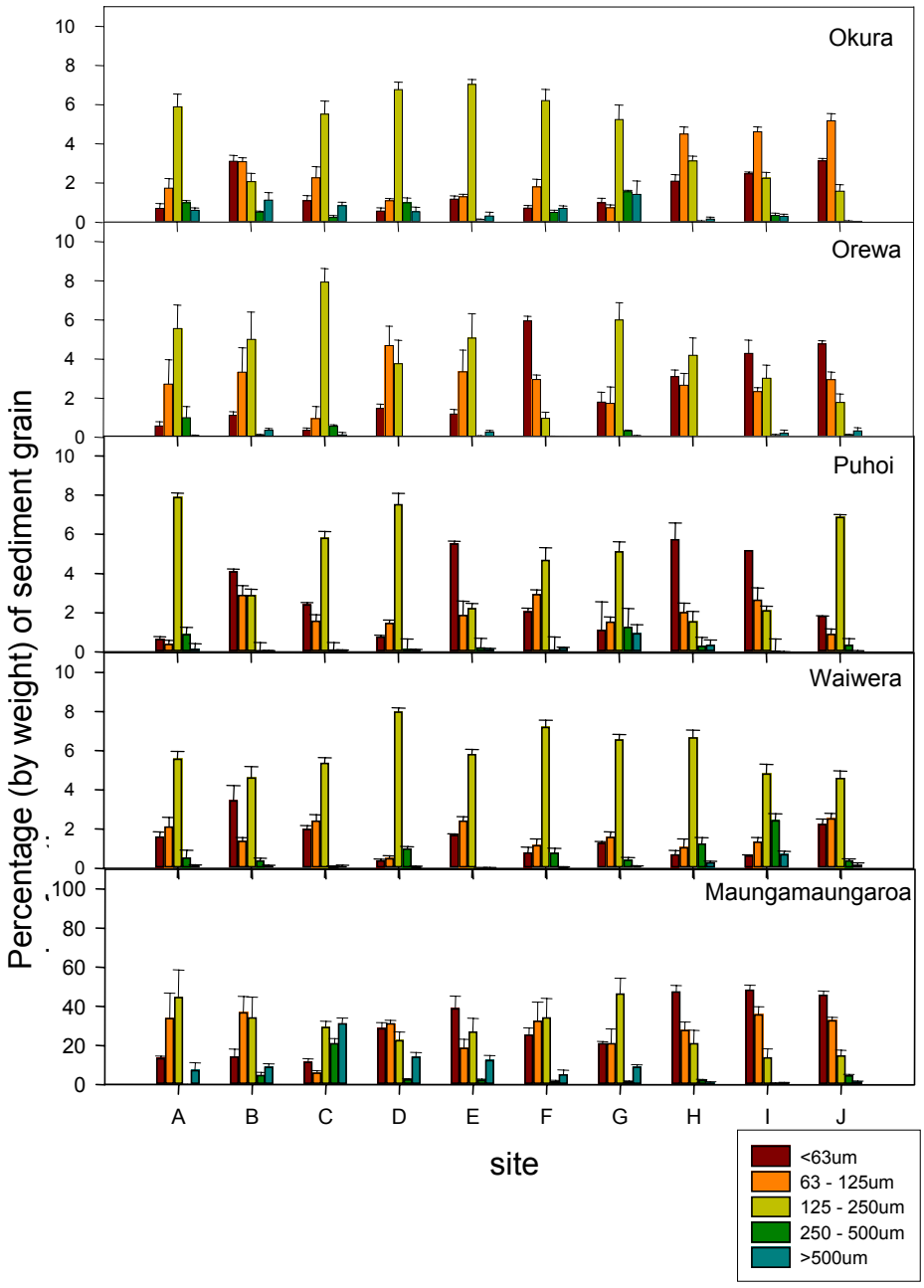

Fig. 7. Mean (+S.E., *n*=6) percentage of ambient sediments of different grain sizes for the August 2002 sampling of all sites in all estuaries.

In all estuaries, median values for bed height change were close to zero, however the variability in bed height change among sites varied by approximately an order of magnitude (0.6 - 6 $mm \cdot day^{-1}$, Fig. 8). All sites in Maungamaungaroa showed low variability and negatively skewed distributions of bed height change, which means that erosive events tended to be of greater magnitude than events of accretion. Bed level variation was greatest at Orewa site C, and least at Maungamaungaroa site B. Sites in Okura estuary showed bed height changes intermediate to these extremes. In addition, changes in bed height were not necessarily correlated with distance from the mouth of the estuary.

Sediment deposition at each site varied by a factor in excess of 100. The median values of sediment deposition at sites ranged from 0.007 to 1.8 $g.cm^{-2}.d^{-1}$ (Fig. 9). Sediment deposition was very spatially variable, with relatively high and low depositional sites often being in close proximity to each other (e.g., see Orewa sites A-D). Sites that showed a large variability in bed height change usually showed high rates of sediment deposition in traps (e.g., Puhoi A and J, Waiwera C, Orewa A and C) although there were exceptions to this trend (Orewa G). Maungamaungaroa showed the least deposition of sediments across the whole estuary compared to other estuaries, whilst Puhoi site B had the lowest median value of sediment deposition and Orewa C the highest. All median values of sediment deposition at sites in Okura were intermediate between these extremes.

The grain size composition of trapped sediments was highly variable (Fig. 10). There was an apparent relationship between the texture of ambient sediment and trapped sediment at each site (cf. Figs. 7 and 10). High correlations were found ($|r| > 0.80$) between the percentage of ambient sediments in the size range 125-250 μm and the percentage of trapped sediments in the size ranges of 63-125 μm and 250-500 μm. The highest average percentage of fine sediments (>80% of sediments <63 μm diameter) in traps was found at site PE and the coarsest sediments (>90 % of sediments >125 μm diameter) were found at site WA. The sediment trapped at Okura estuary was between these two extremes in terms of texture.

Multivariate analyses of environmental characteristics showed no consistent patterns in terms of differences among estuaries or different distances along estuaries. An MDS plot of all sites (Fig. 11) showed the most clumped or "internally similar" estuaries in terms of environmental characteristics were Okura and Maungamaungaroa. In contrast, the most "internally dissimilar" estuary (i.e. having the greatest environmental variation among sites) was Waiwera. The dendrogram of sites (based on hierarchical agglomerative clustering, Fig. 12) suggested that a gradient might perhaps be used to characterize sites across all estuaries in terms of the environmental variables. In addition, we were interested in characterizing sites into separate groups on the basis of environmental characteristics. A three-group model was obtained using the k-means divisive partitioning algorithm. The groups of sites obtained wer shown in Table 3. The three groups were found to be relatively distinct, as shown in the MDS plot (Fig. 11b). Group C had the largest internal variability. Group A was the largest and group C was the smallest group. Sites from Okura estuary and Maungamaungaroa estuary

only occurred in groups A and B, while the other three estuaries had at least one site in each group (A, B and C).

Principal component analysis was used to characterise these three "environmental" groupings in terms of the original environmental variables (Fig. 13). Groupings A, B and C appeared to be ordered along the first PC axis. That is, group A labels all occur to the left of the plot, group B labels in the middle and group C labels to the right (Fig. 13). The environmental variables that most strongly correlated with PC axis 1 were GS1, GS3, sdBH and Avdep. Thus, moving from left to right in Figure 13 corresponds to a shift from sites with high percentages of fine sediments, low amounts of sediment deposition and low variability in bed height ("low-energy sites") to sites with high percentages of coarse sediments, high amounts of sediment deposition and high variability in bed height ("high-energy sites").

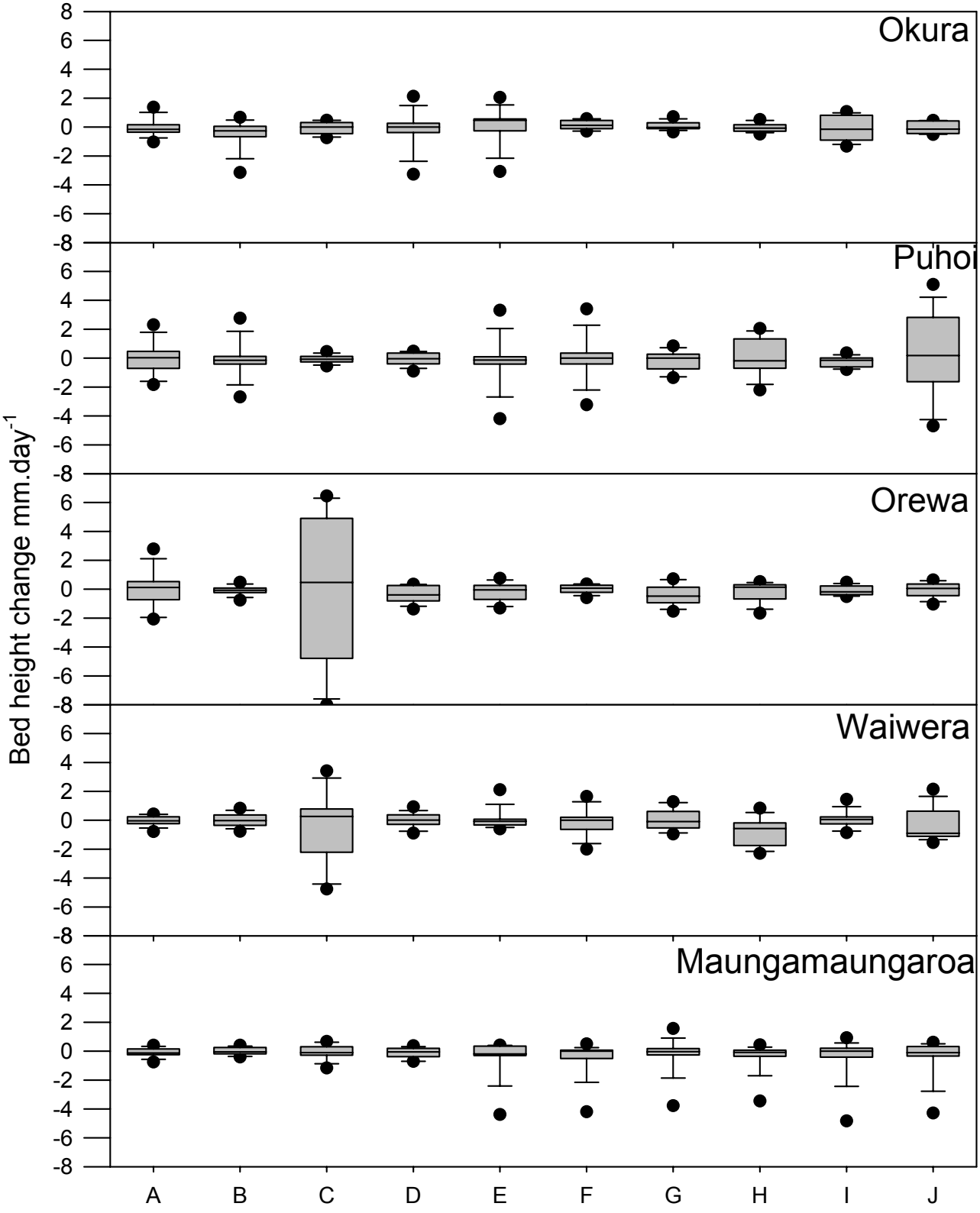

Fig. 8. Bed height change of all sites in all estuaries over the sampling period. All sites have *n*=8 to 11 times.

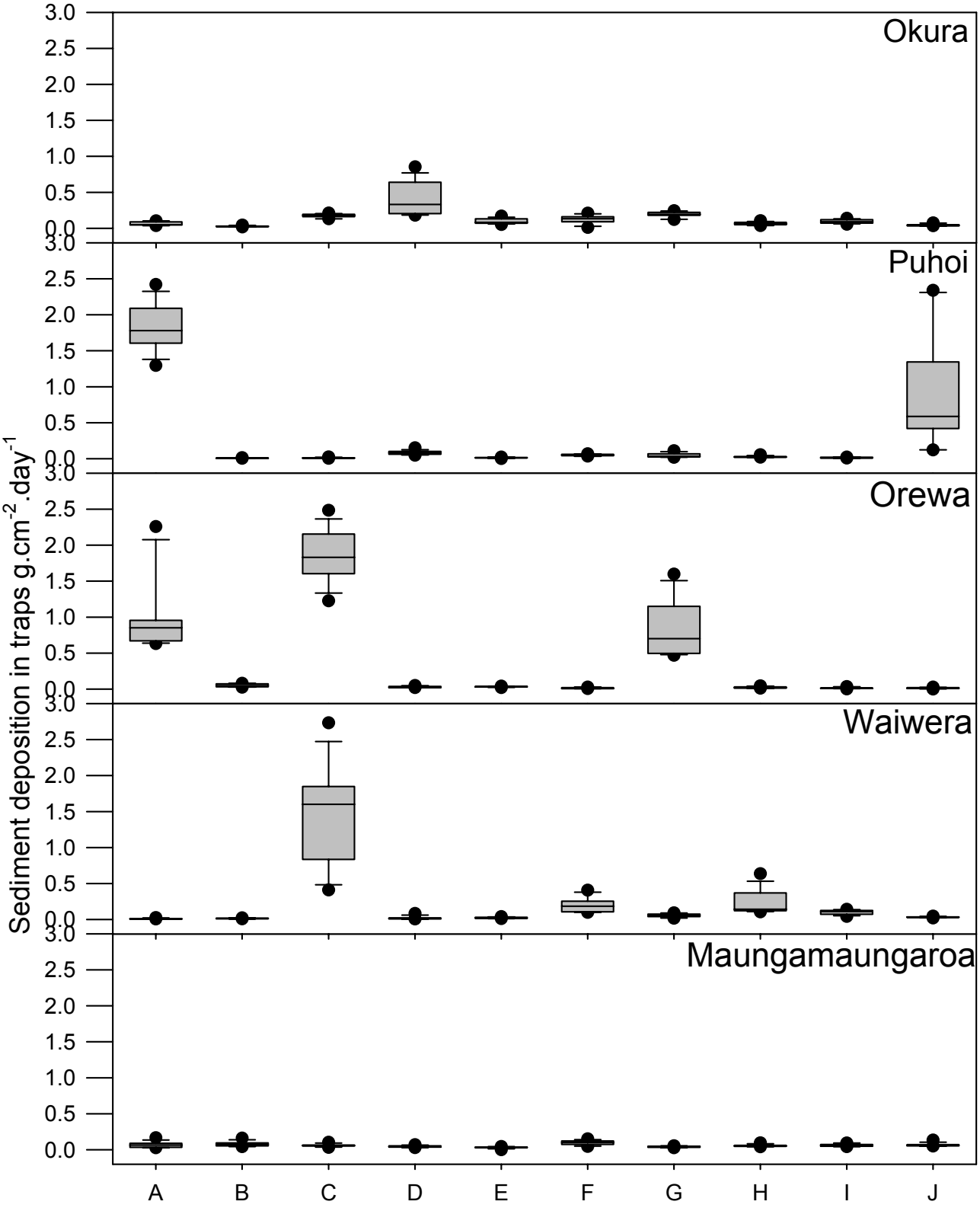

Fig. 9. Sediment trap deposition rate of all sites in all estuaries over the sampling period. All sites have *n*=7 to 10 times.

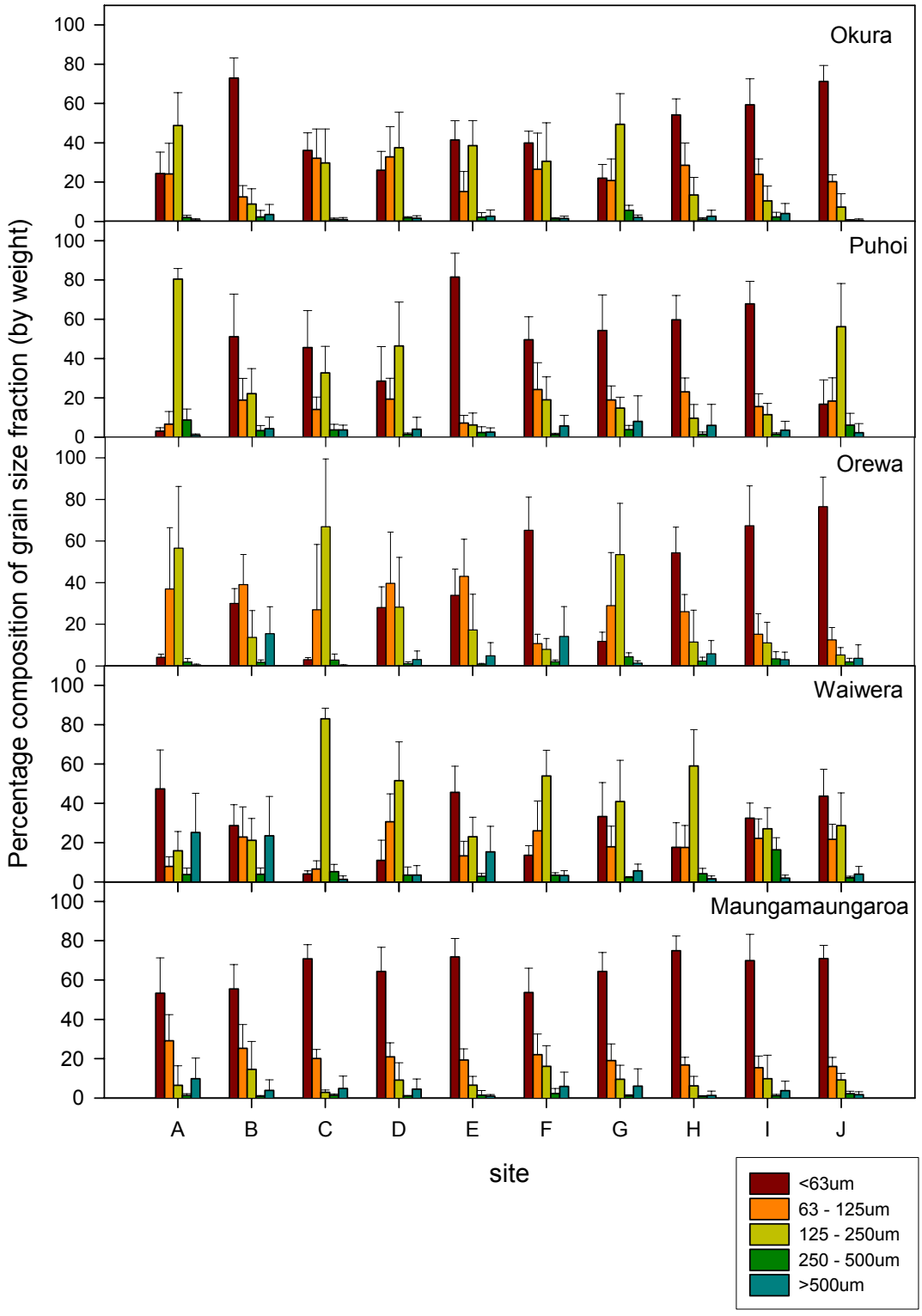

Fig. 10. Mean (+S.E., *n*=10) percentage composition of sediment of different grain sizes collected in traps for all sites in all estuaries pooled over the sampling period.