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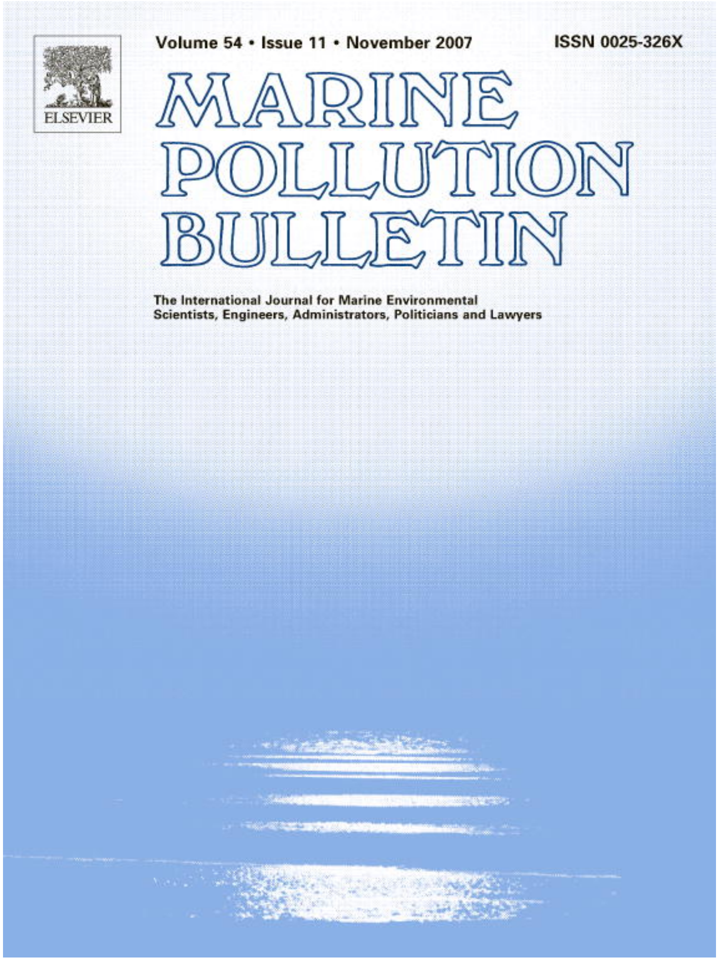
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Benthic meiofauna community composition at polluted and non-polluted sites in New Zealand intertidal environments

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Abstract

Meiofauna composition was investigated for six field sites, including polluted and non-polluted sites, within two regions (Auckland and Bay of Plenty) during winter (July–August 2004) in the North Island of New Zealand. Physico-chemical parameters were measured during the sampling period and meiofauna distribution and abundance were compared with these measured parameters. Analysis of meiofauna abundance indicated that foraminiferans, nematodes and ostracods were the taxa that contributed to the variability between field sites within the Auckland region. However, no clear taxa dominance was seen in the Bay of Plenty region. Comparison of meiofauna abundance and physico-chemical parameters was done using multivariate analysis (PRIMER). However, no clear relationships between the parameters were observed in any field site in either region. The Shannon-Weiner index of diversity did not show any clear differentiation between polluted and non-polluted field sites. Therefore, from the present study, the taxa or physico-chemical parameters used could not effectively characterise pollution at the investigated field sites.

Keywords: Meiofauna; Taxa; Physico-chemical; Pollution; Shannon-Weiner index of diversity; PRIMER statistical analysis

1. Introduction

Estuarine areas are among the most productive ecosystems, and are under increasing pressure from a variety of stressors including urban and industrial waste effluents. Contaminants introduced into the marine environment by human activities, such as heavy metals, polyaromatic hydrocarbons (PAHs) and organochlorines, tend to adsorb to the surface of fine particles and because contaminants typically bind to the finer silty material of estuarine sediments, this then creates a reservoir of contaminants becoming a source of pollution to the water column and associated organisms (Oberholster et al., 2005). The primary contaminants of concern in New Zealand estuaries are zinc (e.g., galvanised steel, tyres), copper (vehicle wiring), lead (vehicle emissions) and polycyclic aromatic hydrocarbons (PAHs) (also originating from vehicle emissions) and have accumulated in estuarine sediments (ANZECC, 2000; ARC, 2003; Williamson and Wilcock, 1994). Studies are beginning to indicate that these contaminants are having an effect on the fauna, particularly sediment dwelling organisms by reducing species abundance, increasing contaminant accumulation in shellfish and crustaceans and causing changes in growth and reproductive rates (Ministry for the Environment, 1997 and references therein).

Intertidal areas are also heavily influenced by environmental factors, including the erosion and deposition of sediments from the currents and the diffusion of nutrients and

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air into the sediment matrix, which contribute to the changes in distribution and abundance of benthic organisms. Studies have investigated the effects of these parameters on benthic dwelling organisms (Dyer et al., 1983; Rees et al., 1999; Schratzberger et al., 2006) but have predominantly investigated the larger macrofauna as they are easily sampled and identified compared with the smaller meiofauna (crustacea, worms etc. between 63 and 500 μm in length).

Meiofauna are an important component of marine benthic communities providing ecosystem services including sediment bioturbation and recycling of organic matter (Higgins and Thiel, 1988; Nozais et al., 2005). In intertidal systems meiofauna provide an important link between primary producers as they are consumers of microphytobenthos (Pace and Carman, 1996; Pinckney et al., 2003) and provide an important food source to juvenile fish that use intertidal habitats as a nursery ground (Nakagami et al., 2000; Reichert, 2003; Uye et al., 2004). Because of their small size and intimate association with the sediments, meiofauna are rapidly affected by changes in abiotic and biotic environmental parameters, therefore resulting changes in community structure can directly affect higher trophic organisms which depend on the meiofauna as a source of food.

The purpose of the present study was to, (1) examine the distribution and abundance of benthic meiofaunal communities at different field locations exposed to known levels of sediment associated contaminants, (2) to investigate relationships between physico-chemical sediment characteristics (redox potential, grain size composition and sediment organic content) and meiofauna distribution and abundance and (3) identify whether abundance of key taxa can be used to characterise polluted and non-polluted sites.

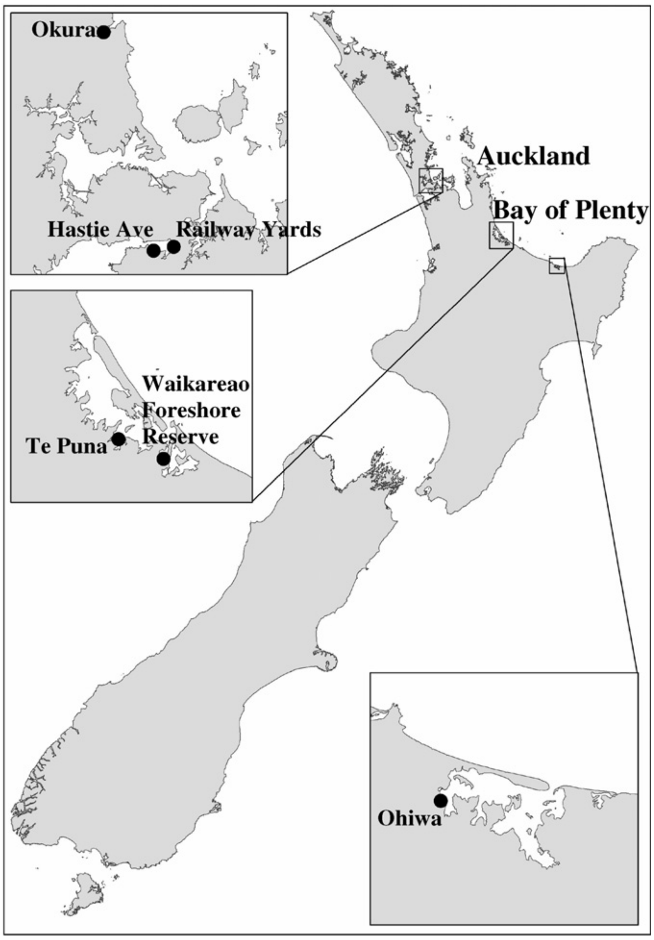

Fig. 1. Map of New Zealand indicating location of field sites within the Auckland and Bay of Plenty regions.

2. Materials and methods

2.1. Field site locations

2.1.1. Auckland region (see Fig. 1)

The Manukau harbour is the second largest coastal harbour on the west coast of the North island of New Zealand, adjacent to the city of Auckland and is the sixth largest harbour in the world. Tidal influences range from a mean high water spring (MHWS) value of 4.17 m to a mean low water spring (MLWS) value of 0.45 m (LINZ, 2006). The harbour covers an area of approximately 350 km^2 and is surrounded with extensive urban, industrial and rural land uses. The catchment area supports a population of around 1.3 million (Statistics New Zealand, 2006). Previous studies have shown that parts of the harbour close to urban and industrial areas are moderately to heavily polluted by metals (Williamson et al., 1992) and organic pollutants (Fox et al., 1988; Holland et al., 1993; Williamson and Wilcock, 1994; Hickey et al., 1995). Okura estuary is located within the Long Bay-Okura Marine reserve near the northern edge of the North Shore area of Auckland, New Zealand and is under increasing pressure from urbanisation (Ford et al., 2003). Tidal influences in this area range from MHWS 3.26 m to MLWS 0.45 m (LINZ, 2006).

2.1.2. Bay of Plenty region (see Fig. 1)

The Tauranga harbour is located on New Zealand's northeast coast in the Bay of Plenty and experiences a MHWS level of 1.86 m and a MLWS level of 0.16 m (LINZ, 2006). The harbour catchment covers an area of approximately 200 km^2 and is well developed with extensive horticultural, agricultural, urban and commercial uses. Tauranga city supports a population of around 110 000 (Statistics New Zealand, 2006). Ohiwa harbour (2872800E, 6346725N; MHWS 1.9 m, MLWS 0.3 m) is located in the Whakatane region, south of Tauranga city with a population around 33 000 (LINZ, 2006; Statistics New Zealand, 2006). The harbour catchment covers an area of approximately 27 km^2 and is surrounded by rural pastures and low density housing, mainly in the northern Whakatane town area.

2.2. Field site classification (see Fig. 1)

Contaminant information for each field site detailed in Table 5 was taken from available Regional Council publications and does not represent contaminant analysis undertaken as part of this study. Sites within the large metropolitan Auckland region included two polluted sites, Hastie Ave (2670560E, 6471585N, Manukau harbour) and the Railway Yards (2673345E, 6472140N, Manukau harbour) and one reference site within the Okura estuary (2663765E, 6501480N). Both sites within the Manukau harbour have been classified as having 'unhealthy' benthic communities and the area surrounding the Okura estuary as having 'healthy' benthic communities (ARC, 2003). Okura estuary is surrounded by a small urban area and rural pastures and levels of contaminants have been recorded at or below the ANZECC (2000) water quality guideline values. The primary contaminants of concern for the urbanised Auckland region are zinc, lead, copper and polyaromatic hydrocarbons (PAHs) (ARC, 2003). The selected sites within the harbour have recorded contaminants above the ARC (2003) high contaminant guideline values for zinc, lead and copper (i.e., >150 mg/kg, >50 mg/kg and >34 mg/kg respectively), but below the PAH guideline value (i.e., <0.66 mg/kg). Lead concentrations in the Railway Yard field site have recorded levels below the guideline value. Conversely, contaminant levels recorded within the Okura estuary have been recorded at levels at or below the low contaminant guideline values; <125 mg/kg, <30 mg/kg, <19 mg/kg and <0.66 mg/kg, for zinc, lead, copper and PAHs, respectively (ARC, 2003).

Sites within the smaller metropolitan Tauranga region included two polluted sites, Waikareao Foreshore Reserve (2788350E, 6384875N, Tauranga harbour) and Te Puna estuary (2779155E, 6388855N, Tauranga harbour) and one reference site within the Ohiwa harbour (2866425E, 6347630N, Whakatane). Both polluted sites have lower levels of sediment associated contaminants compared with those recorded in the Auckland field sites, namely, zinc, lead and copper (25–40 mg/kg, 4–6 mg/kg, 1–3 mg/kg, respectively), but these values are nevertheless a cause of concern for the region. PAH compounds exceeded the analytical detection limits (2 μg/kg) within the Waikareao Foreshore reserve field site (32 μg/kg; Environment Bay of Plenty, 2003) indicating a low to moderate environmental impact, however this recorded value was lower than the ARC (2003) low contaminant guideline value (i.e., <0.66 mg/kg). No data for PAH levels was available for Te Puna. Contaminants in the Ohiwa harbour (Whakatane) have been recorded well below the low contaminant guideline values: <125 mg/kg, <30 mg/kg, <19 mg/kg and <0.66 mg/kg, for zinc, lead, copper and PAHs, respectively (ARC, 2003).

2.3. Experimental procedure

Sediment samples for physico-chemical and meiofauna community analyses were collected at each of the six field sites (Okura estuary (reference), Hastie Ave, Railway Yards, Ohiwa harbour (reference), Waikareao Foreshore Reserve and Te Puna) during winter (July–August) 2004. Three 30 m transects were laid perpendicular to the shoreline and located below mean high water spring level at all field sites. Samples for biological and physico-chemical analyses were collected at 0, 10, 20, 30 m intervals and sampled from within two 1 m^2 quadrats. The sampling procedure included the collection of three haphazard 30 ml sediment samples for meiofauna composition analysis and two 30 ml sediment samples for organic analysis. Organic samples were collected by scraping the upper oxic sediment layer. The samples were analysed for total organic carbon and calcium carbonate composition by Landcare Research Ltd., New Zealand using the methods outlined by Leco (Laboratory Equipment Corporation), (1996) and Blakemore et al. (1987). Redox potential discontinuity (RPD) depth was recorded from within each replicate quadrat and consisted of three measurements of the organic (oxic) layer. Samples for mean sediment grain size analysis were collected at 15 m from each transect and analysed by Auckland University, New Zealand using a Malvern Mastersizer 2000 laser diffraction particle analyser (Allen, 1992).

2.4. Statistical analysis

Meiofaunal abundance data for each site and field region were analysed using multidimensional scaling (MDS) analyses using the PRIMER (Plymouth Routines in Multivariate Ecological Research) statistical package. The MDS plots were carried out on totals over the quadrats and cores, giving 12 samples (3 transects and 4 distances) for each of the six field sites. Similarity matrices for each region were calculated using the Bray Curtis similarity measure and to reduce the influence of taxa with very large abundances, data was square root transformed prior to calculating the similarities.

Principal component analysis (PCA) was also undertaken to explain the variation in the data and identify which taxa contribute to the variation. However, as results were consistent with the SIMPER and ANOSIM analyses, results have not been included. Analysis of similarity (ANOSIM) was used to test for differences between the sites (data were averaged over transects and distances) and also between each transect distance combination. Bray Curtis was used as a similarity (SIMPER) measure to identify those taxa primarily responsible for the differences between the sites (Clarke and Warwick, 1994). The Shannon-Weiner Index of Diversity was also used to investigate the biodiversity of the meiofauna community at each distance and site combination in addition to average field site calculations.

3. Results

3.1. Multivariate analysis of meiofaunal composition

The stress values (degree of correspondence between the distances among points reflects the similarity to other points/samples) of 0.05 and 0.09 for both the Auckland and Bay of Plenty regions respectively, corresponds to the data having "excellent" or "good" ordination in 2-dimensional space, respectively, with "no real prospect of a misleading interpretation" as stated in Clarke and Warwick (1994). Based on the rank similarities between the samples, the closeness of the points on the Auckland and Bay of Plenty MDS plots reflects how similar the field sites are. The current results indicate that predominantly all field sites both reference and polluted, within both regions are different because of the clustering of data points, however, there was some overlap with the two polluted Auckland region field sites, Hastie Ave and the Railway Yards (Fig. 2a and b).

Analysis using ANOSIM indicated that there were differences between all Auckland field sites when averaged over transects and distances (Table 1A). Further investigation showed that in the Okura (reference) and Hastie Ave (polluted) field sites, samples from 0 and 10 m were more similar to each other in meiofaunal composition than to the 20 and 30 m samples. For the remaining Railway Yard (polluted) site, distances were indistinguishable from each other (Table 2A). The field site differences were investigated using similarity percentages (SIMPER) which showed that the taxa foraminifera, nematodes and ostracods accounted for between 33% and 85% of the dissimilarity between the three field sites (Table 3A). Furthermore,

Table 1
Analysis of similarity (ANOSIM) values for differences between each field site within the (a) Auckland and (b) Bay of Plenty field regions

Pairwise tests		
Groups	R statistic	P-value
(A)		
Global test		
Sample statistic (global R): 0.507		
Significance level of sample statistic: 0.1%		
Okura, Hastie Ave	0.84	0.001
Okura, Railway Yards	0.29	0.001
Hastie Ave, Railway Yards	0.37	0.001
(B)		
Global test		
Sample statistic (global R): 0.75		
Significance level of sample statistic: 0.1%		
Ohiwa, Waikareao Foreshore Reserve	0.85	0.001
Ohiwa, Te Puna	0.55	0.001
Waikareao Foreshore Reserve, Te Puna	0.84	0.001

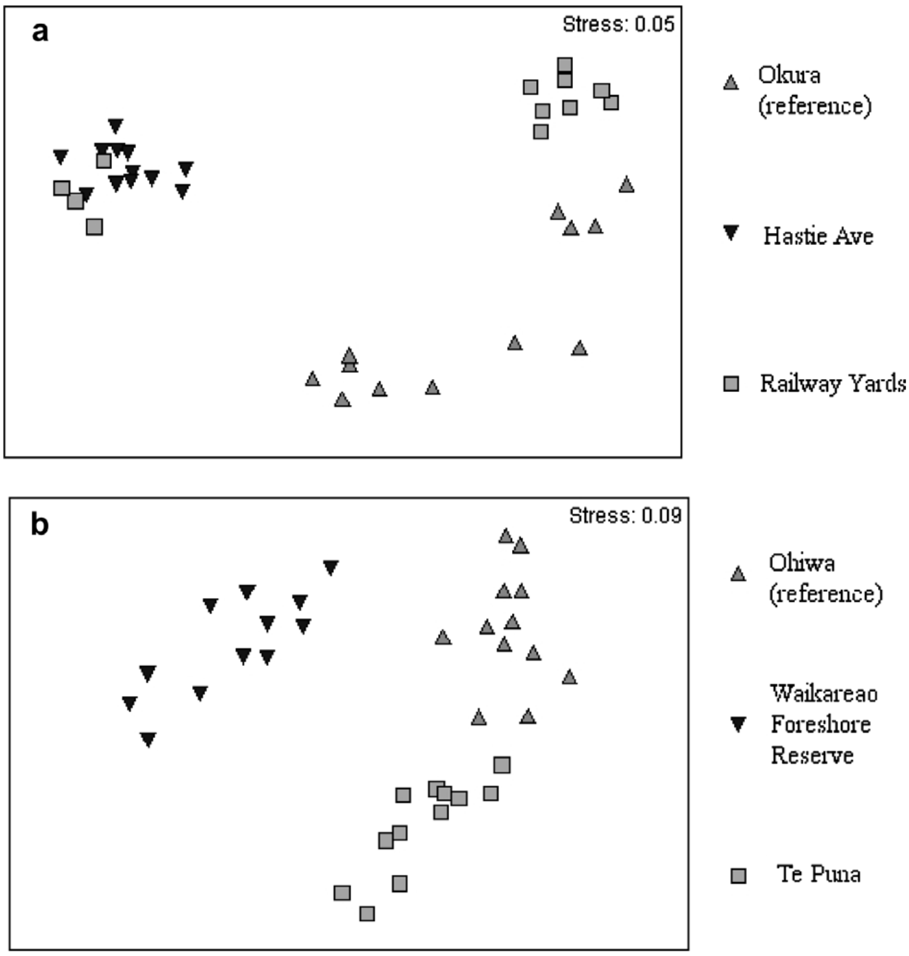

Fig. 2. Multidimensional scaling of taxa abundances from each field site within the (a) Auckland field region and (b) Bay of Plenty field regions.

Table 2
Analysis of similarity (ANOSIM) values for each field site within the (A) Auckland and (B) Bay of Plenty field regions

Pairwise tests			Pairwise tests			Pairwise tests		
Groups	*R* statistic	*P*-value	Groups	*R* statistic	*P*-value	Groups	*R* statistic	*P*-value
(A)								
Okura (reference)			Hastie Ave			Railway Yards		
Global test			Global test			Global test		
Sample statistic (global *R*): 0.043			Sample statistic (global *R*): 0.089			Sample statistic (global *R*): −0.003		
Significance level of sample statistic: 0.1%			Significance level of sample statistic: 4.7%			Significance level of sample statistic: 45.0%		
0, 10	−0.01	0.503	0, 10	0.01	0.363	0, 10	−0.02	0.568
0, 20	0.08	0.041	0, 20	0.06	0.069	0, 20	0.02	0.215
0, 30	0.08	0.042	0, 30	0.21	0.001	0, 30	0.05	0.102
10, 20	0.03	0.13	10, 20	0.05	0.123	10, 20	−0.04	0.934
10, 30	0.05	0.077	10, 30	0.14	0.003	10, 30	−0.003	0.396
20, 30	−0.002	0.385	20, 30	0.07	0.045	20, 30	−0.02	0.635
(B)								
Ohiwa (reference)			Waikareao Foreshore Reserve			Te Puna		
Global test			Global test			Global test		
Sample statistic (global *R*): 0.09			Sample statistic (global *R*): 0.193			Sample statistic (global *R*): 0.051		
Significance level of sample statistic: 0.3%			Significance level of sample statistic: 0.1%			Significance level of sample statistic: 1.3%		
0, 10	−0.02	0.682	0, 10	0.001	0.458	0, 10	0.07	0.046
0, 20	0.11	0.022	0, 20	0.16	0.004	0, 20	0.07	0.031
0, 30	0.23	0.001	0, 30	0.31	0.001	0, 30	0.15	0.001
10, 20	0.04	0.127	10, 20	0.29	0.001	10, 20	−0.03	0.746
10, 30	0.15	0.003	10, 30	0.38	0.001	10, 30	0.04	0.142
20, 30	0.03	0.192	20, 30	0.04	0.164	20, 30	0.01	0.326

Note: 3-decimal places are given for the *R* statistic where numerical information would otherwise have been lost.

Table 3
Similarity percentages (SIMPER) identifying those taxa that are primarily responsible for the differences between the sites from the ANOSIM analyses within the (A) Auckland and (B) Bay of Plenty field regions

Groups Okura and Hastie Ave			Average dissimilarity = 36.09		
Taxa	Okura average abundance	Hastie Ave average abundance	Average dissimilarity	Dissimilarity SD	Cummulative %
(A)					
Foraminifera	63.94	452.74	18.47	4.12	51.16
Ostracods	22.11	90.88	6.58	3.52	69.38
Nematodes	79.5	121.88	4.85	1.37	82.83
Gastropods	0.42	3.14	1.94	2.55	88.21
Polychaetes	2.92	0.36	1.47	1.46	92.28
Groups Okura and Railway Yards			Average dissimilarity = 30.03		
Taxa	Okura average abundance	Railway Yards average abundance	Average dissimilarity	Dissimilarity SD	Cummulative %
Foraminifera	63.94	181.1	10.04	1.26	33.43
Nematodes	79.5	65.94	6.55	1.37	55.24
Ostracods	22.11	49.75	3.45	1.26	66.75
Gastropods	0.42	4.07	3.05	1.74	76.91
Polychaetes	2.92	0.18	2.31	1.6	84.6
Copepods	5.44	7.01	2.2	1.72	91.93
Groups Hastie Ave and Railway Yards			Average dissimilarity = 30.50		
Taxa	Hastie Ave average abundance	Railway Yards average abundance	Average dissimilarity	Dissimilarity SD	Cummulative %
Foraminifera	452.74	181.1	15.77	1.61	51.7
Nematodes	121.88	65.94	6.09	1.7	71.66
Ostracods	90.88	49.75	4.32	1.8	85.83
Copepods	4.4	7.01	1.62	1.72	91.15
(B)					
Groups Ohiwa and Waikareao Foreshore Reserve			Average dissimilarity = 28.38		
Taxa	Ohiwa average abundance	Waikareao average abundance	Average dissimilarity	Dissimilarity SD	Cummulative %
Amphipods	0.24	14.97	7.09	5.3	24.96
Nematodes	14.83	44.21	5.25	1.95	43.47
Polychaetes	0.69	10.54	4.71	3.11	60.06
Foraminifera	31.54	57.07	4.17	1.45	74.75
Ostracods	18.13	37.33	3.54	1.98	87.22
Copepods	8.22	10.78	1.77	1.25	93.47
Groups Ohiwa and Te Puna			Average dissimilarity = 22.55		
Taxa	Ohiwa average abundance	Te Puna average abundance	Average dissimilarity	Dissimilarity SD	Cummulative %
Foraminifera	31.54	66.39	6.36	1.69	28.19
Copepods	8.22	0.29	5.87	2.54	54.22
Ostracods	18.13	36.67	4.18	1.36	72.74
Nematodes	14.83	23.03	2.48	1.33	83.75
Polychaetes	0.69	1.57	1.22	1.49	89.16
Bivalves	0.85		1.15	1.16	94.26
Groups Waikareao Foreshore Reserve and Te Puna			Average dissimilarity = 27.39		
Taxa	Waikareao average abundance	Te Puna average abundance	Average dissimilarity	Dissimilarity SD	Cummulative %
Amphipods	14.97	0.01	7.36	6.58	26.88
Copepods	10.78	0.29	5.48	4.17	46.88
Polychaetes	10.54	1.57	3.66	2.41	60.26
Formainifera	57.07	66.39	3.57	1.43	73.29
Nematodes	44.21	23.03	3.43	1.38	85.81
Ostracods	37.33	36.67	2.53	1.38	95.03

Note: Average dissimilarity is a measure of dissimilarity between the field sites, dissimilarity standard deviation is a measure of the variability, cummulative % is the number of observations that lie above a particular value in the data set.

these taxa groups showed the greatest abundances in the Hastie Ave (polluted) field site in comparison with the Railway Yard (polluted) and Okura (reference) field sites (Fig. 3a–c).

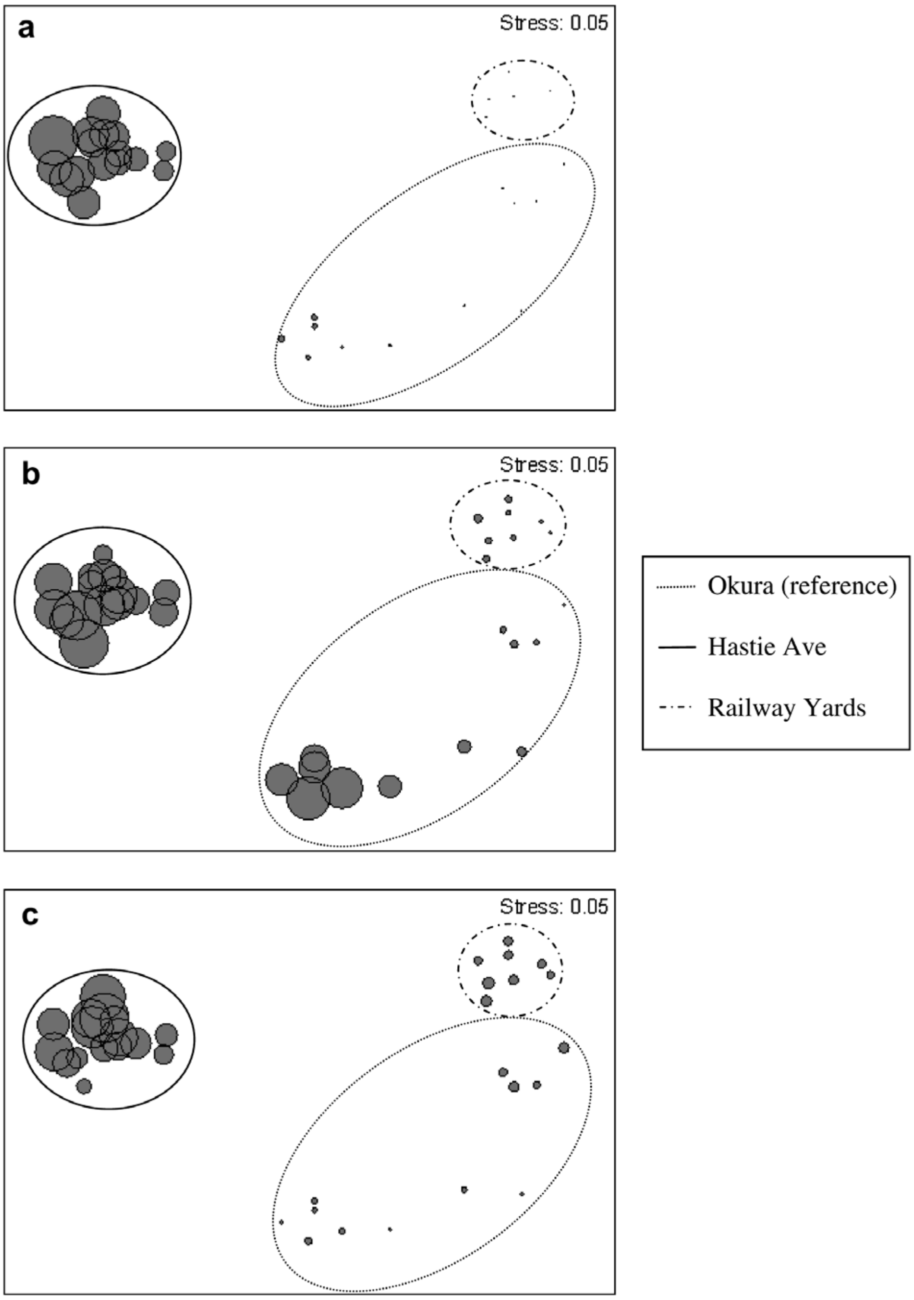

Fig. 3. Multidimensional scaling of taxa abundances for (a) foraminifera, (b) nematodes and (c) ostracods. Bubbles have been grouped relative to the Auckland field sites and the sizes represent the abundance of each taxa within each Auckland field site.

ANOSIM analysis indicated differences between all Bay of Plenty field sites (reference and polluted) when averaged over transects and distances (Table 1B). Furthermore, Ohiwa (reference) and Waikareao Foreshore Reserve (polluted) samples from 0 and 10 m were more similar to each other than to the 20 and 30 m samples (Table 2B). Within the Te Puna field site (polluted), 0 m was different to all other distances (Table 2B). Using SIMPER to analyse the differences between field sites it was found that no particular taxa groups consistently accounted for the dissimilarity between the reference and polluted sites in the Bay of Plenty region (Table 3B).

3.2. Redox potential discontinuity measurements

Mean redox potential discontinuity (RPD) measurements recorded in Okura (reference) were significantly different from the two polluted sites, Hastie Ave and Railway Yards (Table 4). This was further illustrated in Fig. 4a where the mean RPD layer measurements were greater and therefore deeper in Okura followed by the Railway Yards and Hastie Ave field sites. This trend was not observed in the Bay of Plenty region field sites where the polluted Waikareao Foreshore Reserve site was significantly different to both Ohiwa (reference) and Te Puna

Table 4
Average volume weighted sediment grain size (μm) averaged over distances and transects for each field site, mean redox potential discontinuity (RPD) measurements and mean carbon–nitrogen ratios for all distances and transects for each field site within the Auckland and Bay of Plenty regions

		RPD		Carbon–nitrogen		Grain size	
		Mean	95% CI	Mean	95% CI	Mean	Standard error
Auckland	Okura (reference)	15.1	11.6–18.6	11.7	11.4–11.9	88.7	6.4
	Hastie Ave	4.8	3.9–5.7	12.5	11.5–13.4	171.6	46.6
	Railway Yards	8.8	7.0–10.6	14.6	13.0–16.2	223.5	31.9
Bay of Plenty	Ohiwa (reference)	2.6	2.3–2.9	14.4	12.9–15.8	217.2	64.5
	Waikareao Foreshore Reserve	3.8	3.7–4.0	12.1	11.3–12.9	252.2	42.8
	Te Puna	2.7	2.5–2.9	9.8	9.5–10.2	218.7	32.4

Confidence intervals (CI) and standard errors for the means are shown.

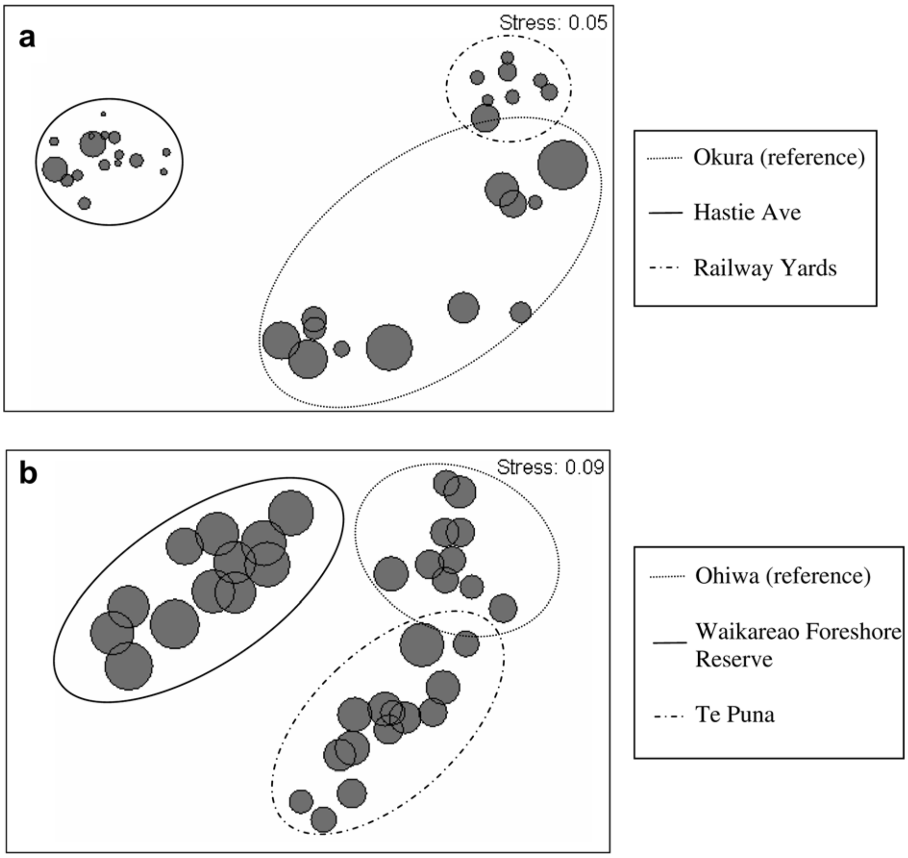

Fig. 4. Multidimensional scaling of taxa abundances superimposed with the redox potential discontinuity (RPD) layer measurements in the (a) auckland and (b) Bay of Plenty field regions. Bubbles have been grouped relative to the Auckland and Bay of Plenty field sites and the sizes represent the mean RPD values for each field site.

(polluted) field sites (Table 4). This was graphically represented in Fig. 4b whereby the mean RPD measurements were deepest in the Waikareao Foreshore Reserve site.

3.3. Carbon–nitrogen ratios

Mean carbon–nitrogen (C–N) ratios recorded in the polluted Railway Yard (14.6) field site were significantly different compared with the Hastie Ave (polluted) (12.5) and Okura (reference) (11.7) field sites (Table 4). This was further represented in Fig. 5a whereby the larger mean C–N ratios occurred in the Railway Yard field site within the Auckland region. In comparison, the mean C–N ratios recorded in the Ohiwa (reference) (14.4) field site were significantly different from both the polluted Waikareao Foreshore Reserve (12.1) and Te Puna (9.8) sites. In addition, Fig. 5b graphically represents in 2-dimensional space the larger mean C–N ratios recorded in the Ohiwa field site compared with the Waikareao Foreshore Reserve and Te Puna field sites.

3.4. Sediment grain size

The average sediment grain size composition in the polluted Hastie Ave and Railway Yards sites within the Auckland region was larger with an average particle size of

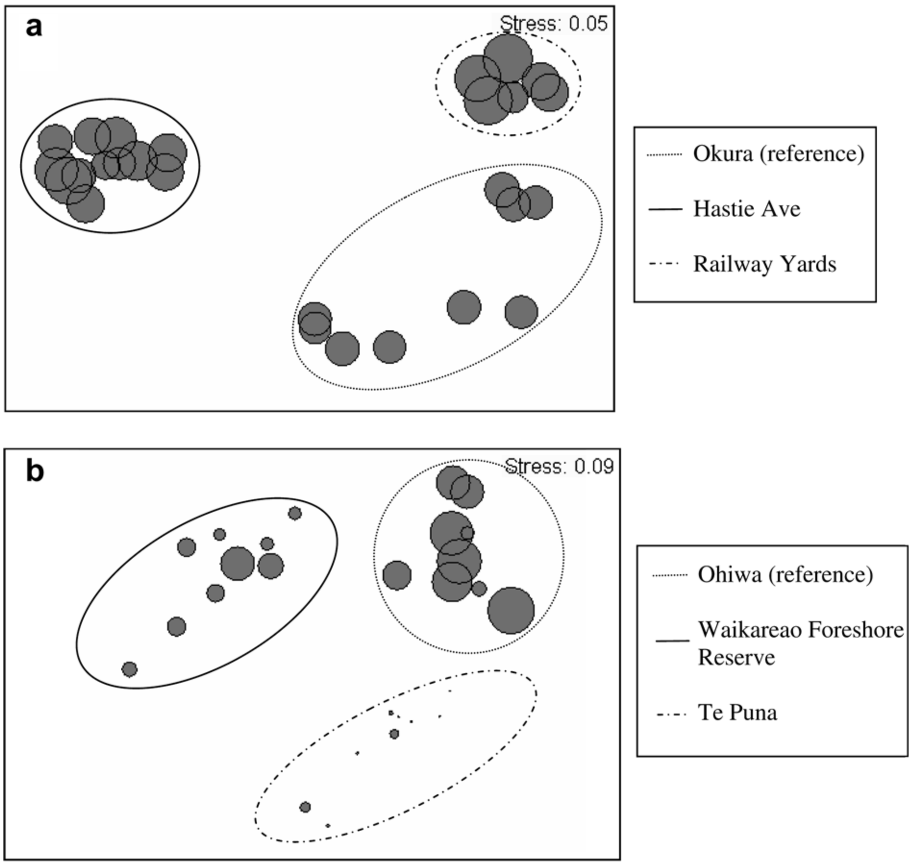

Fig. 5. Multidimensional scaling of taxa abundances superimposed with the carbon- nitrogen ratios in the (a) Auckland and (b) Bay of Plenty field regions. Bubbles have been grouped relative to the Auckland and Bay of Plenty field sites and the sizes represent the mean carbon–nitrogen ratios for each field site.

(171.6–223.5 μm ± standard error, 46.6–31.9 μm, respectively) compared with Okura (88.7 μm ± 6.4 μm) (Table 4). In contrast, sediment grain size in the Ohiwa (reference) and Te Puna (polluted) field sites (217.2–218.7 μm ± 2.1–3.7 μm, respectively) were very similar and differed by only 1.5 μm and in addition, the Waikareao Foreshore Reserve (polluted) field site recorded the greatest average grain size of (252.2 μm ± 42.8 μm) (Table 4).

3.5. Shannon-Weiner index of diversity

Shannon-Weiner diversity measures (H') did not indicate any significant trends with distance down the shoreline in both the Auckland and Bay of Plenty field sites as all the confidence intervals overlapped (Fig. 6a and b). Fig. 7a did illustrate greater variability in species diversity when averaged over all distances in the Okura and Railway Yard sites than compared with the Hastie Ave site due to the wider confidence intervals. Conversely, all diversity measures recorded within the Bay of Plenty field sites (Ohiwa (reference), Waikareao Foreshore Reserve (polluted), Te Puna (polluted)), were significantly different from each other as the confidence intervals did not overlap, however interpretation must be done with caution as the observed differences were marginal (Fig. 7b).

4. Discussion

Extensive sampling of the benthos in the Auckland and Bay of Plenty regions in New Zealand has allowed us to provide an evaluation of the relationships between meiofauna, their sedimentary habitat and sediment contaminants. The results obtained provide a general picture of the spatial distribution of the meiofauna communities and their variability during the winter of 2004. A major limitation in this study was the collection of winter samples only and in the absence of seasonal data, could lead to an underestimation of meiofaunal distribution and abundance and associated physico-chemical parameters at each field site. The sediment physico-chemical parameters selected for investigation in this study (redox potential discontinuity layer (RPD), organic and grain size composition) represent some of the major environmental parameters known to affect the composition and diversity of meiofauna and were used to characterise the ambient situation of the meiobenthos (Higgins and Thiel, 1988). Among these parameters, sediment grain size is one of the most important factors as many species of meiofauna exploit the coarser sediments. Therefore, the greater proportion of fine sediments in a sample determines the degree of accessibility into the coarser substrate. Furthermore, it is known that meiofaunal

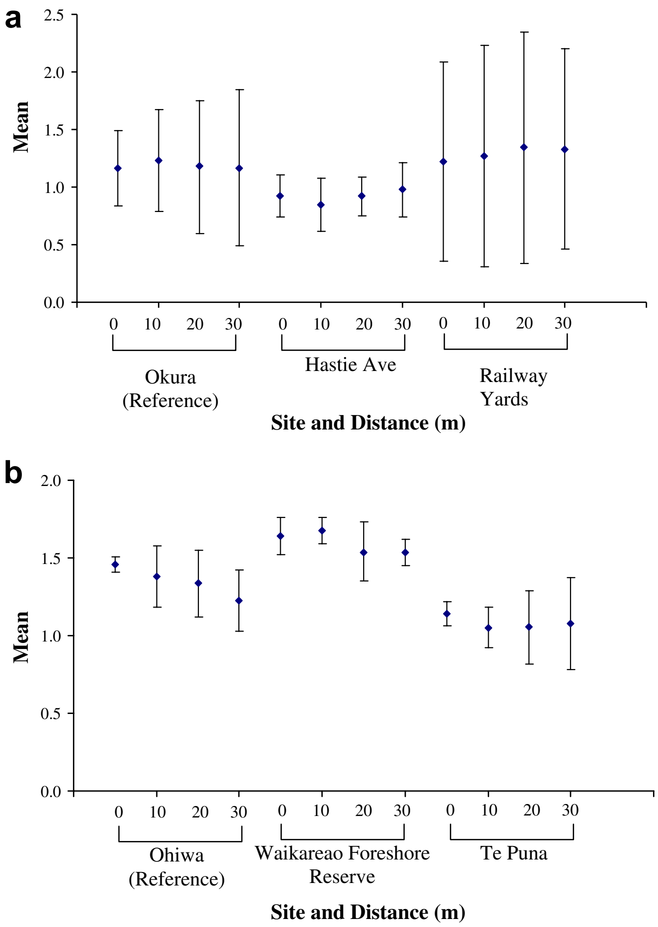

Fig. 6. Mean Shannon-Weiner index of diversity measures for each field site and distance (m) combination for the (a) Auckland and (b) Bay of Plenty field regions. Confidence interval bars for each distance diversity measure are shown.

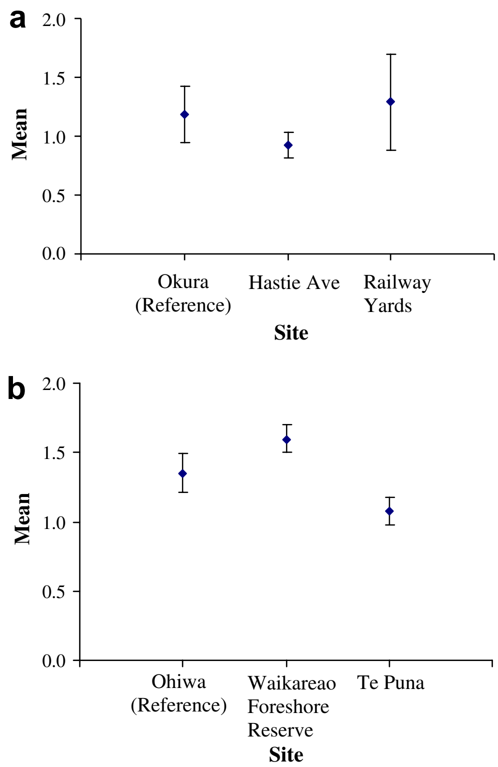

Fig. 7. Mean Shannon-Weiner index of diversity measures for each site within the (a) Auckland and (b) Bay of Plenty field regions. Confidence interval bars for the field site diversity measures are shown.

communities decrease with increasing depth, therefore the depth of the RPD layer directly affects the proportion of oxic sediments available for meiofaunal occupation. Also, in order to understand meiofaunal community distribution and abundance, fluctuations of sediment organic content is required especially as the productivity of meiofaunal communities depends on the availability of organic matter as a food source.

The two polluted sites within the Auckland region (Hastie Ave and Railway Yards) have historically high levels of copper (Cu), lead (Pb), zinc (Zn) and polycyclic aromatic hydrocarbons (PAHs) mainly due to industrial contamination from nearby railway yard operations, steel operations and paint manufacturing (Glasby et al., 1988; Williamson et al., 1995). Elevated levels of contaminants have also been recorded within the Bay of Plenty polluted field sites (Table 5). The Auckland reference site (Okura) is a relatively clean estuary but has recorded elevated levels of contaminants compared to the Ohiwa reference site in the Bay of Plenty (Table 5). Okura was selected for its relatively low impacted catchment and the low levels of sediment associated contaminants in comparison with other estuaries in the Auckland region. Furthermore, while the results of this study do not prove contaminants are affecting meiofaunal community composition, they may still be indicative of effects.

The differences between the Auckland field sites were reflected in the MDS plots of taxa abundances which indicated Okura had more variable taxa abundance compared with the two distinctly different polluted sites. However, the Bay of Plenty MDS plots showed clear distinctions between each field site. In addition, the abundances of the taxa, foraminifera, nematodes and ostracods that contributed to the variation between the Auckland field sites, might suggest high sediment organic content (Higgins and Thiel, 1988). Furthermore, the variable taxa abundances within each field site may be an indication of spatial and temporal environmental variability and does not necessarily indicate variation resulting from sediment contamination.

Mean sediment redox potential layer (RPD) was shallower in the polluted Auckland sites (4.8–8.8 cm) compared with a considerably deeper layer in Okura (15.1 cm) which could be attributed to the lower number of mangroves in the polluted sites able to aerate the sediment matrix via pneumatophore/sediment interactions. This result is also an indication that the dispersion of oxygen and nutrients is limited to a shallower band of sediment. This trend was not observed in the Bay of Plenty sites whereby the Ohiwa (reference) and Te Puna (polluted) field sites

Table 5
Mean contaminant (lead (Pb), copper (Cu) and zinc (Zn)) concentrations (mg/kg^{-1}) in the 500 μm sediment fraction and polyaromatic hydrocarbons (PAH) concentrations (μg kg^{-1}) in the 500 μm sediment fraction recorded in the sediments at each field site within the Auckland and Bay of Plenty field region

Region	Site	Contaminants (mg kg^{-1})			PAH (μg kg^{1})
		Pb	Cu	Zn	
Auckland	Okura (Reference)	10	7	39	16
	Hastie Ave[a]	>50	>34	>150	<66
	Railway Yards	32	37	155	65
Bay of Plenty	Ohiwa (reference)	3.9	4.2	22.9	3
	Waikareao Foreshore Reserve	4.4	1.3	40.5	32
	Te Puna	6	2.8	25.6	N/A

Contaminant data was taken from ARC (2003), Environment Bay of Plenty (2003) and Stephen Park, Environment Bay of Plenty (pers. comm.) and refer to sites as close as possible to those listed in the table below.
[a] ARC (2003) contaminant guideline values are given for the Hastie Ave site as no data was available. ARC (2003) contaminant guideline values were above the tabulated contaminant values.

recorded similar but shallower RPD depth measurements (2.6–2.7 cm) compared with a deeper RPD layer in the Waikareao Foreshore Reserve (polluted) site (3.8 cm). The differences in redox potential depths between each field site may therefore be a limiting factor in the distribution and abundance of meiofauna communities in the selected field sites.

In the present study sediment organic C–N composition was greater in the Auckland region polluted field sites (Hastie Ave and Railway Yards) compared with lower levels in the reference site (Okura), however this trend was not observed in the Bay of Plenty sites. This may be related to the historical pollution loading recorded within the Auckland region and may provide further evidence to support the relationship between organically rich sediments and contaminant sequestration (Knight and Pasternack, 1999; Windom, 1975). Furthermore, the high sediment scour (i.e., low depositional site) resulting from wave action in Te Puna (Bay of Plenty polluted site) may provide a possible explanation for the low levels of sediment associated organics recorded in this site during the current study.

Hydrodymanic forces (e.g., sediment scouring) are a key factor in determining the sediment grain size composition (Liu et al., 2006) and is considered the most likely factor in determining the greater average grain size in the more exposed Auckland polluted field sites as compared with the smaller average grain size recorded in the more sheltered Okura (reference) site. Despite the presence of mangrove stands in the polluted areas, wave action may still be scouring the sediments and reducing the proportion of finer sediment particles settling out of the water column in comparison with a higher depositional environment in the Okura site. Particle size differences were variable in the Bay of Plenty field sites and it appears from the current study that wave action may also be the primary factor in determining average grain size in the Te Puna field site compared with the Waikareao Foreshore Reserve and Ohiwa field sites due to the presence of coarser sediment. However, this does not appear to be related to lower levels of sediment associated contaminants as one would expect (Table 5) (Bryan and Langston, 1992).

The Shannon-Weiner diversity index provides a measure of diversity in a community and we would have expected that the unpolluted field sites, Okura and Ohiwa would have high taxa diversity due to reduced contaminant levels reflected in larger H' values and conversely, the polluted sites lower taxa diversity and lower H' values. This trend was also reported in a study by Chen et al. (2006) where the Shannon-Weiner values were lower in the lower reaches of the vulnerable Tarim River environment. However the current results showed no relationship between taxa diversity and levels of field site sediment associated contaminants (Table 5). Interestingly, the diversity values calculated for each distance down the shore in the Okura (reference) and the Railway Yard (polluted) field sites (Auckland region) were more variable than the Hastie Ave site (polluted) (Fig. 6a) with the possible explanation being that the meiofauna populations in these two field sites were larger than recorded in Hastie Ave resulting in greater variation.

5. Conclusions

Further investigation of the taxa and sediment characteristics utilising a wider range of polluted field sites is necessary to characterise pollution at the field sites. Additional measurements including sediment chlorophyll and phaeopigment compositions should also be recorded. Furthermore, it is recommended that long term monitoring of species composition be done in order to highlight changes in diversity at each field site due to sediment contaminant levels and environmental variability.

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