Te Awarua-o-Porirua Harbour subtidal sediment quality monitoring

Results from the 2010 survey

greater WELLINGTON
REGIONAL COUNCIL
Te Pane Matua Taiao

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Executive summary

Contaminants in urban stormwater discharges have been identified as a potential medium to long-term risk to the health of the marine organisms living in our harbours, largely through the accumulation of these contaminants in the subtidal sediments. This report presents the results of the fourth survey of sediment quality and benthic community health at five subtidal sites in Te Awarua-o-Porirua Harbour (Porirua Harbour). These sites were sampled on 9 November and 2 December 2010.

Consistent with the results of the 2004, 2005 and 2008 surveys, concentrations of total copper, lead and zinc exceed nationally recognised 'early warning' (ie, ARC ERC[1] or ANZECC[2] ISQG-Low) sediment quality guidelines in the subtidal sediments of the Onepoto Arm of Porirua Harbour. Mercury concentrations are approaching guideline trigger levels, but are otherwise, along with the other five metals analysed, currently below guideline levels in both the Onepoto and Pauatahanui arms of the harbour.

Fifty-eight species of benthic fauna were identified in the samples collected from Porirua Harbour in 2010. Of these, 54 species were found in samples taken from the Pauatahanui Arm and 29 species were identified in samples collected from the Onepoto Arm. Polychaete worms (27 species), crustaceans (14 species) and bivalve molluscs (7 species) were the most abundant groups amongst the fauna collected. Five species were found that had not been recorded in any of the previous surveys.

The biomass at sites in the Onepoto Arm was dominated by the shrimp-like tanaidaceans and the bivalve *Cyclomactra ovata*. The bivalves *Cyclomactra ovate* and *Linucula hartvigiana,* and the sea cucumber, *Paracaudina chilensis* were dominant members of the biomass at Pauatahanui Arm sites.

Our analyses indicate that the combination of higher heavy metal, mud and organic content is influencing the structure or 'health' of the benthic invertebrate communities at some sites within the harbour. We are unable to isolate which of these variables are driving the changes though we can conclude that sites in the Pauatahanui Arm are of higher 'environmental quality' and support more diverse invertebrate communities.

After having now completed four surveys of subtidal sediment quality and in the absence of any substantial environmental changes, a comprehensive review of the Porirua Harbour subtidal sediment quality monitoring programme is recommended. This review should take into account the specific aims of the programme, survey frequency, contaminants to be sampled and the key issues identified from Greater Wellington Regional Council's intertidal monitoring programme of Porirua Harbour, particularly the elevated rates of sedimentation, declining levels of sediment oxygenation and increasing sediment mud content.

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[1] Auckland Regional Council (ARC) Environmental Response Criteria (ERC)

[2] Australian and New Zealand Environment and Conservation Council (ANZECC) Interim Sediment Quality Guidelines (ISQG)

Contents

1. Introduction

Te Awarua-o-Porirua Harbour (Porirua Harbour) is regionally significant, offering a multitude of landscape, ecological, cultural, geological and recreational values. However, like other coastal environments surrounded by densely populated areas, the harbour receives significant urban stormwater inputs with the potential to adversely impact on the health of its ecosystems.

The Porirua Harbour subtidal sediment quality monitoring programme was initiated in 2004 by the Greater Wellington Regional Council (GWRC) as part of a broader investigation into the possible impacts of urban stormwater discharges on aquatic receiving environments[3]. Five subtidal sites are being used in the programme, two in the Onepoto Arm and three in the Pauatahanui Arm, with each site having adjoining sediment chemistry and benthic fauna collection areas.

This report presents the results of the fourth survey of Porirua Harbour subtidal sediment quality carried out in 2010; previous surveys were undertaken in May 2004, October 2005 and November 2008 (Williamson et al. 2005; Stephenson & Mills 2006; Milne et al. 2009). Following analysis of the 2010 survey samples in mid-2011, inconsistencies were discovered in the sediment particle size results. After a lengthy investigation into the cause of the data issues, the sediment samples from all four Porirua Harbour surveys were reanalysed in mid-2013, significantly delaying the completion of this report.

1.1 Monitoring objectives

The Porirua Harbour subtidal sediment quality monitoring programme has the following objectives:

1. To make regular assessments of the Porirua Harbour receiving environment in terms of sediment quality and benthic community health to provide a sound scientific basis for any management response in relation to urban stormwater discharges.

2. To detect changes in sediment quality and benthic community health over time, thereby allowing the ongoing evaluation of urban stormwater management actions directed at maintaining or enhancing the Porirua Harbour receiving environment.

[3] The reader is referred to Williamson et al. (2001) for further background on the effects of urban stormwater discharges on aquatic receiving environments in the Wellington region and the need for marine receiving environment monitoring.

2. Sites and methods

2.1 Sampling sites

To be suitable for long-term monitoring, sampling sites should preferably have a relatively high proportion of mud because many contaminants tend to bind to fine sediment particles and their low settling velocities mean they are likely to be widely dispersed (ie, represent far-field sources) (Ray et al. 2003). A description of the sampling sites, including the rationale for the selection of subtidal, as opposed to intertidal, sites, can be found in Williamson et al. (2005).

Taking into account the above criteria, Williamson et al. (2005) identified four locations in Porirua Harbour at which long-term sediment quality monitoring could be conducted (in parallel with assessments of benthic community health). An additional site, PAH3, was subsequently added by GWRC to monitor any impacts arising from urbanisation of land to the northwest of the Pauatahanui Arm, giving a total of five long-term monitoring sites (Table 2.1, Figure 2.1). These sites represent a selection of the subtidal habitats present in the harbour.

Table 2.1: Site position and collection details for the Porirua Harbour subtidal sediment quality monitoring undertaken in November/December 2010

Site	Location	Date	Position (NZTM) Easting	Northing	Depth[1] (m)
PAH1	Pauatahanui Arm off Browns Bay	2/12/2010	1758157	5448052	2.0
PAH1B		9/11/2010	1758136	5448074	
PAH2	Pauatahanui Arm off Duck Creek	2/12/2010	1759727	5448139	1.7
PAH2B		9/11/2010	1759759	5448116	
PAH3	Pauatahanui Arm off Camborne	2/12/2010	1758151	5449206	1.7
PAH3B		9/11/2010	1758154	5449222	
PAH3C		2/12/2010	1758141	5449182	
POR1	Onepoto Arm South	2/12/2010	1754864	5445871	2.0
POR1B		9/11/2010	1754834	5445890	
POR2	Onepoto Arm North	2/12/2010	1755179	5446506	2.8
POR2B		9/11/2010	1755158	5446538	
POR2C		2/12/2010	1755181	5446512	

[1] Approximate water depth at mean low water neap tide
B = Benthic fauna collection area
C = Bulk sediment reference sample collection site

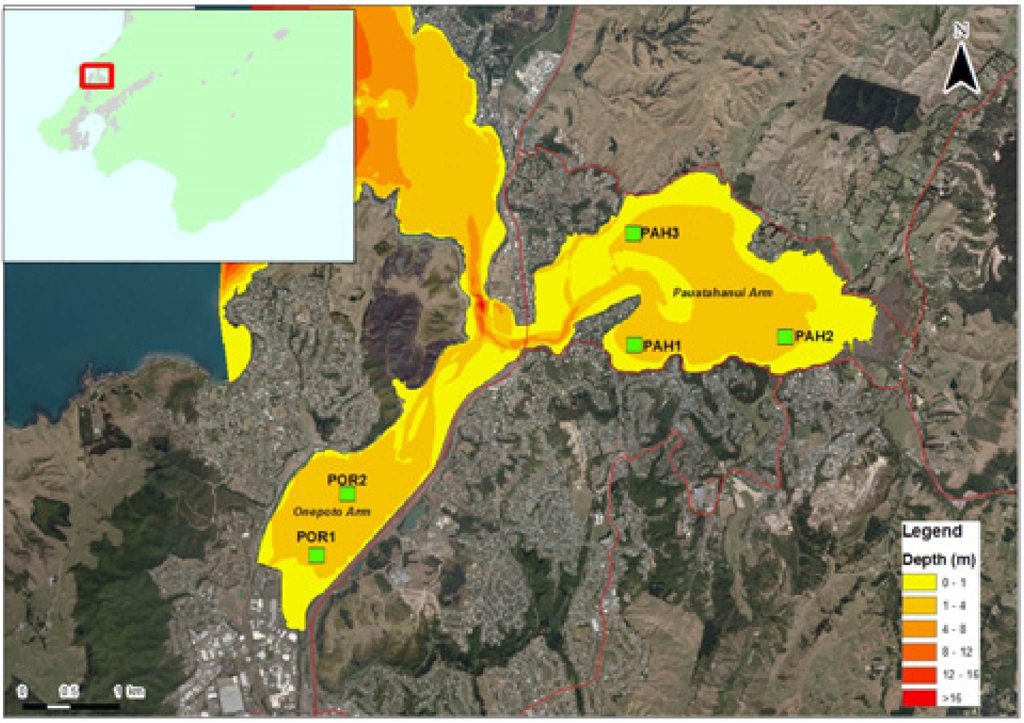

Figure 2.1: Map of Porirua Harbour and bathymetry showing the five subtidal locations sampled in November/December 2010

2.2 Sediment particle size distribution and chemistry

2.2.1 Sample collection

Sampling was conducted using a boat and divers equipped with SCUBA. At each site, the centre of the sediment chemistry collection area (a circle 20 m in diameter) was located by a Global Positioning System (GPS) and the boat anchored at this point. On the seabed, the collection area was divided into quadrants on the cardinal points of the compass and six 50 mm diameter x 120 mm deep sediment cores were collected at random from each quadrant by the divers. A separate screw-top polyethylene bottle, with the bottom cut off and replaced with a plastic insert, was used for each core (Figure 2.2). Bearings and distances from the boat to the dive points were determined from random number tables and measured by compass (nearest 10˚) and tape (nearest m), respectively. A further sediment core was taken from near the centre of the collection area to give a total of 25 samples. The samples were kept upright whilst being brought to the surface and placed in a chilli bin containing ice-packs for transport to the laboratory.

Figure 2.2: Example of a sediment core from Porirua Harbour. Only the top 30 mm of the sediment is used to analyse sediment particle size distribution and chemistry
(Photo: G. Stephenson)

The sediment samples were stored upright in a refrigerator at 4°C for a minimum of 12 hours to allow the water content of the surface sediment to reduce. The 25 samples from a site were randomly assigned to five groups. These groups became the five replicate composite samples for that site. With each sample, the bottle was placed on a tray, the top cap removed, and any overlying water carefully siphoned off. The bottom plug was loosened and the core extruded until the top 30 mm remained unexposed. The core was cut at this level with a plastic ruler and the sediment beyond 30 mm depth was discarded. The top 30 mm of the sediment was transferred into a polyethylene bag along with that from the four other samples in the group[4]. The composite sample was then frozen.

In addition, two bulk surficial sediment samples were collected using a small Ekman grab from subtidal areas adjoining sites PAH3 and POR2 (Table 2.1). This followed a recommendation made by Milne et al. (2009) to collect and prepare a 'Porirua Harbour Reference Sediment' for on-going quality assurance and control of sediment chemistry analyses. The two bulk sediment samples were stored in a refrigerator at 4°C to allow the water content of the sediment to reduce. Any overlaying water was carefully siphoned off and the samples frozen for transport to the laboratory.

2.2.2 Sample preparation

Sample preparation was consistent with previous surveys and followed the steps shown in Figure 2.3. Each thawed replicate composite sample was

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[4] Only the top 30 mm of the sediment column from each core sample was retained as this depth is equivalent to the average depth of the surface mixed layer observed in X-radiographs of dated sediment cores collected in an historical sedimentation survey of the Pauatahanui Arm by Swales et al. (2005).

homogenised by mixing it in a shallow plastic tray. A sub-sample was wet-sieved through a nylon mesh to obtain a representative <63 µm fraction that was then freeze-dried for later analysis of weak acid-extractable metals and for long-term storage. The remainder of each whole replicate sample was freeze-dried in preparation for analysis of sediment particle size, total organic carbon and total metals (Olsen & Stewart 2011). Prior to these analyses, the freeze-dried replicate samples were dry-sieved through a 500 µm screen to remove coarse debris (eg, shell fragments).

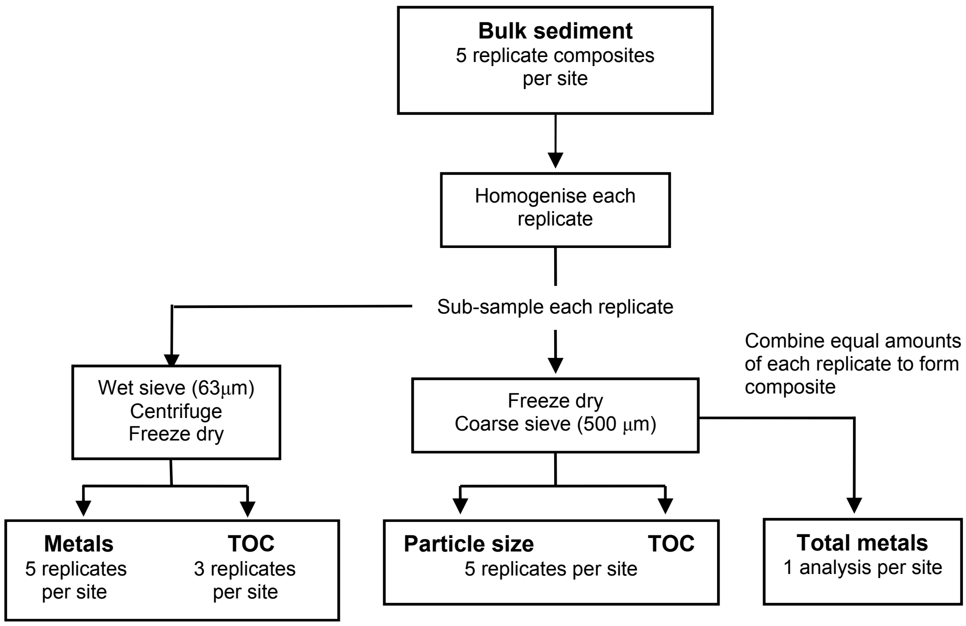

Figure 2.3: Sample preparation scheme (adapted from Williamson et al. 2005)

2.2.3 Sample analysis, quality assurance and storage

(a) Sediment particle size distribution

Particle size analysis of the <500 µm fraction was conducted using an Eyetech particle size analyser. Each sediment sub-sample was freeze-dried and then dry-sieved through a 500 µm screen to remove coarse debris. The material was ultrasonically dispersed for four minutes before analysis. Typically, 10^5–10^6 particles are counted per sample. Traceable standards were used to ensure the reliability of particle size results. Particle volumes were calculated from the measured particle diameters and used to produce a particle-size volume distribution for each sample (Olsen et al. 2013).

Initially, the samples were analysed using the A-lens of the Eyetech analyser, consistent with the analysis of Porirua Harbour subtidal sediments in 2008[5] (Milne et al. 2009) and Wellington Harbour subtidal sediments in 2006 (Stephenson et al 2009). However, inconsistencies were found in the particle size data sets across the four Porirua Harbour and two Wellington Harbour sediment surveys that were attributed to a change of particle size analyser in 2007. This prompted reanalysis of all sediment particle size samples from the

[5] This differed from the 2004 and 2005 particle size assessments which were undertaken using a Galai CIS-100 'time-of-transition' stream-scanning laser particle sizer.

2004, 2005, 2008 and 2010 surveys. This reanalysis work was all carried out in mid-2013 using the B-lens of the Eyetech particle sizer, following experimental trials at NIWA which found that this lens was better suited to mud samples that also contain a very small amount of sand particles. The B-lens has a larger measurement volume (10–500 µm compared with 0.1–300 µm using the A-lens) and provided a higher level of repeatability (Olsen et al. 2013).

(b) Total organic carbon

A portion of the freeze-dried <500 µm fraction of each replicate sample was analysed for total organic carbon (TOC) using an Elementar Combustion Analyser, after acid pre-treatment to remove carbonates. Organic carbon is usually included in sediment quality monitoring programmes because it can influence the bio-availability of toxic organic compounds. In addition, comparison of toxic organic compound concentrations with the sediment quality guidelines used in New Zealand requires concentrations to be normalised to 1% organic carbon. Although the 2008 and 2010 Porirua Harbour sediment sample analyses primarily focused on metals rather than organic contaminants, TOC was still analysed because it plays a central role as a binding phase for many trace metals, such as copper and zinc, and correlation of metal concentrations with organic carbon can allow detection of unusual contaminant depletion or enrichment patterns. For this reason, a portion of the <63 µm fraction of three of the five replicate samples from each site was also analysed for TOC.

(c) Total metals

A single composite was prepared from portions of the freeze-dried <500 µm sub-samples of the five replicates from each sampling site. This composite was digested using strong, hot hydrochloric and nitric acids, and the digest analysed by inductively coupled plasma-mass spectrometry (ICP-MS) for total recoverable arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver and zinc.

(d) Weak acid-extractable metals

A portion of the <63 µm fraction of each replicate sample was extracted using weak (2M) cold hydrochloric acid and the extract analysed by ICP-MS for copper, lead and zinc. This technique minimises analytical variability and, therefore, is better for trend analysis. The weak acid-extractable fraction is considered to be a better measure of bio-available metals (Auckland Regional Council 2004).

(e) Polycyclic aromatic hydrocarbons (PAHs)

A portion of the freeze-dried <500 µm fraction of each replicate at site POR1 was analysed for the standard 16 USEPA priority pollutant polycyclic aromatic hydrocarbons (PAHs) and eight additional PAHs. All samples were spiked with analytical surrogates and extracted with organic solvents using accelerated solvent extraction (ASE). Silica/alumina column chromatography and silica column chromatography were used to clean up and fractionate the extracts, respectively. Internal standards were added to all extracts before analyses.

Quantitative analysis of PAHs was carried out by capillary gas chromatography using mass selective (GC/MS) detection in selected ion mode. Concentrations were corrected for surrogate recoveries. Minimum detection limits were approximately 0.1–7 ng/g dry weight.

(f) Organochlorine pesticides (OCPs)

A portion of the freeze-dried <500 µm fraction of each replicate at all sites was analysed for selected organochlorine pesticides. Quantitative analyses were carried out by capillary gas chromatography. As for PAH analyses, the samples were spiked with analytical surrogates and extracted with organic solvents using accelerated solvent extraction (ASE). Silica/alumina column chromatography and silica column chromatography were used to clean up and fractionate the extracts, respectively. Internal standards were added to all extracts before analyses.

Quantitative analysis of OCPs was carried out by GC/MS in selected ion mode. Concentrations were corrected for surrogate recoveries. Minimum detection limits were approximately 0.1–0.2 ng/g dry weight.

(g) Quality assurance

Quality assurance (QA) for the sediment chemistry involved duplicate or triplicate analyses of samples to assess ‘within-sample’ variability. In addition, archived Porirua Harbour and Wellington Harbour samples collected in 2008 and 2006, respectively, were analysed to assess ‘between-sample’ variability. Quality assurance analyses are summarised below:

- Particle size (500 µm fraction): 9 duplicate or triplicate analyses, 13 archived samples (2004, 2005 and 2008)
- Total organic carbon (500 µm fraction): 1 duplicate sample, 1 archived sample (2008)
- Total organic carbon (63 µm fraction): 1 duplicate sample, 1 archived sample (2008)
- Total metals: 1 archived Porirua Harbour sample (2008)
- Weak acid-extractable metals: 1 duplicate sample, 1 archived sample (2008)
- Polycyclic aromatic hydrocarbons: 1 archived Wellington Harbour sample (2006), 1 Sediment Reference Material (SRM 1941b)
- Organochlorine pesticides: 1 duplicate, 1 archived sample (2005)

(h) Long-term sediment sample storage

The remaining portions of all replicate samples have been stored in stable conditions to permit future analysis and quality control.

2.3 Benthic fauna

2.3.1 Sample collection

At each site the centre of the benthic fauna collection area (a circle 20 m in diameter) was relocated using a Global Positioning System and the boat anchored at this point. The collection area was divided into quadrants on the cardinal points of the compass and two 200 mm diameter x 250 mm deep sediment cores were collected from each quadrant by divers to give a total of eight samples. Bearings and distances from the boat to the dive points were determined from random number tables and measured by compass (nearest 10˚) and tape (nearest m) respectively. Two 50 mm diameter x 120 mm deep sediment cores were taken from near the centre of the collection area for particle size analysis.

2.3.2 Sample preparation and analysis

(a) Benthic fauna analyses

Benthic fauna samples were transferred from the corers into labelled plastic bags for transport to the laboratory, where they were washed on a 500 µm screen. The material retained by the screen was placed in 400 mL polyethylene jars and fixed in a solution of 5% formalin in seawater. Animals were picked out under a binocular microscope, identified as far as practicable[6], counted, and preserved in 70% isopropyl alcohol. Shell lengths of selected species of bivalves were measured to the nearest 0.1 mm using an ocular micrometer (≤ 10 mm) or digital callipers (>10 mm).

At the conclusion of the analysis of the fauna, representative specimens of species not found in the previous surveys were labelled and added to the existing Porirua Harbour benthic fauna reference collection.

(b) Sediment grain size analyses

Following recommendations made in the 2008 survey report (Milne et al. 2009) and concerns about the within-site variability of particle size distribution, sediment samples from the benthic collection areas were analysed using two methods: wet sieving and laser particle size distribution.

(i) Laser particle size distribution

Sediment samples were prepared and analysed for particle size in the same manner as the sediment chemistry samples. For each site, the sediment in the top 30 mm of the two cores was removed and combined to form a composite, which was then homogenised, freeze-dried, dispersed by ultrasound and sieved at 500 µm. Particle size analysis of the <500 µm fraction was conducted using the A-lens of an Eyetech Particle Size Analyser, as described in Section 2.2.3. For QA purposes, two sediment chemistry samples were also analysed to assess within-sample variability.

(ii) Wet sieving grain size distribution

A portion of the material collected for particle size distribution was digested for at least two days using 6–10% hydrogen peroxide to remove organics. Samples were wet sieved using a stack of sieves (2 mm, 500 µm, 250 µm, 125 µm and 63 µm) with final wash water collected for further analysis. The sediment was washed from each sieve into an appropriate pre-weighed labelled container. Any overlying water was decanted after one hour and then the sample was dried to constant weight in an oven at 60ºC.

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6 Where genus and species names could not be assigned with certainty due to damage to the specimens, small size, immaturity or taxonomic difficulties, the species were designated "#1", "#2", "#3", etc., following the class, family or generic name as appropriate.

The wash water containing the mud fraction was further processed using the pipette analysis method to provide data for the fractions <31µm (clay) and between 31µm and 63µm (silt). Mud was washed into a 1L measuring cylinder (at room temperature) and sealed with parafilm. The cylinder was inverted and two samples then collected immediately using a 10mL pipette (ie, 20 mL) at 10 cm below the water surface. Both samples were transferred to one pre-weighed container and dried to constant weight in an oven at 60ºC (Olsen & Ovenden 2011).

2.4 Data analysis

2.4.1 Sediment chemistry

(a) Sediment quality guidelines

Both the Australian and New Zealand Environment and Conservation Council (ANZECC 2000)[7] and the Auckland Regional Council's (2004) 'Environmental Response Criteria' (ERC) sediment quality guidelines were used to assess the potential ecological effects of contaminants in the Porirua Harbour subtidal sediments (Table 2.2). These guidelines are generally considered to be reasonably robust, and conservative (ie, they err on the side of environmental protection). They are not 'pass or fail' numbers, and the developers of the guidelines emphasise that they are best used as one part of a 'weight of evidence' approach to evaluating potential effects of contaminants on benthic biota.

The ANZECC (2000) guidelines, and other international sediment quality guidelines on which they are based (ie, Long & Morgan 1990), provide 'low' and 'high' values:

1. The 'low' values (ANZECC ISQG-Low) are nominally indicative of the contaminant concentrations where the onset of biological effects could possibly occur. These values provide an 'early warning', enabling management intervention to prevent or minimise adverse environmental effects.

2. The 'high' values (ANZECC ISQG-High) are nominally indicative of the contaminant concentrations where significant biological effects are expected. Exceedance of these values therefore indicates that adverse environmental effects are probably already occurring, and management intervention may be required to remediate the problem.

The Auckland Regional Council's (2004) amber and red ERC were derived from the Threshold Effect Levels (TEL) and Effects Range Low (ERL) values (with rounding) of MacDonald et al. (1994) and Long and Morgan (1990) respectively (Kelly 2007). These guidelines provide a conservative, yet practical[8] early warning of environmental degradation which allows time for

[7] Note that the ANZECC sediment quality guidelines are currently under review and some guideline values are likely to change.

[8] Some of the ANZECC guideline values are not practical. For example, the organochlorine pesticide dieldrin has an ANZECC ISQG-Low value of 0.02 µg/kg (parts per billion), which is below the analytical detection limits of almost all laboratories, and probably represents a level that would be present at most rural and urban estuaries in New Zealand. Some other examples of differences between the ANZECC and ARC ERC guidelines are discussed in ARC (2004).

investigations into the causes of contamination to be carried out and the options for limiting the extent of degradation to be developed (ARC 2004; Kelly 2007).

Table 2.2: Sediment quality guidelines used in assessing the results of the November/December 2010 Porirua Harbour subtidal sediment quality survey. Guideline values are taken from ANZECC (2000) and ARC (2004)

Analyte	ANZECC trigger values		ARC ERC thresholds	
	ISQG-Low	ISQG-High	amber	red
Metals (mg/kg dry wt):				
Arsenic[1]	20	70		
Cadmium	1.5	10		
Chromium	80	370		
Copper	65	270	19	34
Lead	50	220	30	50
Mercury	0.15	1		
Nickel	21	52		
Silver	1	3.7		
Zinc	200	410	124	150
Organics (ng/g)				
LMW PAH (1% TOC)	552	3,160		
HMW PAH (1% TOC)	1,700	9,600	660	1700
Total PAH (1% TOC)	4,000	45,000		
Dieldrin	0.02	8		0.72
Total DDT	1.6	46		3.9

[1] Arsenic is, strictly speaking, a metalloid (ANZECC 2000)

(b) Statistical analyses

Differences in the concentrations of copper, lead and zinc (obtained using weak acid digestion), and the proportion of TOC and mud (<63 µm), were plotted using means and 95% confidence intervals[9] (CI) so that differences among sites and changes through time (ie, between 2004 and 2010) could be visualised. Least-squares linear regression was then used to identify statistically significant temporal trends.

2.4.2 Benthic fauna

The number of species, wet weight of each species (biomass), mean number of species per sample and mean number of individuals per sample were determined for each site. The size frequency distributions of selected species of bivalves were determined and summarised in diagrammatic form as dot plots.

Spatial and temporal variation in the composition of benthic communities was examined using diversity indices and multivariate analyses. Multivariate analysis was also used to examine the relationship between community structure and environmental variables (ie, sediment texture, metal concentrations and TOC). All analyses were carried out using Primer-E (v6.1.15), and readers are referred to Clarke and Gorley (2006) and Clarke and Warwick (2001) for further details on most of the analyses used.

[9] Points with confidence intervals that don't overlap are significantly different from each other.

Species were also assigned to one or more of five feeding modes (predators/ scavengers, surface deposit feeders, subsurface deposit feeders, suspension feeders and unknown) (Stephenson & Mills 2006). However, as the feeding biology of many of the species encountered has yet to be studied, it was often necessary to utilise data on their nearest taxonomic relatives and/or apparent ecological equivalents elsewhere to predict the most likely feeding mode for the species. Species whose feeding mode was uncertain or could not be predicted from the available data were placed in a separate class, giving five categories in all. For species which were assigned to more than one feeding mode, equal proportions of the individuals of that species were arbitrarily assigned to each mode; if the numbers would not divide equally the last individual was placed in what was known or considered to be the dominant feeding mode for the species in this environment. The percentage of individuals in each feeding mode at each site was calculated.

(a) Diversity

The Shannon diversity index is a commonly used measure of diversity that takes into account the number of species present (species richness) and how evenly the number (or biomass) of individuals is spread amongst these species (equitability). The latter consideration is an important feature of the index, as one community may have more species, but lower diversity than another, if one (or a few) species are numerically dominant. Interpretation of Shannon's diversity index is therefore aided by specific information on species richness and equitability. Three measures of diversity were therefore examined:

- the number of species per sample;
- the Shannon diversity index (using base *e*); and
- Pielou's evenness index.

Pielou's evenness index is a measure of how even (ie, similar) the abundances of individual species are at a site. Low index values indicate that the site is dominated by a single, or a few, species which occur in high abundance(s). The remaining species occur in relatively low abundances. In contrast, high index values indicate that the abundances of all species are fairly similar. Temporal variation in the number of species, the Shannon diversity index and Pielou's evenness index were examined by plotting mean (± 95% CI) values for each of the sites sampled in 2004, 2005, 2008 and 2010.

(b) Community structure

Non-metric multi-dimensional scaling (MDS) and cluster analysis were used to identify patterns in ecological data, based on the similarity (or dissimilarity) of species assemblages. Untransformed (ie, raw) and log x+1 transformed count data, using Bray Curtis similarity, were used to examine spatial differences and temporal changes in the composition of the benthic communities. These techniques were used to identify patterns in ecological data, based on the similarity (or dissimilarity) of species assemblages. These provide an easily interpretable representation of the data (ie, samples that are close together on an MDS plot are more similar than samples that are further apart). Identification of the key species involved in producing the observed patterns was made by looking at similarity percentages (using Primer's SIMPER routine) and overlaying bubbleplots of species abundance on the MDS plots. Similarly, the relationship between community structure and various environmental variables (both physical and chemical) was examined by overlaying bubbleplots of the variables on MDS plots.

For the above analyses, the mean values for environmental variables from a site and year were applied to all eight replicate benthic fauna samples obtained from that site and year. Although the locations of sediment chemistry and benthic fauna collection areas differ slightly at each site, Stephenson and Mills (2006) could find no evidence of significant faunal or environmental differences between each set in the 2004 and 2005 surveys, and the same appeared to be the case in the 2010 survey (Stephenson pers. comm.). It is therefore assumed that the data obtained from each sediment chemistry collection area are representative of its adjoining benthic fauna collection area.

The above methods provide a relatively good representation of the dominant patterns in benthic community structure, and allow the visualisation of relationships between a representation of community structure (which emphasised the influence of the most abundant species) and a range of environmental variables. However, the most abundant species are not necessarily the most sensitive species to environmental change. Canonical analysis of principal coordinates (CAP) was therefore used to examine more subtle relationships between the environmental variables and benthic community structure. Readers are referred to Anderson et al. (2002) and Anderson et al. (2006) for a description of CAP and the methods used.

Canonical analysis of principal coordinates was carried out using Bray Curtis similarities of square root transformed species counts (using total counts for each site-year), and PCA1 values derived from Principal Component Analysis (PCA) of the normalised environmental variables: copper, lead, zinc, silver, arsenic, cadmium, chromium, mercury, nickel, TOC and sediment texture (% mud – ie, <63 µm). Normalisation allowed a combination of variables with different measurement scales to be included in the analysis (ie, metal concentrations, and TOC and sediment texture percentages). An important consequence of normalisation is that it ‘equalises’ the contributions of each variable to the multivariate analysis. This was considered to be desirable for metals, because the ecological effects of small changes in the concentration of one metal could be similar to large changes in the concentration of another metal (Milne et al. 2009).

3. Results

The sediment particle size and chemistry results from the 2010 subtidal sediment quality survey are summarised in this section, along with the benthic fauna results. Comparisons are also made with the results of the 2008, 2005 and 2004 subtidal surveys. The complete set of sediment particle size and associated quality assurance results for the sediment quality and benthic ecology collection areas are listed in Appendix 1 and Appendix 2, respectively. The chemistry results and relevant quality assurance results are listed in Appendix 3. The list of benthic fauna recorded in Porirua Harbour in 2010 and their respective feeding modes are listed in Appendix 4.

3.1 Sediment particle size and chemistry

3.1.1 Sediment particle size distribution

A summary of particle size results from the five sediment chemistry collection areas are given in Table 3.1 and Figure 3.1. Mean particle size and the mean percentage of particles in the <63 µm size fraction at each of the five monitoring sites are shown in Table 3.2.

The mean particle size was greater in sediments from the Pauatahanui Arm (73.2–108 µm) than the Onepoto Arm (44.5–53.3 µm). Consistent with previous surveys, the mean percentages of particles <63 µm in the sediments of sites in the Pauatahanui Arm were significantly lower (22–42%) than those of sites in the Onepoto Arm (71–82%) (Table 3.2). Variability in the mean percentage of particles <63 µm was reasonably low in sediments from all sites (coefficient of variation [c.v.] 3.9–8.1%).

3.1.2 Total organic carbon

Mean total organic carbon (TOC) content in the <63 µm and <500 µm fractions of the sediments from the five monitoring sites is summarised in Table 3.2. Consistent with previous surveys, the mean TOC (<500 µm) content in the sediments of sites in the Pauatahanui Arm were lower (0.98–1.67%) than those of sites in the Onepoto Arm (1.91–2.4%) (Figure 3.1), reflecting the greater proportions of sand in the Pauatahanui Arm sediments. Variability in the mean TOC content of both the <63 and <500 µm fractions was reasonably low for all sites (c.v. 1.1–4.1%, <63 µm fraction; 1.5–4.2%, <500 µm fraction).

Quality assurance results indicate good agreement (within 6%) was obtained in the ‘within-sample’ and ‘between-sample’ comparisons (Appendix 3).

Table 3.1: Summary of particle size results from the sediment chemistry collection areas of sites sampled in the Porirua Harbour in November/December 2010

Sample	Mean (µm)	<63 µm (%)	63–125 µm (%)	125–250 µm (%)	250–500 µm (%)	Description of <500 µm fraction
PAH1/1	87.7	41.3	34.5	24.1	0	Very muddy sand
PAH1/2	80.5	44.3	37.8	18.0	0	Very muddy sand
PAH1/3	85.4	43.4	33.1	23.5	0	Very muddy sand
PAH1/4	88.4	37.0	40.5	22.5	0	Very muddy sand
PAH1/5	88.0	41.1	33.8	25.1	0	Very muddy sand
PAH2/1	69.2	44.8	48.9	6.25	0	Very muddy sand
PAH2/2	73.3	42.4	48.6	9.01	0	Very muddy sand
PAH2/3	70.0	44.6	48.9	6.49	0	Very muddy sand
PAH2/4	75.0	39.5	51.8	8.74	0	Very muddy sand
PAH2/5	78.7	37.0	49.3	13.6	0	Very muddy sand
PAH3/1	109.4	21.6	43.0	35.4	0	Muddy sand
PAH3/2	108.2	20.5	45.4	34.1	0	Muddy sand
PAH3/3	106.2	22.6	45.0	32.4	0	Muddy sand
PAH3/4	106.7	23.3	45.0	31.7	0	Muddy sand
PAH3/5	110.2	20.8	43.7	34.5	0.99	Muddy sand
POR1/1	49.1	75.2	24.7	0	0	Sandy mud
POR1/2	54.3	68.8	27.5	3.68	0	Sandy mud
POR1/3	62.6	63.9	26.6	9.31	0	Sandy mud
POR1/4	50.0	73.3	26.7	0	0	Sandy mud
POR1/5	50.4	72.3	27.1	0.55	0	Sandy mud
POR2/1	42.8	83.1	16.8	0	0	Sandy mud
POR2/2	50.5	77.2	15.2	7.49	0	Sandy mud
POR2/3	45.1	81.3	17.4	1.22	0	Sandy mud
POR2/4	43.4	83.3	16.6	0.02	0	Sandy mud
POR2/5	40.7	85.9	14.0	0	0	Sandy mud

3.1.3 Total metals

The total concentrations of each of the nine metals tested were generally higher in the sediments from sites in the Onepoto Arm than from sites in the Pauatahanui Arm (Table 3.2). This is consistent with the results of the 2004, 2005 and 2008 surveys (Figures 3.2–3.4).

Total copper and lead concentrations in the sediments from both sites in the Onepoto Arm (POR1, POR2) exceeded the ARC (2004) ERC amber thresholds for these metals, but were below their respective ANZECC (2000) ISQG-Low trigger values (Table 3.2, Figure 3.2). Total zinc concentrations at these two sites exceeded the ERC red threshold, with the concentration at site POR1 (Onepoto Arm south) equal to the ANZECC (2000) ISQG-Low trigger value of 200 mg/kg. These results are consistent with the 2008 survey findings (Milne et al. 2009).

Total arsenic, cadmium, chromium, nickel and silver concentrations in the sediments of sites in both the Pauatahanui and Onepoto Arms were all below their respective ANZECC ISQG-Low trigger values (Table 3.2, Figures 3.3 &

3.4). Total mercury concentrations were also below guidelines at all sites, although concentrations at both sites in the Onepoto Arm were close to the ISQG-Low trigger value.

The sediment concentrations of most metals were strongly correlated, particularly total copper, lead and zinc concentrations (Pearson r=0.973–0.994).

3.1.4 Weak-acid extractable metals

The mean concentrations of weak acid-extractable copper, lead and zinc in the <63 µm fraction of the sediments followed a similar spatial distribution to the total metal concentrations, being higher in the sediments of sites in the Onepoto Arm than in the Pauatahanui Arm (Table 3.2, Figure 3.5). The data displayed relatively low variability (c.v. 1.3–5.9%) which, as with previous surveys, suggests that it should be possible to detect relatively small changes in metal concentrations over time.

3.1.5 Polycyclic aromatic hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons were only analysed in sediments from one site (POR1) in the Onepoto Arm. TOC-normalised levels of total PAH, low molecular weight (LMW) PAH and high molecular weight (HMW) PAH were all below ANZECC (2000) ISQG-Low criteria and the ARC ERC amber criteria (Figure 3.6). Variability in PAH concentrations was low (c.v. 4.4, 4.4 and 5.0% for total PAH, LMW PAH, and HMW PAH, respectively) (Table 3.3).

The surrogate recoveries for PAH analyses were generally good (78–95%), with the exception of naphthalene (40%) which was typically low. There was good agreement for the ‘between-sample’ comparisons (9.1%) and good precision for the analyses of PAHs in the standard reference material (0.6%) (Appendix 3).

3.1.6 Organochlorine pesticides (OCPs)

The TOC-normalised total DDT isomers exceeded the ARC ERC red threshold of 3.9 mg/kg at all three sites in the Pauatahanui Arm, and at one site (POR1) in the Onepoto Arm (Table 3.3). The second site (POR2) exceeded ANZECC (2000) ISQG-Low trigger value of 1.6 mg/kg (Figure 3.7).

Hexachlorobenzene was detected at the two sites in the Onepoto Arm, but concentrations were largely below laboratory detection limits in the samples from the Pauatahanui Arm. Dieldrin exceeded the ANZECC (2000) ISQG-Low trigger value of 0.02 mg/kg at all five sites (Table 3.3). Chlordanes were all below laboratory detection limits.

Table 3.2: Mean particle size, mean percentage of particles <63 µm, and summary of concentrations and variability (coefficient of variation [c.v., %], *n*=5) of total organic carbon (TOC) and metals in sediments of five sites sampled in Porirua Harbour in November/December 2010. Sediment quality guidelines for comparison are ANZECC (2000) and Auckland Regional Council Environmental Response Criteria (ARC ERC; ARC 2004). Values in amber exceed the ARC ERC amber threshold and values in red exceed the ARC ERC red and/or ANZECC ISQG-Low thresholds

Analyte	Fraction	ANZECC		ARC ERC		PAH1		PAH2		PAH3		POR1		POR2	
	analysed	ISQG-Low	ISQG-High	amber	red	mean	c.v.	mean	c.v.	mean	c.v.	mean	c.v.	mean	c.v.
Mean particle size (µm)	<500 µm					86.0	3.85	73.2	5.26	108	1.57	53.3	10.5	44.5	8.33
Mean % particles <63 µm	<500 µm					41.4	6.74	41.6	8.08	21.8	5.42	70.7	6.29	82.2	3.92
TOC (%)	<63 µm					1.38	1.10	1.50	4.08	1.11	2.38	1.60	1.80	1.58	3.49
TOC (%)	<500 µm					1.56	1.48	1.67	3.17	0.98	4.14	2.40	4.17	1.91	2.97
Metals (mg/kg, 2 M HCl):															
Copper	<63 µm					9.24	3.64	9.04	4.33	8.32	2.61	16.2	5.95	13.2	3.65
Lead	<63 µm					19.8	1.26	17.2	4.25	17.0	2.15	32.2	4.05	32.0	2.21
Zinc	<63 µm					72.2	2.66	60.8	4.26	60.6	1.88	150	3.34	126	1.48
Total Metals (mg/kg):															
Silver	<500 µm	1	3.7			0.07	--	0.07	--	0.05	--	0.16	--	0.12	--
Arsenic	<500 µm	20	70			8.6	--	5.8	--	7.0	--	10.7	--	12.8	--
Cadmium	<500 µm	1.5	10			0.029	--	0.063	--	0.041	--	0.138	--	0.040	--
Chromium	<500 µm	80	370			16.9	--	13.1	--	14.1	--	20.0	--	22.0	--
Copper	<500 µm	65	270	19	34	10.4	--	8.7	--	7.7	--	23.0	--	19.2	--
Mercury	<500 µm	0.15	1			0.109	--	0.077	--	0.063	--	0.122	--	0.141	--
Nickel	<500 µm	21	52			11.4	--	8.9	--	9.6	--	12.6	--	13.8	--
Lead	<500 µm	50	220	30	50	21.0	--	17.2	--	15.6	--	40	--	38	--
Zinc	<500 µm	200	410	124	150	71.0	--	62.0	--	62.0	--	200.0	--	153.0	--

Table 3.3: Summary of concentrations and variability (coefficient of variation [c.v., %] *n*=3 (TOC), *n*=5 (PAHs, OCPs)) of total organic carbon (TOC), polycyclic aromatic hydrocarbons (PAHs) and selected organochlorine pesticides (OCPs) in sediments of sites sampled in Porirua Harbour in 2010. Sediment quality guidelines for comparison are ANZECC (2000) and Auckland Regional Council Environmental Response Criteria (ARC ERC; ARC 2004). Values in amber exceed the ANZECC ISQG-Low and values in red exceed the ARC ERC red thresholds respectively

Analyte	Fraction analysed	ANZECC		ARC ERC		PAH1		PAH2		PAH3		POR1		POR2	
		ISQG-Low	ISQG-High	amber	red	mean	c.v.	mean	c.v.	mean	c.v.	mean	c.v.	mean	c.v.
TOC (%)	<500 µm					1.56	1.48	1.67	3.17	0.98	4.14	2.40	4.17	1.91	2.97
Organics (ng/g)															
Total PAH[1,2]	<500 µm					--		--		--		651	5.05	--	
LMW PAH[1,2]	<500 µm					--		--		--		62.1	5.38	--	
HMW PAH[1,2]	<500 µm					--		--		--		386	5.92	--	
Dieldrin	<500 µm					0.34	26.5	0.31	25.9	0.43	11.2	0.20	48.4	0.10	0.00
Hexachlorobenzene	<500 µm					0.06	38.9	0.05	0.00	0.05	0.00	0.28	16.8	0.19	19.3
Total DDT[2,3]	<500 µm					6.14	3.78	8.83	4.92	4.08	5.99	11.4	12.0	6.51	1.41
Total PAH[4]	1% TOC	4,000	45,000			--		--		--		271	4.40	--	
LMW PAH[4]	1% TOC	552	3,160			--		--		--		25.9	4.39	--	
HMW PAH[4]	1% TOC	1,700	9,600	660	1,700	--		--		--		160	5.04	--	
Dieldrin[4]	1% TOC	0.02	8		0.72	0.22	26.5	0.19	26.4	0.44	12.3	0.08	48.6	0.05	2.13
Hexachlorobenzene[4]	1% TOC					0.04	38.9	0.03	2.21	0.05	2.90	0.12	18.2	0.10	21.0
Total DDT[4]	1% TOC	1.6	46		3.9	3.95	4.52	5.29	5.15	4.17	5.51	4.75	11.4	3.40	2.75

[1]Polycyclic aromatic hydrocarbons have been summarised as 'Total PAH' (all PAH compounds analysed); 'Total Low Molecular Weight PAH' (sum of concentrations of acenaphthene, acenaphthylene, naphthalene, fluorene, phenanthrene, anthracene, 2-methylnaphthalene); 'Total High Molecular Weight PAH' (sum of concentrations of chrysene, fluroanthene, pyrene, benz[a]anthracene, benzo[a]pyrene, and dibenzo[a,h]anthracene). This is the total used for the ANZECC (2000) sediment quality guidelines and ARC (2004) Environmental Response Criteria. All the PAH compounds are listed in Appendix 2.

[2]Total PAH, Total HMWPAH, Total LMWPAH, and Total DDT values have been calculated using 'less than detection' limit values as '0.5 times the detection limit'.

[3]DDT and related compounds have been summarised as 'Total DDT', which is the sum of concentrations of 2,4'-DDE, 2,4'-DDD, 2,4'-DDT, 4,4'-DDE, 4,4'-DDD and 4,4-DDT.

[4]Total PAH, Total HMW PAH, Total LMW PAH, dieldrin, hexachlorobenzene, and Total DDT concentrations expressed for a sediment containing 1%TOC. TOC normalisation is used in the ANZECC (2000) sediment quality guidelines and ARC Environmental Response Criteria for comparing sediments with different TOC content.

3.1.7 Comparison with previous surveys

The following section presents a summary of broad trends in the 2004, 2005, 2008 and 2010 sediment grain size and chemistry data.

(a) Sediment particle size distribution

The mean percentage of mud in the <63 µm fraction has remained higher in the Onepoto Arm over the course of the four surveys compared with the Pauatahanui Arm (Figure 3.1). Least squares linear regression analyses found that the percentage of mud showed a weak but statistically significant decrease at site PAH3 between 2004 and 2010 (R^2=0.326, p=0.009) (Table 3.4).

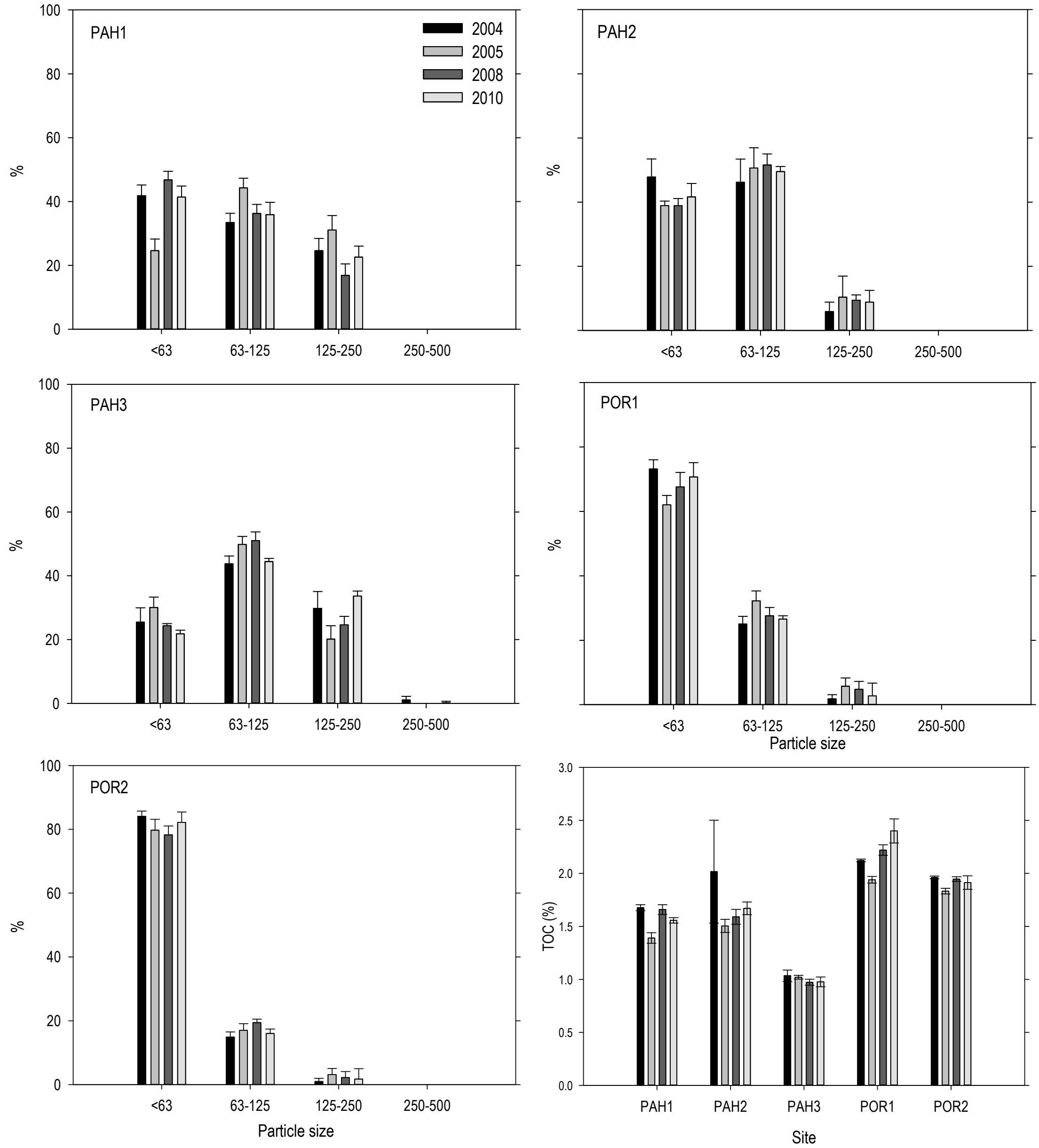

Figure 3.1: Sediment particle size distributions and TOC contents of sediments at five sites sampled in Porirua Harbour in 2004, 2005, 2008 and 2010, based on mean values (± 95% CI) from the <500 µm fraction of five composite samples from each site

The very fine (63–125 µm) and fine (125–250 µm) sand fractions showed little change through time at all sites (Figure 3.1). The coarse sand fraction (250–500 µm) was recorded at site PAH3 only, and in two of the four sampling years (2004 and 2010), representing less than 1% of the particle size distribution (Figure 3.1).

(b) Total organic carbon (TOC)

Total organic carbon content has remained reasonably stable and low at site PAH3 throughout the four surveys, likely reflecting the heterogeneous nature of the sediments at this site (Figure 3.1). In contrast, TOC is consistently higher at both sites in the Onepoto Arm, and increased significantly at site POR1 from 2.2% in 2008 to 2.4% in 2010, concurrent with an increase in mud content (Table 3.4).

(c) Total metals

The total concentrations of each of the nine metals analysed were generally lower, or similar, in 2010 than in the 2008 survey. Copper, lead and zinc continue to exceed ARC ERC amber thresholds for these metals at sites in the Onepoto Arm (Figure 3.2). At site POR1 zinc has exceeded the ARC ERC red threshold in all survey years and the ANZECC ISQG-Low thresholds in all survey years, except 2005. Overall, there have been small decreases in the concentrations of lead and moderate decreases in the concentrations of copper since 2004 at all sites.

Mercury has increased in concentration at sites PAH1, POR1 and POR2, and although the values approach the ANZECC (2000) ISQG-Low trigger value, they do not exceed it (Figure 3.3). All other metals analysed were well below sediment quality guidelines in all surveys (Figures 3.3 & 3.4).

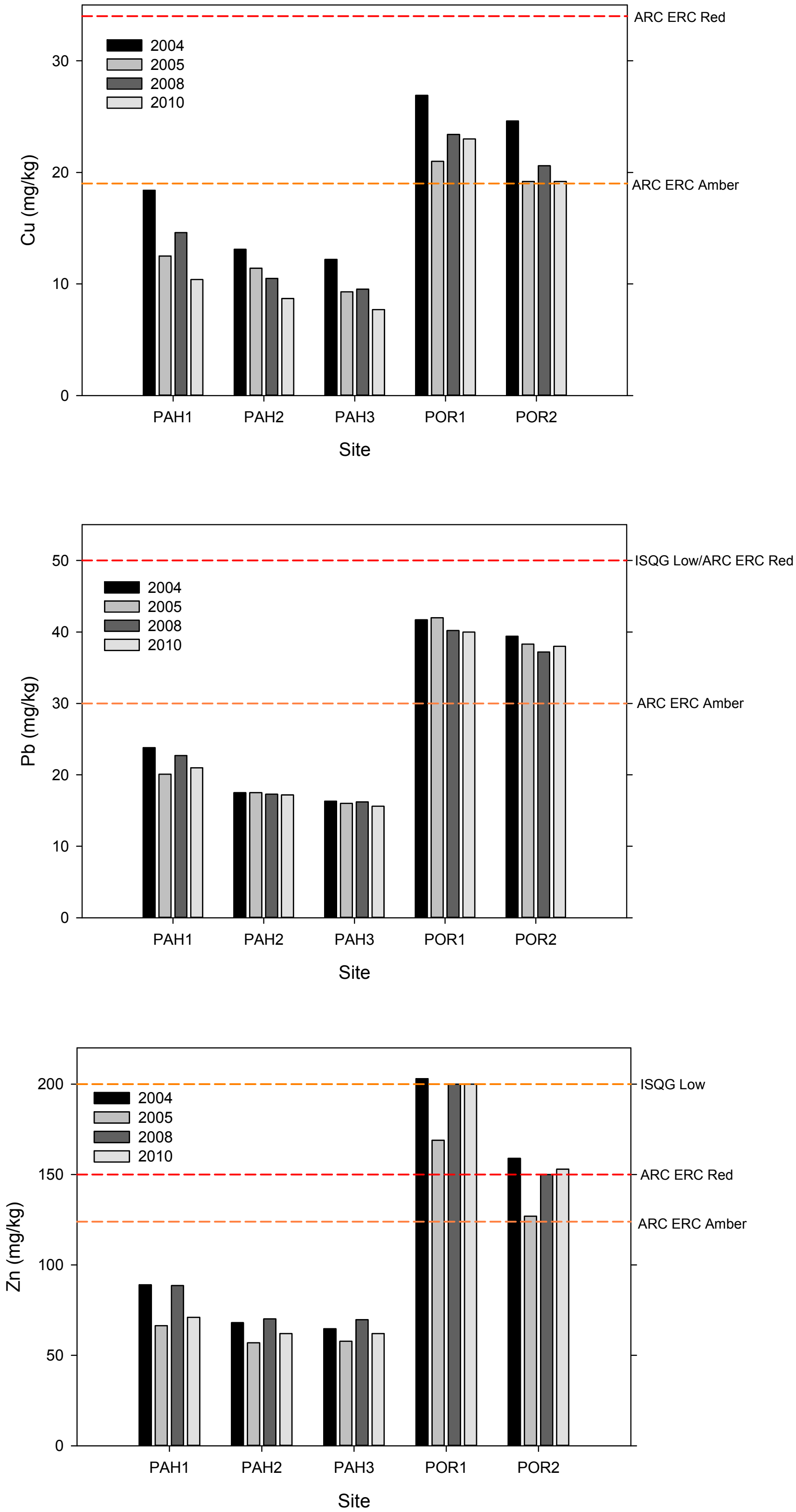

Figure 3.2: Concentrations of total copper (Cu), lead (Pb) and zinc (Zn) in sediments of five sites sampled in Porirua Harbour in 2004, 2005, 2008 and 2010, based on the <500 µm fraction of a single composite sample from each site

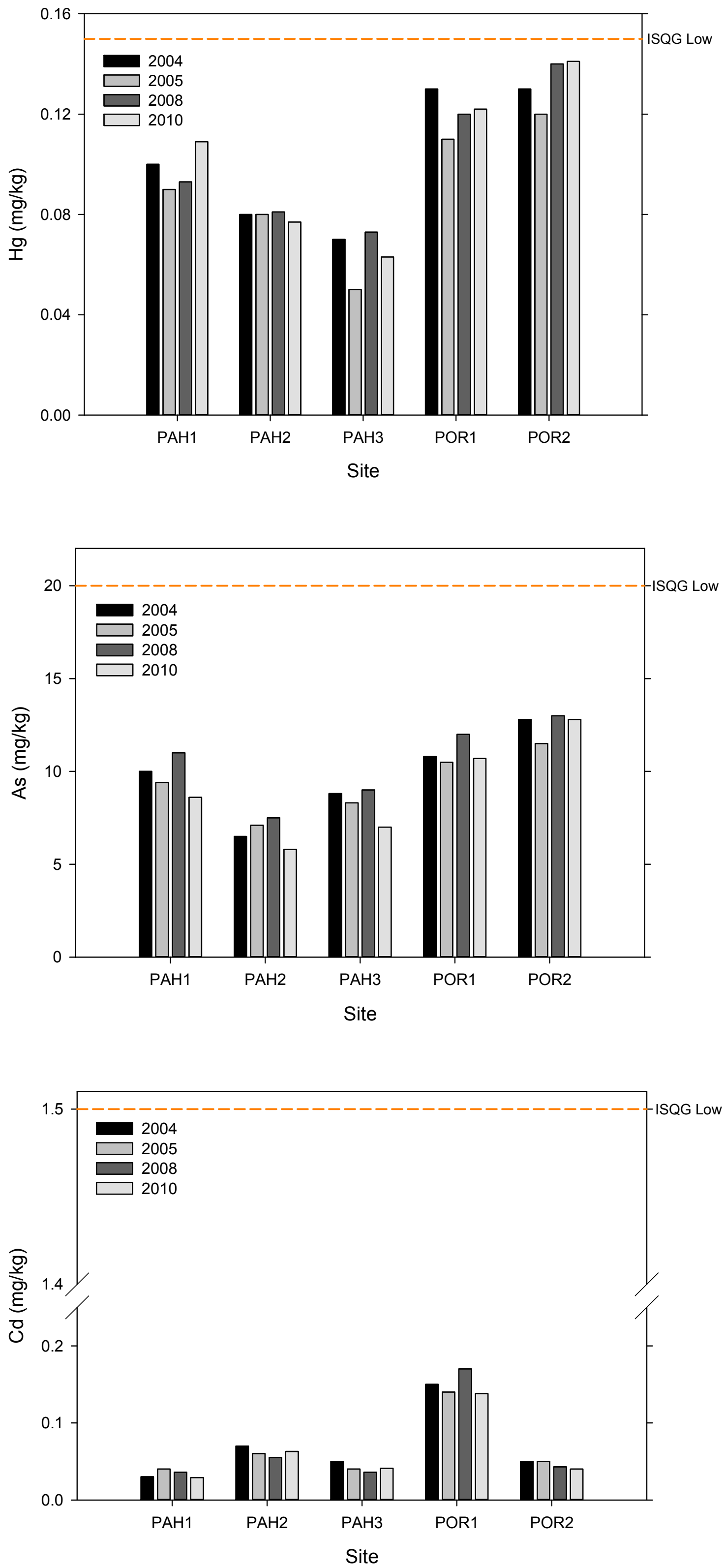

Figure 3.3: Concentrations of total mercury (Hg), arsenic (As) and cadmium (Cd) in sediments of five sites sampled in Porirua Harbour in 2004, 2005, 2008 and 2010, based on the <500 µm fraction of a single composite sample from each site

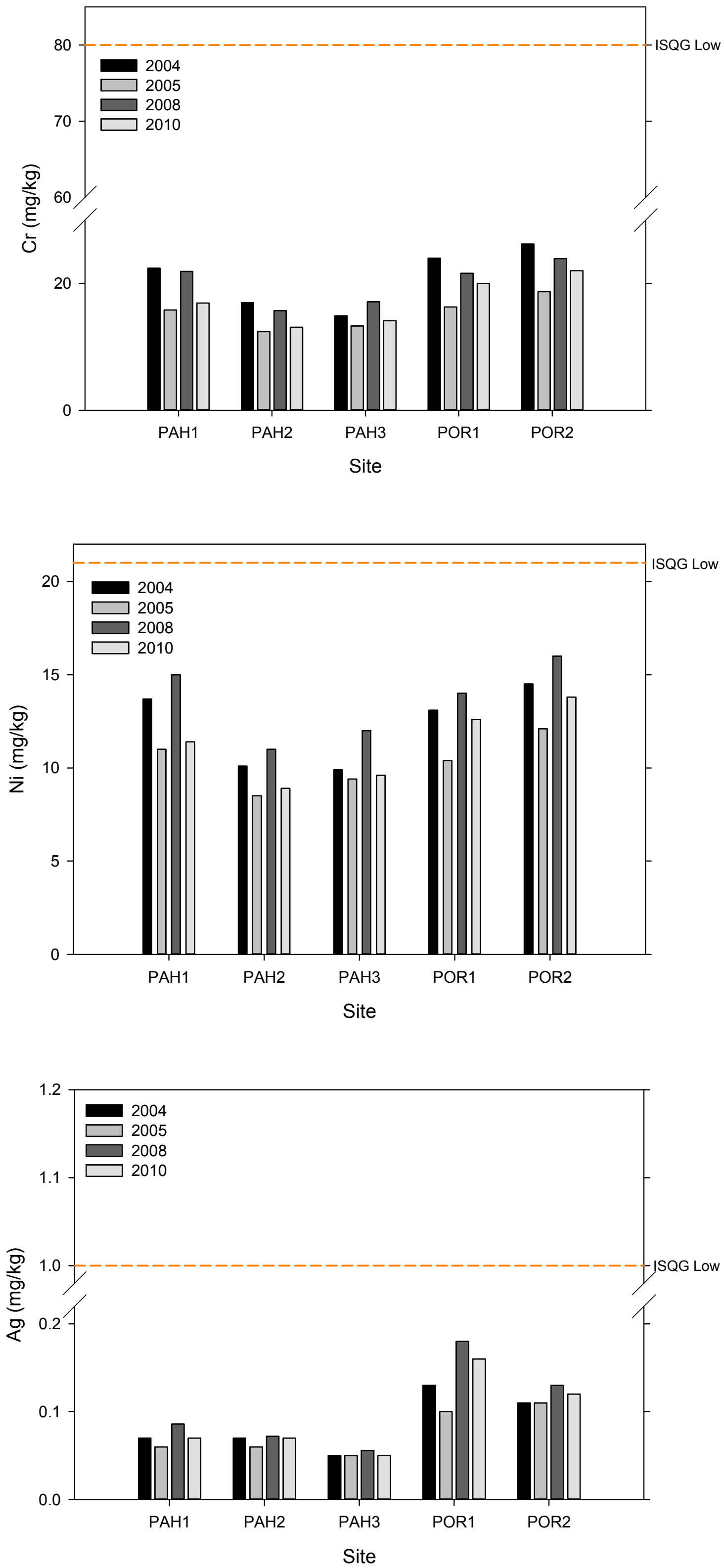

Figure 3.4: Concentrations of total chromium (Cr), nickel (Ni) and silver (Ag) in sediments of five sites sampled in Porirua Harbour in 2004, 2005, 2008 and 2010, based on the <500 µm fraction of a single composite sample from each site

(d) Weak-acid extractable metals

Regression analyses detected statistically significant increases in zinc concentrations in the mud fraction through time at all sites, except POR2, at which concentrations have been relatively stable (Table 3.4). Lead concentrations decreased significantly at sites PAH1, POR1 and POR2, with no detectable changes at sites PAH2 and PAH3. Copper concentrations decreased significantly at sites PAH1 and POR2 and increased through time at site PAH2. The regression analyses did not detect any significant overall increase in copper concentrations since 2004 at site POR1, however, concentrations within the mud fraction have been highly variable; copper decreased significantly from 2004 to 2008 and then increased between 2008 and 2010 (Figure 3.5).

Table 3.4: R^2 and probability values from least squares linear regression models of the change in weak acid-extractable copper, lead and zinc concentrations (<63 µm sediment fraction), mud content (% <63 µm), and TOC (%<500 µm)[1] in sediments of five sites sampled in Porirua Harbour in 2004, 2005, 2008 and 2010. Concentrations that have changed significantly over time are highlighted in red and the direction of change is indicated as + (increase) or – (decrease)

Site	Copper		Lead		Zinc		Mud		TOC	
	R^2	*p*	R^2	*p*	R^2	*p*	R^2	*p*	R^2	*p*
PAH1	0.4150	0.0022 (-)	0.9280	<0.0001 (-)	0.5346	0.0002 (+)	0.176	0.066	0.0116	0.6703
PAH2	0.3055	0.0115 (+)	0.1536	0.0874	0.8572	<0.0001 (+)	0.133	0.114	0.0715	0.2833
PAH3	0.0591	0.3016	0.0163	0.5916	0.6425	<0.0001 (+)	0.326	0.009 (-)	0.3081	0.0168 (-)
POR1	0.0765	0.2379	0.7940	<0.0001 (-)	0.3730	0.0042 (+)	0.008	0.708	0.5987	0.0002 (+)
POR2	0.5580	0.0002 (-)	0.8979	<0.0001 (-)	0.0343	0.4341	0.0328	0.445	0.0106	0.6849

[1] <63 µm TOC fraction data could not be used as TOC was only tested on the <500 µm fraction in 2004 and 2005.

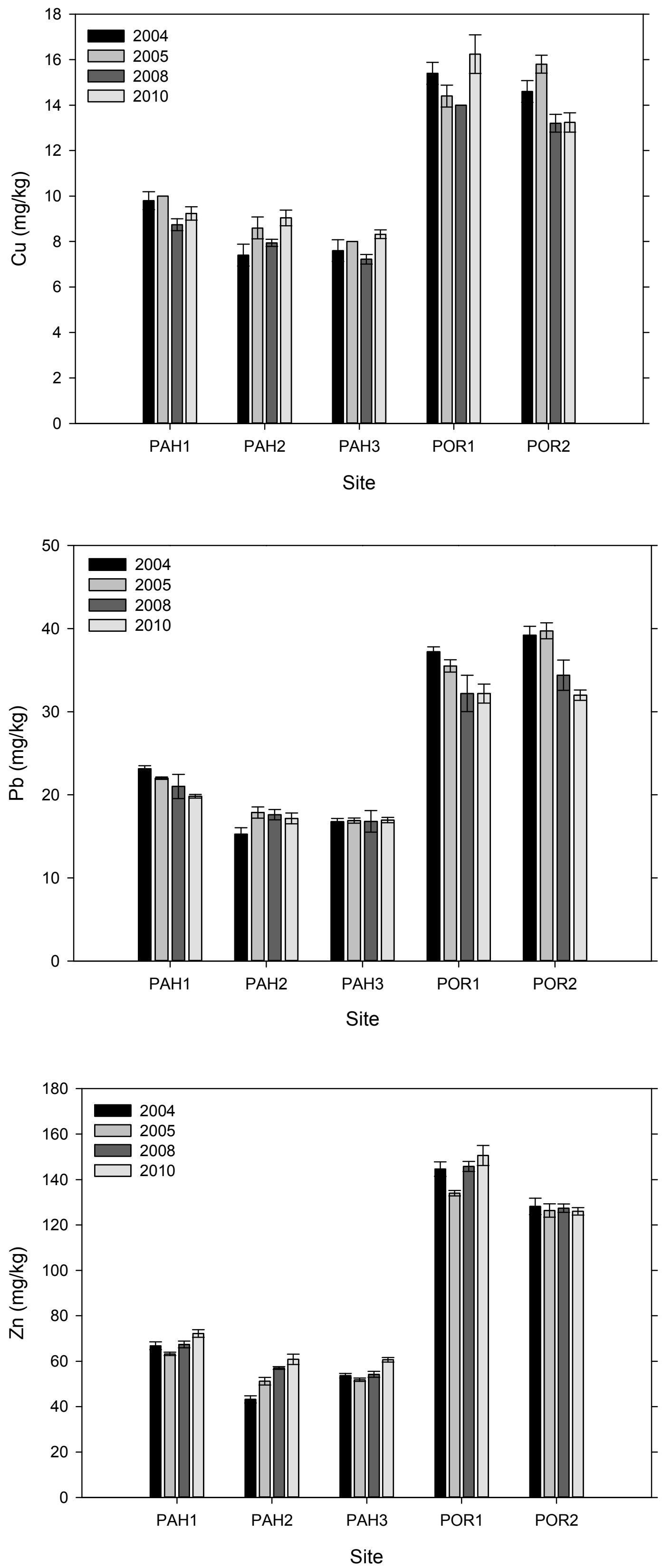

Figure 3.5: Mean (± 95% CI) concentrations of weak acid extractable copper (Cu), lead (Pb) and zinc (Zn) in sediments of five sites sampled in Porirua Harbour in 2004, 2005, 2008 and 2010, based on the <63 µm fraction of five composite samples from each site

(e) Polycyclic aromatic hydrocarbons (PAHs)

Mean total PAH concentrations at site POR1 in 2010 were not significantly different from previous surveys (Figure 3.6). However, TOC-normalised total PAH concentrations were significantly lower at this site in 2010 than in 2004 and 2005. Likewise, total HMW PAH concentrations were not significantly different from concentrations recorded in 2004 and 2005, but TOC-normalised HMW PAH values were significantly lower in 2010 than previous surveys.

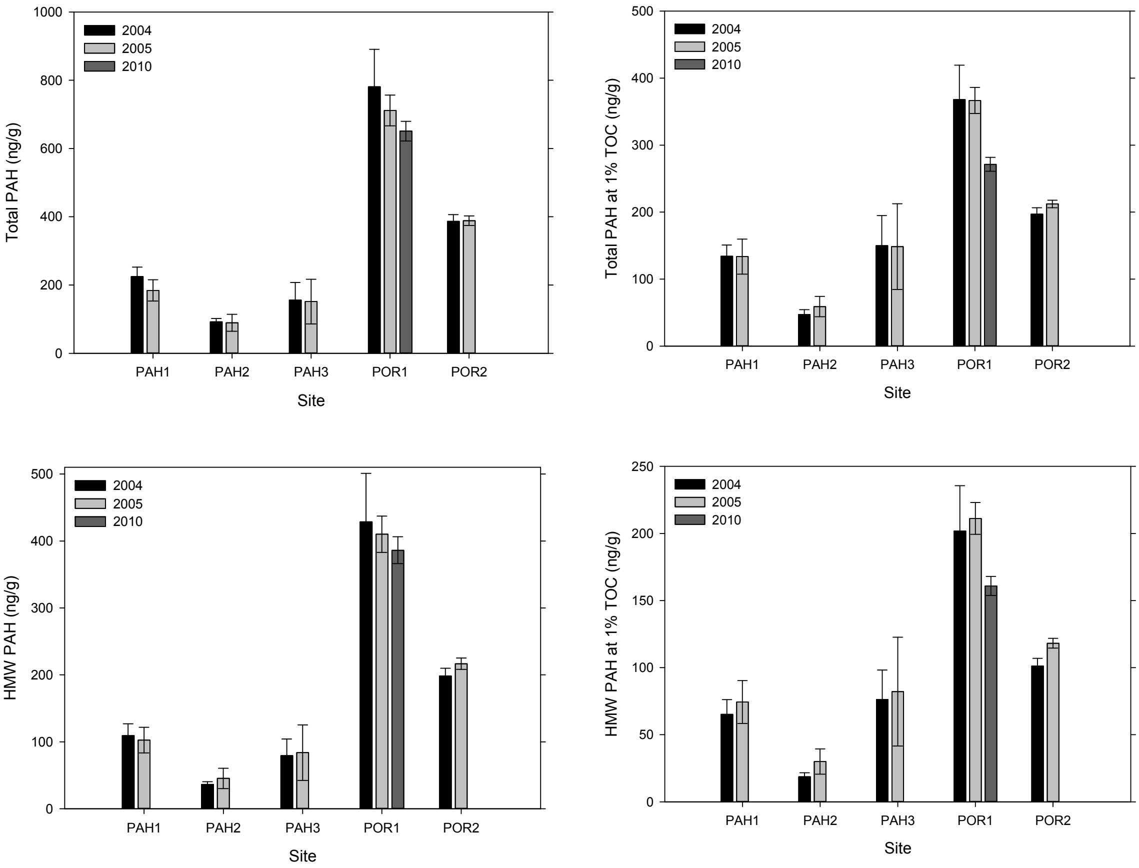

Figure 3.6: Mean (± 95% CI) concentrations of total PAH, total PAH at 1% TOC, HMW PAH and HMW PAH at 1% TOC in sediments of five sites sampled in Porirua Harbour in 2004, 2005 and 2010, based on the <500 µm fraction of five composite samples from each site

(f) Organochlorine pesticides (OCPs)

Mean concentrations of 4,4'-Total DDT have shown a general decline since first measured in 2004 at most sites, with the exception of site POR1 (Figure 3.7). Site POR1 recorded an increase in total DDT concentration from 2004 to 2005 and concentrations have remained consistently high since then.

TOC-normalised total DDT concentrations continue to exceed the ANZCC (2000) ISQG-Low trigger value at all sites (Figure 3.7). Concentrations at sites PAH2, PAH3 and POR1 also exceed ARC ERC red trigger value.

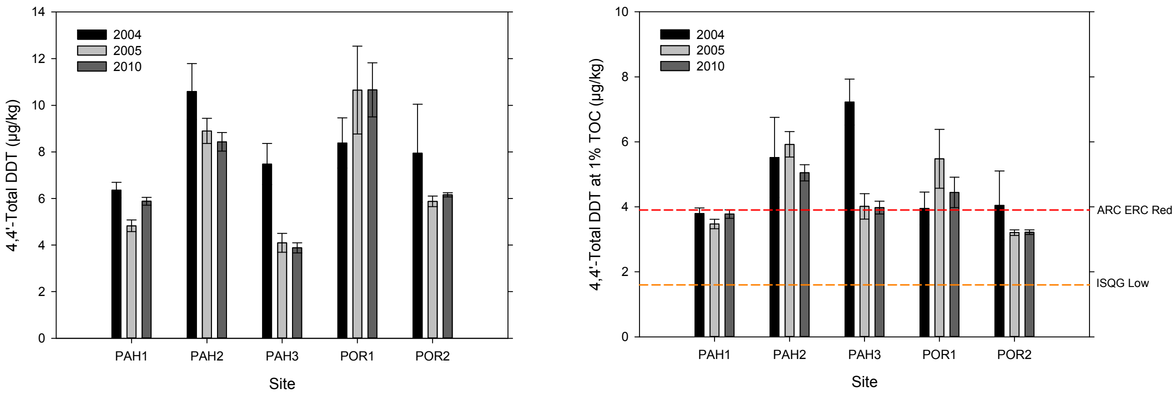

Figure 3.7: Mean (± 95% CI) concentrations of 4,4'- Total DDT and 4,4'- Total DDT at 1% TOC in sediments of five sites sampled in Porirua Harbour in 2004, 2005 and 2010, based on the <500 µm fraction of five composite samples from each site

As in the 2004 and 2005 surveys, DDE was the dominant constituent of total DDT, with smaller amounts of DDD and DDT (Figure 3.8). This was most marked in the Pauatahanui Arm sites (PAH1, 2, and 3), where DDE made up approximately 70% of total DDT. This is consistent with the presence of an aerobically weathered DDT source, such as the agricultural soils that dominate the catchment.

Dieldrin concentrations exceeded the ANZECC (2000) ISQG-Low trigger value at all sites in 2004, 2005 and 2010, but the trigger value concentration is extremely low (Table 3.3). The concentrations at all sites were below the ARC ERC-red threshold, ranging from 0.05 to 0.44 ng/g (at 1% TOC).

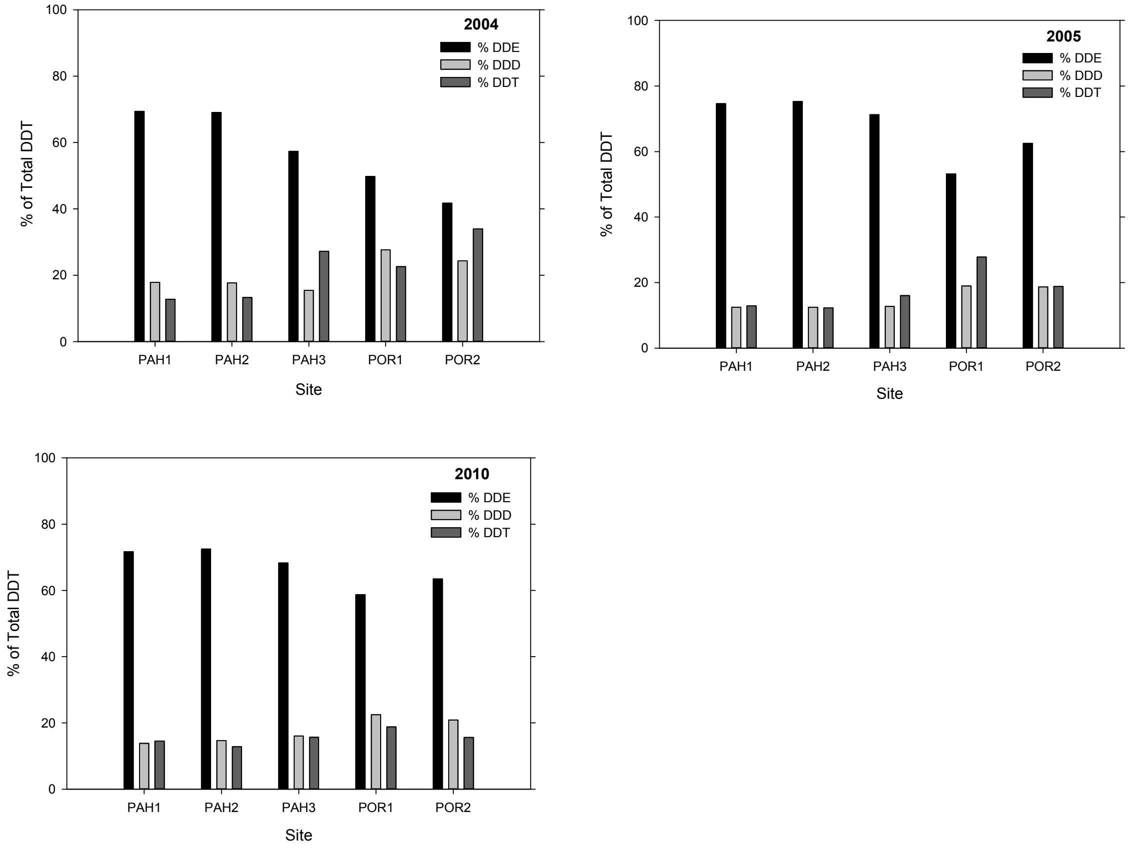

Figure 3.8: Mean percentage composition of Total DDT in sediments of five sites sampled in Porirua Harbour in 2004, 2005 and 2010, based on the <500 µm fraction of five composite samples from each site. Values include 'less than detection limit' values as '0.5 times the detection limit'

3.2 Benthic fauna

3.2.1 Sediment particle size distribution

A summary of the laser particle size results by volume for sediment samples from the five benthic fauna collection areas in Porirua Harbour during November/December 2010 is presented in Table 3.5. The <500 µm fraction of the near-surface sediments at sites in the Pauatahanui Arm was muddy sand (<63 µm fraction 20–35%), while at sites in the Onepoto Arm it was sandy mud (<63 µm fraction 68–75%). At all sites the near-surface sediments also contained a minor gravel component (>500 µm) made up primarily of shell fragments.

Table 3.5: Sediment particle size distribution results from each of the five benthic fauna collection areas sampled in Porirua Harbour in 2010, based on the mean of two (PAH1, PAH2, POR2) or three (PAH3, POR1) samples from each site

Site	Mean (µm)	<63 µm (%)	63–125 µm (%)	125–250 µm (%)	250–500 µm (%)	Description of <500 µm fraction
PAH1	91.1	34.8	36.8	28.4	0	Very muddy sand
PAH2	82.2	31.4	56.4	12.1	0	Very muddy sand
PAH3	106.3	20.3	46.5	32.5	0	Muddy sand
POR1	58.1	67.8	25.3	6.9	0	Sandy mud
POR2	50.7	75.3	20.1	4.6	0	Sandy mud

The results of the 2010 survey found that, on average the mud content (<63 µm fraction) of sediments from the benthic fauna collection areas was within 10% of the mud content of sediment from the corresponding chemistry collection areas.

3.2.2 Wet sieving vs laser particle size measurements

A summary of the mean particle size distributions determined by wet sieving is presented in Table 3.6. These percentages reflect the proportion of the total sample within each size fraction by weight. In contrast, the particle size distribution determined by the laser sizer (Table 3.5) gives the proportion of the total sample within each size fraction by volume. This is an important distinction between the two methods.

Overall, there was a close relationship between the <63 µm fraction results for the wet sieving and the Eyetech laser particle sizer ($R^2 = 0.97$) and the two methods agree that the <500 µm fraction of the near-surface sediments at sites in the Pauatahanui Arm were less muddy (<63 µm fraction 61–81%), compared to sites in the Onepoto Arm (<63 µm fraction 95–97%). However, the actual results for the two methods differed by 22 to 46%, with the wet sieving method consistently reporting a higher mud fraction (Figure 3.9). This discrepancy may be explained by the non-spherical shape of very fine sand particles which appear to be passing through the smallest sieve to be classified as mud (<63 µm), thus overestimating the mud fraction.

Table 3.6: Mean particle size distribution results determined by wet sieving from each of the five benthic fauna collection areas sampled in Porirua Harbour in 2010, based on the mean of two (PAH1, PAH2, POR2) or three (PAH3, POR1) samples from each site

Site	<63 µm (%)	63–125 µm (%)	125–250 µm (%)	250–500 µm (%)
PAH1	80.9	14.8	3.57	0.71
PAH2	70.8	28.2	0.64	0.35
PAH3	61.1	30.1	7.97	0.79
POR1	94.6	4.78	0.55	0.37
POR2	97.2	2.35	0.49	0.12

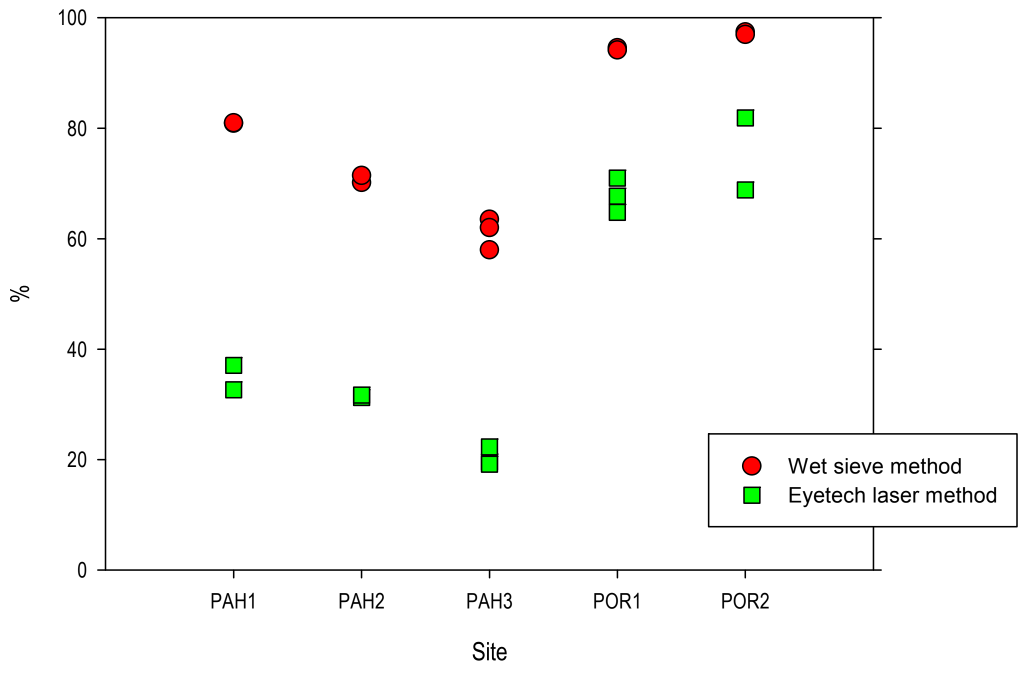

Figure 3.9: Percent mud fraction (< 63 µm) as determined by both wet sieve gravimetric and laser methods in the sediments of the five benthic fauna sites sampled in Porirua Harbour in 2010. Laser particle size measurements are presented as proportion by volume

3.2.3 Number of species

A total number of 58 taxa (species) were identified in the samples collected from Porirua Harbour in 2010. Polychaetes (27 species), crustaceans (14 species) and bivalve molluscs (7 species) were the most abundant groups amongst the fauna collected. Of the 58 species identified, 54 species were found in the samples taken from the Pauatahanui Arm; the highest number of species was recorded at site PAH1 (41), followed by 34 species at PAH3 and 24 species at PAH2 (Table 3.7). At the two sites in the Onepoto Arm, 23 and 22 species were recorded from sites POR1 and POR2, respectively, representing 29 of the total 58 species identified (Table 3.7). Across all five sites, five species were found that had not been recorded in any of the previous three surveys.

3.2.4 Number of individuals

A total of 8,945 individual invertebrates were counted in the Porirua Harbour sediment samples. Crustaceans and bivalve molluscs were the most numerous groups, each representing 39% of the total fauna. Of the crustaceans, Tanaidacea sp.#1, a small shrimp-like animal, was the most abundant (84%), followed by the burrowing amphipod, Phoxocephalidae sp.#1 and sp.#2 (5% each of all crustaceans). The most abundant bivalve molluscs were *Arthritica* sp.#1 (78% of all bivalves), and the nut clam, *Linucula hartvigiana* (21% of all bivalves).

Polychaetes, or bristle worms, were the third most dominant group by number (19%), the most abundant species being *Asychis* sp.#1 (39% of all polychaetes) and *Cossura consimilis* (24% of all polychaetes).

In terms of biomass, tanaidaceans dominated at site POR2, but the bivalves *L. hartvigiana* and *Cyclomactra ovata* dominated the biomass at all the other sites. The holothurian, *Paracaudina chilensis,* was also a dominant member of the biomass at site PAH1.

The mean number of individuals ranged from 101 at site POR1 to 508 at site PAH1. This equates to an estimated total number of individuals of 3,240 to 16,256 per m^2 (Table 3.7).

3.2.5 Shannon diversity index

Mean Shannon diversity index values ranged from 1.34 (±0.09, 95% CI) at site PAH1 to 2.19 (±0.16, 95% CI) at site PAH3 (Table 3.7), which equates to 47% to 78% of their theoretical maximum based on the number of individuals being evenly distributed across each species present at the site.

3.2.6 Pielou's Evenness Index

The mean values for Pielou's Evenness Index were the lowest at sites PAH1 and POR2 (0.47 and 0.55, respectively), indicating that these sites were dominated by one or two species in high abundances, with the remaining species occurring in relatively low abundances (Table 3.5). Mean values for Pielou's Evenness Index were higher at sites PAH2, PAH3 and POR1 (0.75, 0.78 and 0.77, respectively) reflecting the relatively even abundance of species at these sites.

3.2.7 Trophic structure

All feeding modes, except herbivores, were represented in the benthic fauna collected from Porirua Harbour (Figure 3.10). Predators and scavengers, such as the tanaidaceans and some polychaete worms, were dominant at sites PAH1 and POR2, a continuation of the 2008 observation. The proportion of suspension feeders increased to 38% at site PAH1 from 10% in 2008. This was driven by the increasing abundance of the filter-feeding bivalve, *Arthritica* sp.#1.

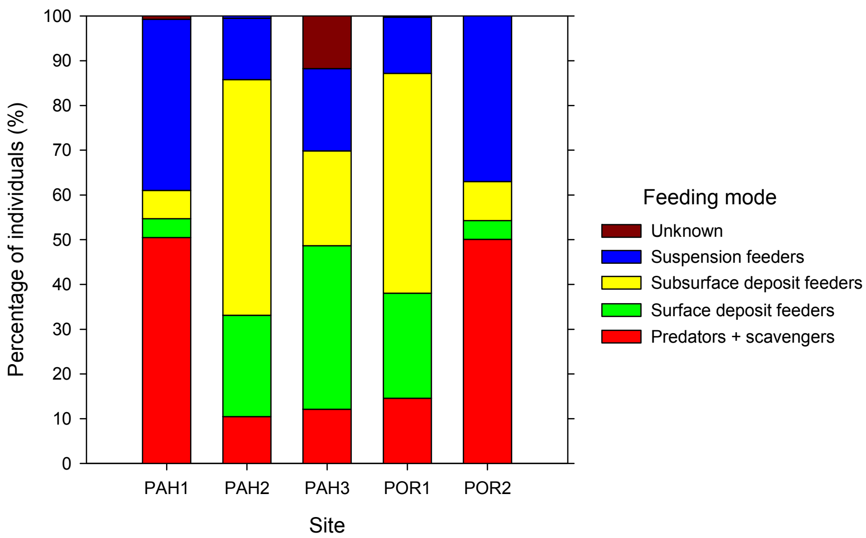

Figure 3.10: Percentage of individuals in each feeding mode at each of five sites sampled in Porirua Harbour in November 2010

Table 3.7: Summary of features of the subtidal benthos at five sites in Porirua Harbour in 2010

Feature	**Site**				
	PAH1	**PAH2**	**PAH3**	**POR1**	**POR2**
Number of species	41	24	34	23	22
Estimated total individuals per m^2 [1]	16,256	3,936	3,436	3,240	8,912
Dominant species by numbers [2]	Tanaidacea sp.#1 *Arthritica* sp.#1	*Cossura consimilis* *Heteromastus filiformis* *Linucula hartvigiana* *Arthritica* sp.#1	*Linucula hartvigiana* *Arthritica* sp.#1 Ostracoda sp.#3 Oligochaeta sp.#1, *Asychis* sp.#1 *Heteromastus filiformis* Phoxocephalidae sp.#2	*Asychis* sp.#1 *Linucula hartvigiana* *Cossura consimilis* *Arthritica* sp.#1 Phoxocephalidae sp.#1	Tanaidacea sp.#1 *Arthritica* sp.#1
Dominant species by biomass [3]	*Paracaudina chilensis* *Cyclomactra ovata* *Linucula hartvigiana*	*Cyclomactra ovata* *Linucula hartvigiana* *Macrophthalmus hirtipes*	*Linucula hartvigiana* *Cyclomactra ovata* *Macrophthalmus hirtipes*	*Cyclomactra ovata* *Linucula hartvigiana* *Asychis* sp.#1	Tanaidacea sp.#1 *Asychis* sp.#1 *Linucula hartvigiana*
Shannon diversity index (mean ± 95% CI)	1.34 ± 0.09	1.99 ± 0.04	2.19 ± 0.16	2.02 ± 0.12	1.46 ± 0.06
Pielou's Evenness Index	0.47 ± 0.09	0.75 ± 0.04	0.78 ± 0.16	0.77 ± 0.13	0.55 ± 0.06
<u>Trophic structure</u>:[4]					
Predators/scavengers (%)	50.47	10.47	12.11	14.57	50.09
Surface deposit feeders (%)	4.21	22.66	36.55	23.46	4.17
Subsurface deposit feeders (%)	6.32	52.64	21.19	49.13	8.71
Suspension feeders (%)	38.24	13.72	18.39	12.59	37.03
Unknown (%)	0.76	0.51	11.76	0.25	0.00

[1] Estimate based on a sample area of 0.03 m^2 and a conversion factor of "mean number of individuals per sample multiplied by 31.8" (*n*=8).

[2] Species are listed in descending order of mean number of individuals per sample, with the sum of the individuals of these species comprising 75–85% of the individuals recorded at the site.

[3] Species are listed in descending order of mean biomass per sample.

[4] For allocation of each species to a feeding mode (or modes) see Appendix 4.

Surface and sub-surface deposit feeders were the most numerous trophic modes at the remaining three sites, PAH2, PAH3 and POR1, representing 75%, 58% and 73% of all feeding modes, respectively (Figure 3.10). Dominating the surface deposit feeders was the nut shell *L. hartvigiana*, and amongst the subsurface deposit feeders, the highly abundant polychaete worms, *Asychis* sp.#1, *C. consimilis* and *Heteromastus filiformis*.

3.2.8 Bivalve populations

The shell lengths of four species of bivalves were measured to establish their population structure at each of the five sites. The cockle *Austrovenus stutchburyi* was represented by a single specimen at site PAH1 (11.5 mm shell length). Across all sites, measurements were made of 16 individual *C. ovata*, 12 *Macomona liliana*, and 727 *L. hartvigiana* (Figure 3.11, Appendix 4).

Cyclomactra ovata (Oval trough shell)
C. ovata was recorded at all sampling sites except at the outer estuary site in Onepoto Arm (POR2), with estimated densities ranging from 12 to 24 individuals per m^2. All but one of the 16 individuals measured had a shell length >20 mm (Figure 3.11), with animals at site POR1 noticeably larger than at other sites.

Macomona liliana (Wedge shell)
M. liliana was recorded at sites PAH2 and PAH3 only, with estimated densities of 24 individuals per m^2 at both sites. The majority of shell lengths ranged from 1.7 to 9.2 mm in length, with one individual measuring 24.7 mm in shell length (Figure 3.11).

Linucula hartvigiana (Nut shell)[10]
L. hartvigiana was recorded at all five sampling sites with estimated densities ranging from 72 per m^2 at site POR2 to 1,085 per m^2 at site PAH3. The population structure was bimodal at sites PAH1, PAH3 and POR1 with the majority of animals measuring between 1–2 mm and 5–9 mm size classes (Figure 3.11).

[10] Previously reported as *Nucula hartvigiana.*

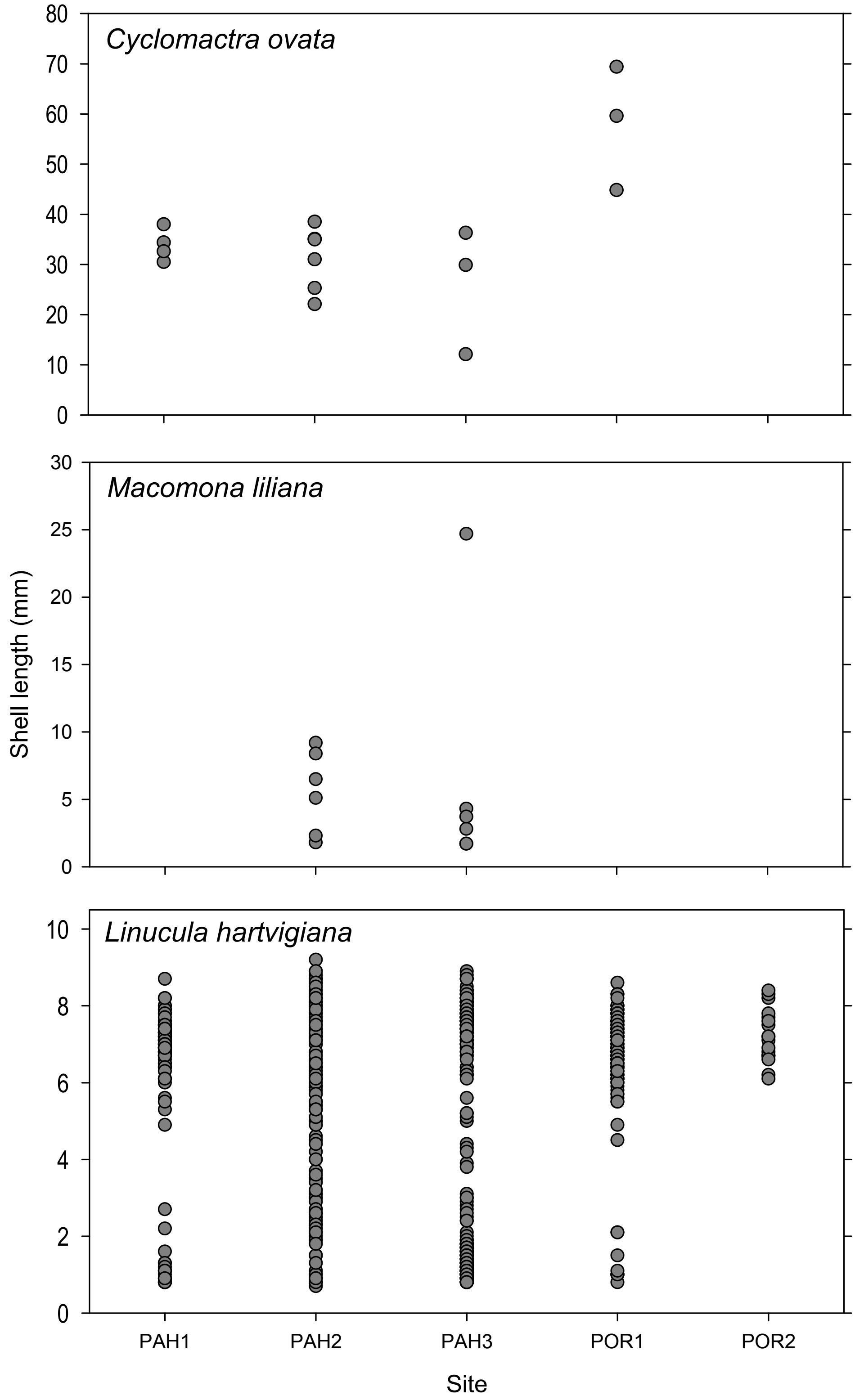

Figure 3.11: Size distribution of three bivalve species at each of the five benthic fauna sites sampled in Porirua Harbour in November 2010

3.2.9 Comparison with previous surveys

The assessment of changes in benthic ecology focuses on within-site temporal changes in species diversity and benthic community structure, as opposed to between-site changes. This reflects the fact that the five sites are influenced by differing levels of urban and rural inputs and represent subtly different habitat types. The statistical methods used to measure the changes are outlined in Section 2.4.2.

(a) Species diversity

At site PAH1 the plots of diversity indices indicate that although the number of species is similar to 2008 and relatively high compared with 2004 and 2005, Shannon diversity and Pielou's evenness have decreased, also consistent with the 2008 survey (Figure 3.12). This decrease has been driven by the continued dominance of tanaids, shrimp-like crustaceans, and the added abundance of a single bivalve, *Arthritica* sp#1.

Similarly, at site POR2, the on-going dominance of tanaids has sustained a low diversity and skewed evenness of individuals amongst species in 2010 (Figure 3.12). In contrast, species numbers and diversity have been stable through time at the inner Onepoto Arm site, POR1 (Figure 3.12). The species assemblage at this site has remained largely the same throughout the four surveys with relatively similar species abundances.

An influx of the polychaete worm, *H. filiformis,* in 2005 temporarily depressed the Shannon diversity index at site PAH2 (Figure 3.12). Generally species numbers, diversity and evenness remain high at sites PAH2 and PAH3 due to the wide range of well represented species.

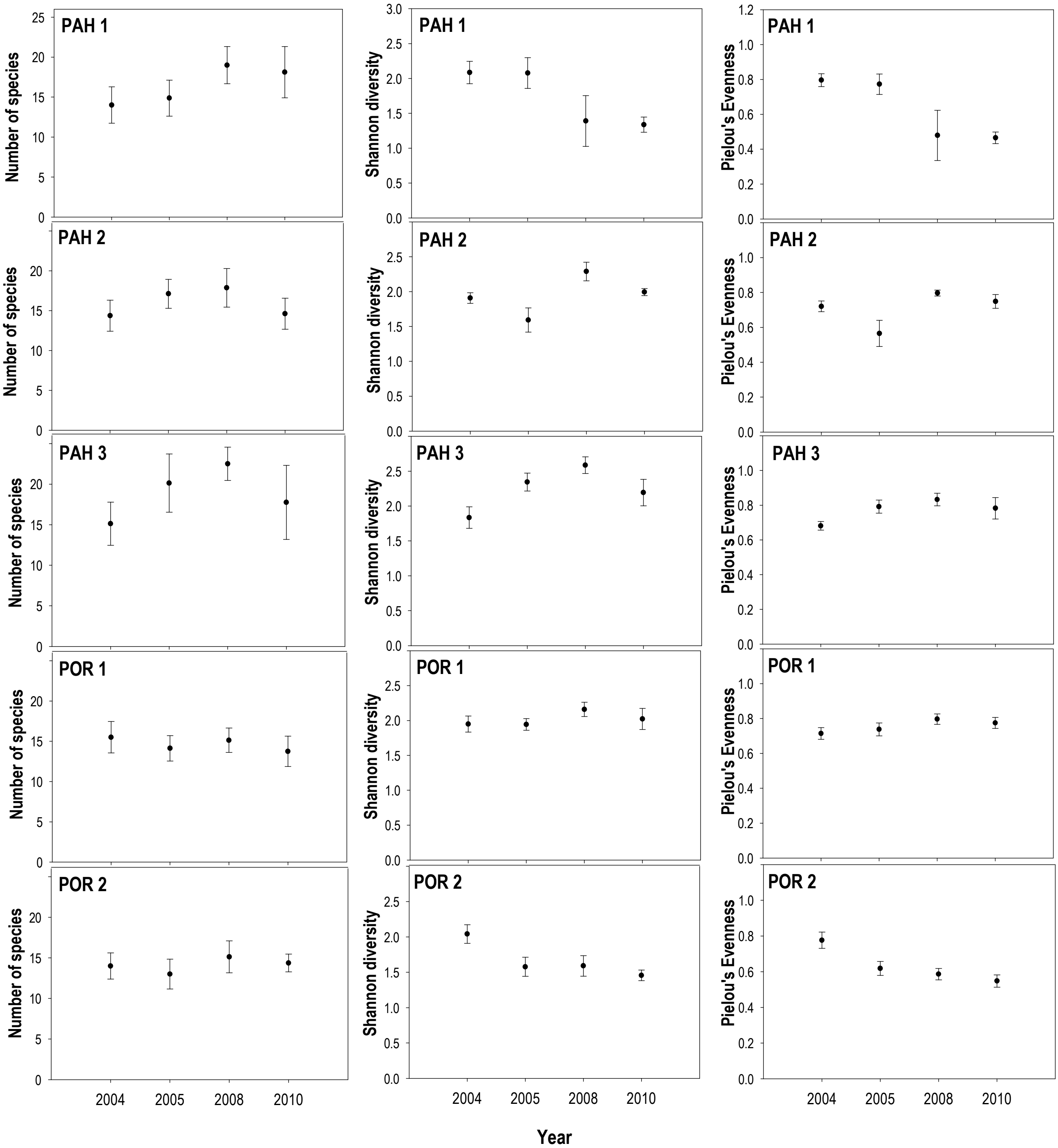

Figure 3.12: Mean number of species, Shannon diversity index values and Pielou's evenness index values (± 95% CI) at each of five sites sampled in Porirua Harbour during four surveys between 2004 and 2010

(b) Community structure

Hierarchical clustering and multidimensional scaling techniques were performed on untransformed (ie, raw) site data because they provided a better representation of the benthic fauna both amongst and within sites (as indicated by the lower stress values) and more clearly reflected the influence of dominant species, compared with transformed data (Figure 3.13). The two-dimensional representation of the transformed data was poor, as indicated by the stress value of 0.21. Clarke and Warwick (2001) advise that MDS results with stress values of between 0.2 and 0.3 should be treated with caution, and that results should be discarded in the upper half of this range.

Cluster analysis of the untransformed data differentiated four groups of samples which had <35% similarity in species composition (Figure 3.13). These groups were:

1. site PAH2 in 2005;
2. sites PAH1 and POR2 in 2005, 2008 and 2010;
3. a single replicate from site PAH3 in 2010; and
4. all other samples.

There was a shift in species composition at sites PAH1 and POR2 between 2004–05 and 2008–10. Similarity percentages (SIMPER) indicated that this was primarily driven by an increase in Tanaidacea sp.#1 and *Arthritica* sp.#1 (Figure 3.14). These two species explained 62% of the dissimilarity between groups 2 and 4.

A temporary influx of *H. filiformis* also distinguished site PAH2 in 2005 from all other samples, explaining 62% of the dissimilarity between groups (Figure 3.14). Numbers of this species subsequently declined and the species composition at site PAH2 in 2010 returned to that previously recorded in 2004.

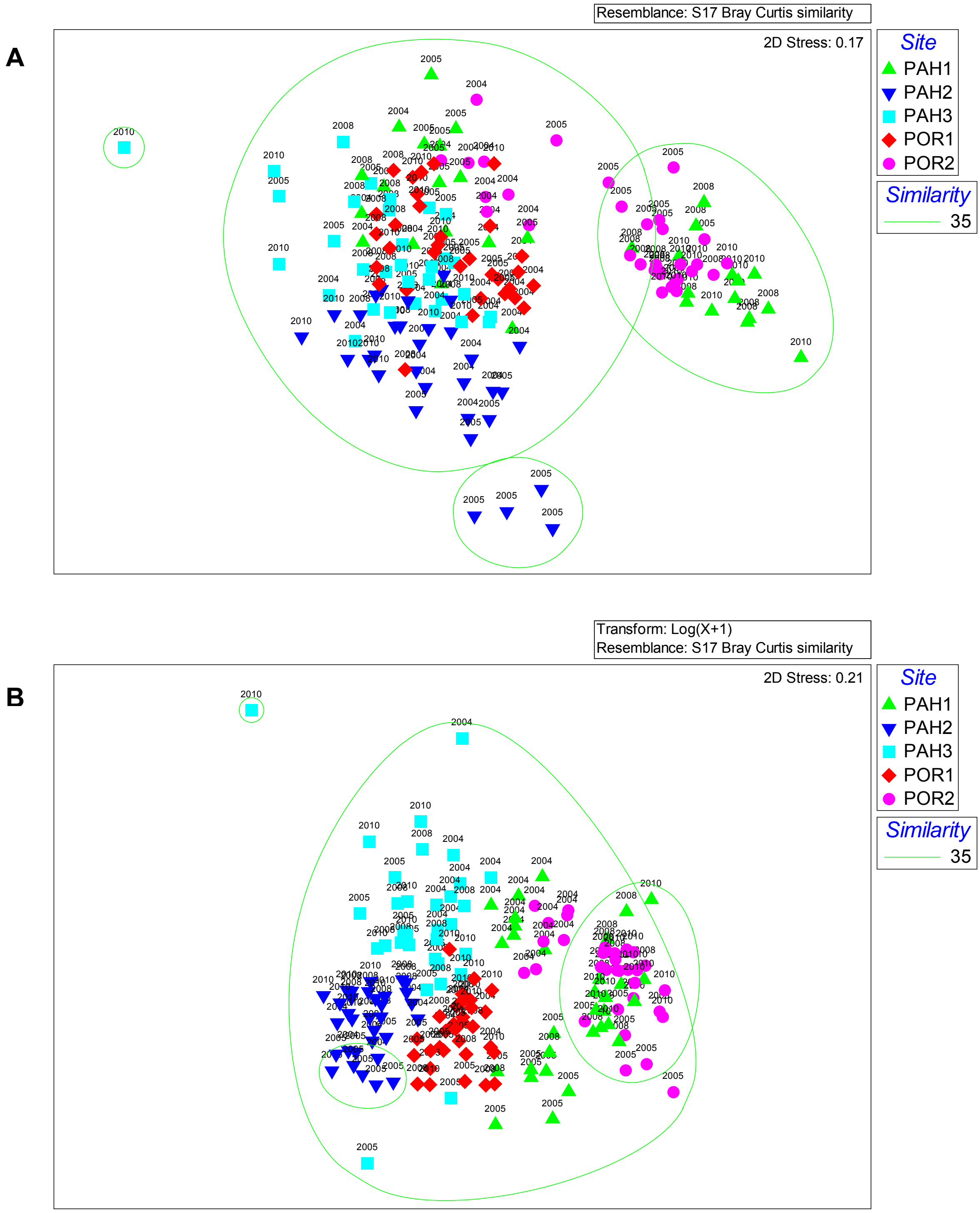

Figure 3.13: MDS plots of benthic fauna composition data from five sites in the Porirua Harbour in 2004, 2005, 2008 and 2010, using A) untransformed data, and B) log x+1 transformed data. Samples are grouped using the results of cluster analysis with separate clusters having <35% similarity

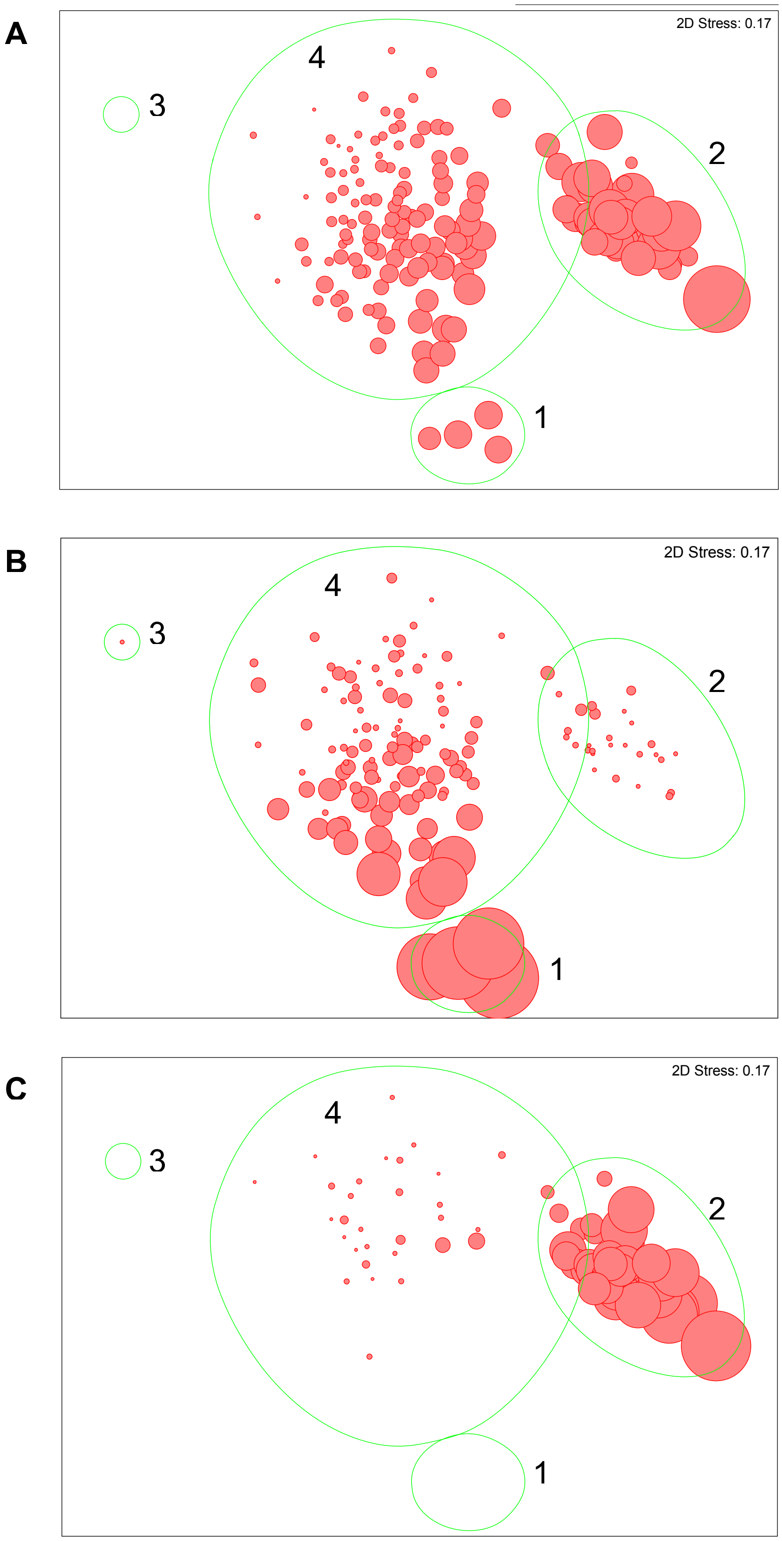

Figure 3.14: MDS plots with abundance bubbles of A) *Arthriticia* sp.#1, B) *Heteromastus filiformis*, C) Tanaidacea sp.#1 overlain. The groups identified by cluster analysis of untransformed data are shown. Data are drawn from the four surveys of Porirua Harbour between 2004 and 2010

3.3 Linking the benthic community to environmental variables

MDS plots were overlain with bubble plots of environmental variables (metal concentrations, mud content, TOC) from all four surveys to examine relationships between benthic communities and environmental variables (Figure 3.15, a selection of plots are presented as an example). No clear relationships between benthic fauna and environmental data were obvious. Sediments from all sites, and groups resulting from the cluster analysis, had overlapping and highly variable mud content and TOC and metal concentrations.

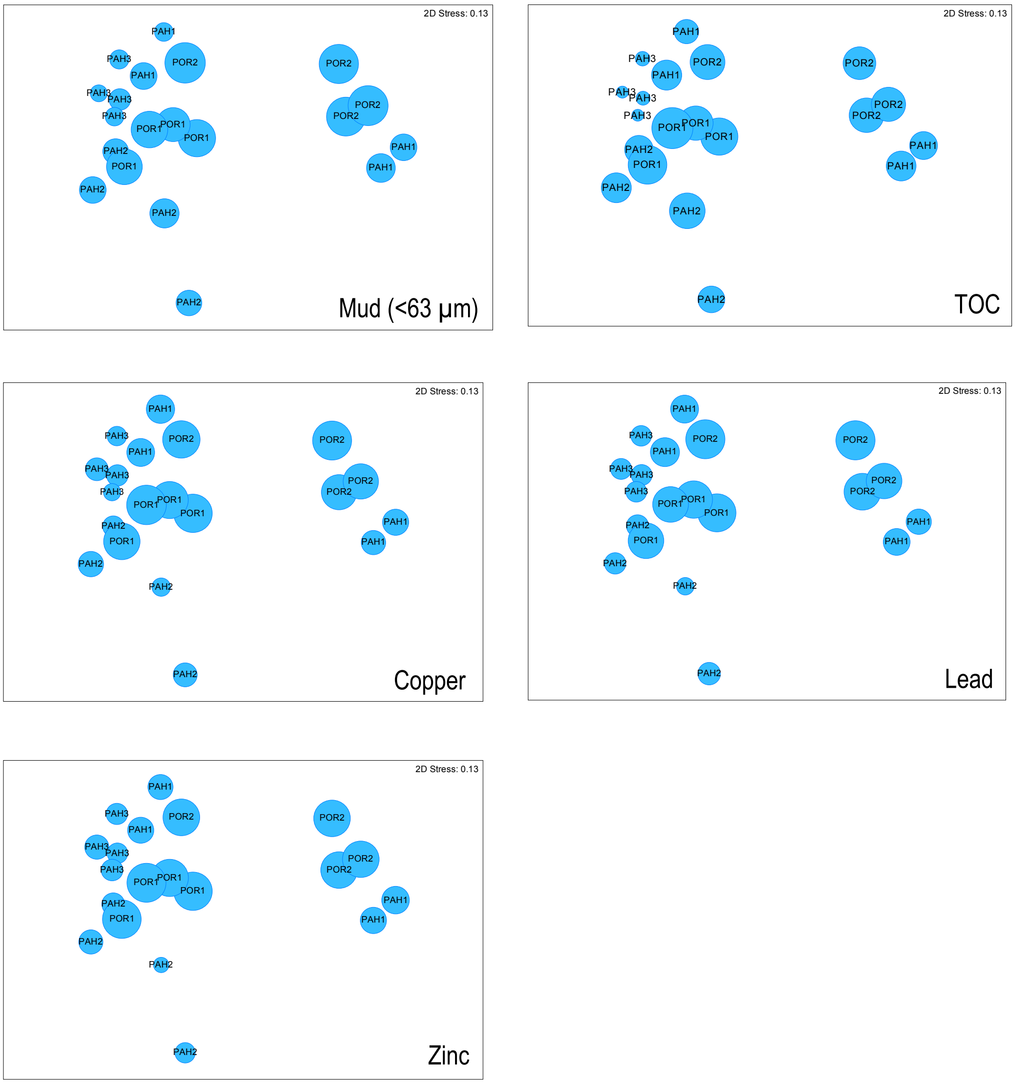

Figure 3.15: MDS plots of benthic fauna samples overlain with bubble plots showing the relative values of selected environmental variables. Metal concentrations are given for the <63 µm fraction. Circle diameters are proportional to the percentage or concentration at each site on a linear scale

More subtle, lower order community effects were then examined by carrying out a canonical analysis of principal coordinates (CAP) of species counts, constrained by a quantitative index of 'environmental quality'. This index was obtained by a PCA of environmental variables used to examine the relationship between the chemical and physical (ie, sediment quality) characteristics of the sediment.

The first principal component (PC1) obtained from the PCA explained 68% of the variation in environmental variables; the second principal component (PC2) accounted for much of the remaining variation, ie. 86% between them. Therefore, the 2-D PCA provided a good proxy for overall environmental quality and broadly speaking, PC1 represents an axis of decreasing sediment contamination. Figure 3.16 shows a gradient of environmental change moving from the more contaminated Onepoto Arm sites at the left of the plot to the less muddy and less contaminated sites of Pauatahanui Arm on the right. PC1 is primarily driven by a gradient in the concentrations of key urban contaminants (eg, copper, lead, zinc), mud content and TOC, whereas PC2 is driven by relatively minor variations in secondary contaminants (eg, nickel, arsenic, cadmium, mercury).

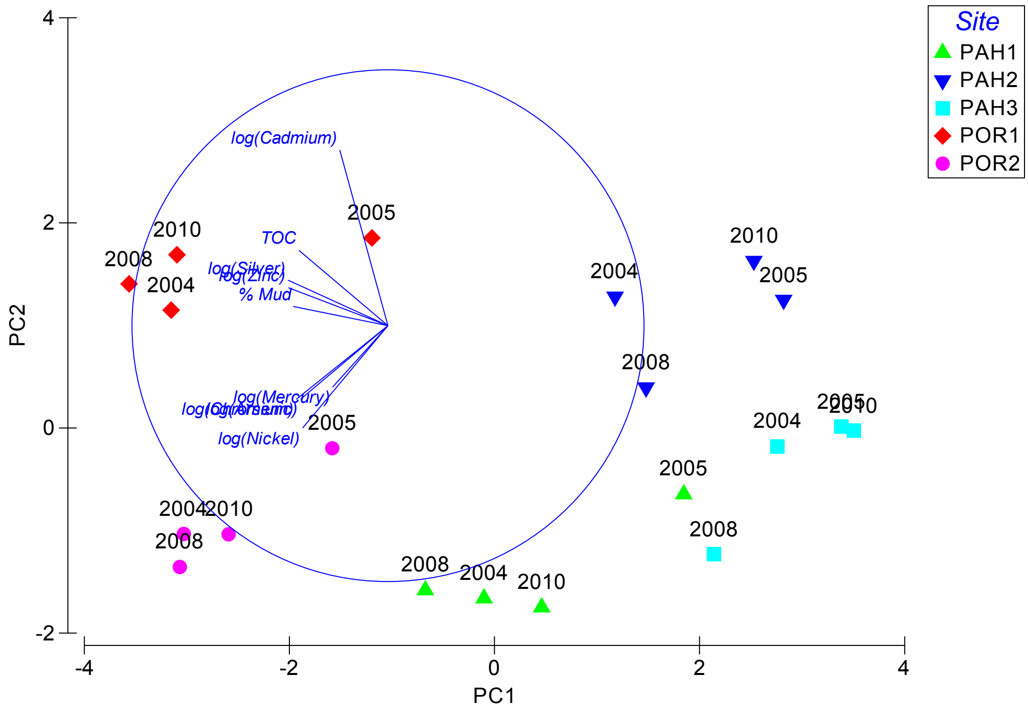

Figure 3.16: Principal Components Analysis (PCA) analysis of log-transformed, normalised sediment metal concentrations (extracted using strong acid digestion of the <500 µm sediment fraction[11]), total organic carbon and sediment mud (<63 µm) content

The CAP analysis indicated there was a strong relationship between community structure and the PC1 (Figure 3.17). This suggests that benthic community structure or 'health' improves with increasing environmental quality. The analysis does not discriminate between sediment mud content, TOC and metal contaminants and it was not possible to determine which aspects of environmental quality were driving the changes.

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[11] The weak-acid extractable metals in the <63 µm fraction of the sediments and total copper and lead in the <500µm fraction were removed from the PCA analysis because there was high co-linearity with zinc concentrations in the <500 µm fraction. Therefore, zinc in this analysis is a proxy for lead, copper and zinc concentrations in both the <63 µm and <500µm fractions.

Closer examination of the changes at each site through time suggests that although species abundances may vary from year to year, the community structure (diversity, abundance and evenness), or ‘health’ has remained largely unchanged at all sites throughout the four surveys (Figure 3.18). Overall, community structure is better at sites in Pauatahanui Arm suggesting that communities may be in better health.

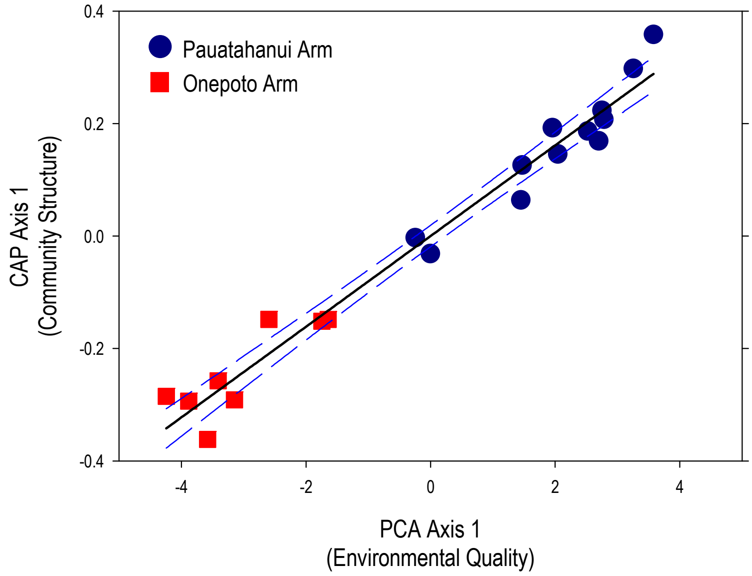


Figure 3.17: Canonical analysis of principal coordinates (CAP) based on Bray Curtis similarities of square root transformed species counts and the PCA1 values derived from PCA of environmental variables. Note that the CAP axis can be viewed as an index of ecological community structure and the PCA axis viewed as an index of ‘environmental quality’. Least squares regression and 95% confidence intervals are shown

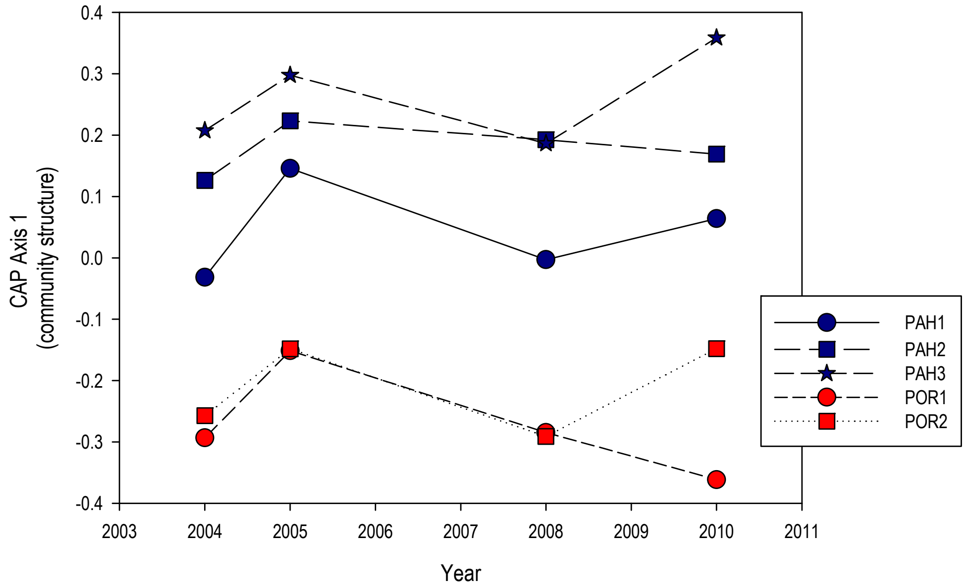


Figure 3.18: Canonical analysis of principal coordinates (CAP) based on Bray Curtis similarities of square root transformed species counts for each of the five monitoring sites in Porirua Harbour. Note that the CAP axis can be viewed as an index of ecological community structure

4. Discussion

Concentrations of copper, lead, zinc, and to a lesser extent mercury, have been consistently elevated in the subtidal sediments of Onepoto Arm since the first sediment survey in 2004 (Figures 4.1 and 4.2). The general trend across the five sites over the last four surveys has been for weak acid-extractable zinc concentrations to increase steadily, for lead concentrations to decrease and for copper concentrations to be variable, showing both increases and decreases. Overall, the rates of change are relatively small at around 5–6% per year.

Total recoverable copper, lead and zinc concentrations currently exceed low or ‘early warning’ sediment quality guideline values at both monitoring sites in the Onepoto Arm, while total recoverable mercury concentrations remain close to the ANZECC (2000) ISQG-Low trigger value. Total recoverable arsenic, cadmium, chromium, nickel and silver concentrations are all below sediment quality guideline values.

The elevated metal concentrations in the highly urbanised Onepoto Arm are generally consistent with spatial patterns in contaminant concentrations of urbanised coastal catchments elsewhere in New Zealand (eg, McHugh & Reed 2006; Kelly 2007). Catchment stormwater and stream investigations (Cameron 2001; Kingett Mitchell Ltd 2005; Milne & Watts 2008) and other sediment quality studies in Porirua Harbour (Glasby et al. 1990; Botherway & Gardner 2002; Sorensen & Milne 2009) have demonstrated that urban stormwater is contributing to metal (and other) contamination of the Onepoto Arm, either directly via outfalls, or indirectly, via the Porirua and Kenepuru streams.

In 2010, Boffa Miskell Ltd carried out a survey of subtidal sediments at 22 sites within Porirua Harbour. They found concentrations of total copper, lead and zinc to be well below sediment guidelines at all sixteen sites in the Pauatahanui Arm and at five of the six sites in the Onepoto Arm (Boffa Miskell 2011). At one site, closest to the mouth of Porirua Stream, concentrations of lead and zinc exceeded the ARC (2004) ERC amber and ARC (2004) ERC red thresholds, respectively (Figure 4.3). Concentrations of lead, copper and zinc at the other five Onepoto Arm sites were less than half those reported here. It is unclear why the concentrations of metals differ so much at sites relatively close together and sampled within the same month. Analytical methods were consistent between surveys, though a difference in the field sampling methods and the inherent patchiness of the marine environment may have introduced some variability. Concentrations of heavy metals in the sediments of Pauatahanui Arm were similar between the Boffa Miskel survey and the survey reported here.

As well as higher metal contamination, the sediments of the Onepoto Arm have a higher proportion of mud and elevated levels of TOC relative to sediments in the Pauatahanui Arm. TOC is a non-specific measurement of all organic material and although organic matter is ubiquitous in the marine environment, its concentration influences how contaminants behave in the sediment. Organic matter, like heavy metals, has a high affinity for the fine sediment fractions, and a link between elevated levels of TOC, mud and toxic contaminants is evident in the sediments adjacent to the Porirua CBD.

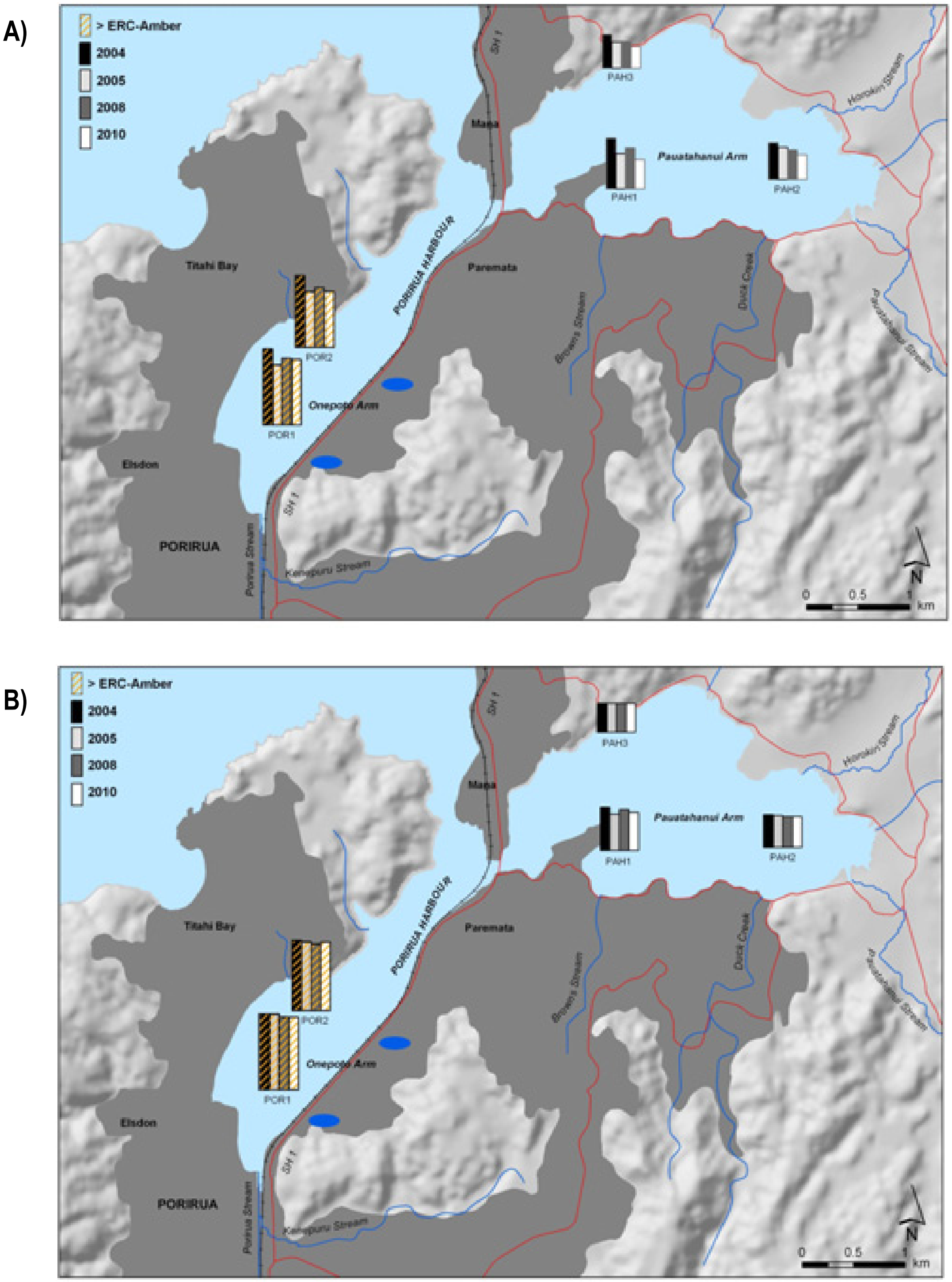


Figure 4.1: Concentrations of total A) copper and B) lead in sediments of five sites sampled in Porirua Harbour in 2004, 2005, 2008 and 2010, based on the <500 µm fraction composite sample from each site. Concentrations exceeding ARC (2004) ERC amber thresholds are indicated by hatching. The length of each bar is proportional to the metal concentration

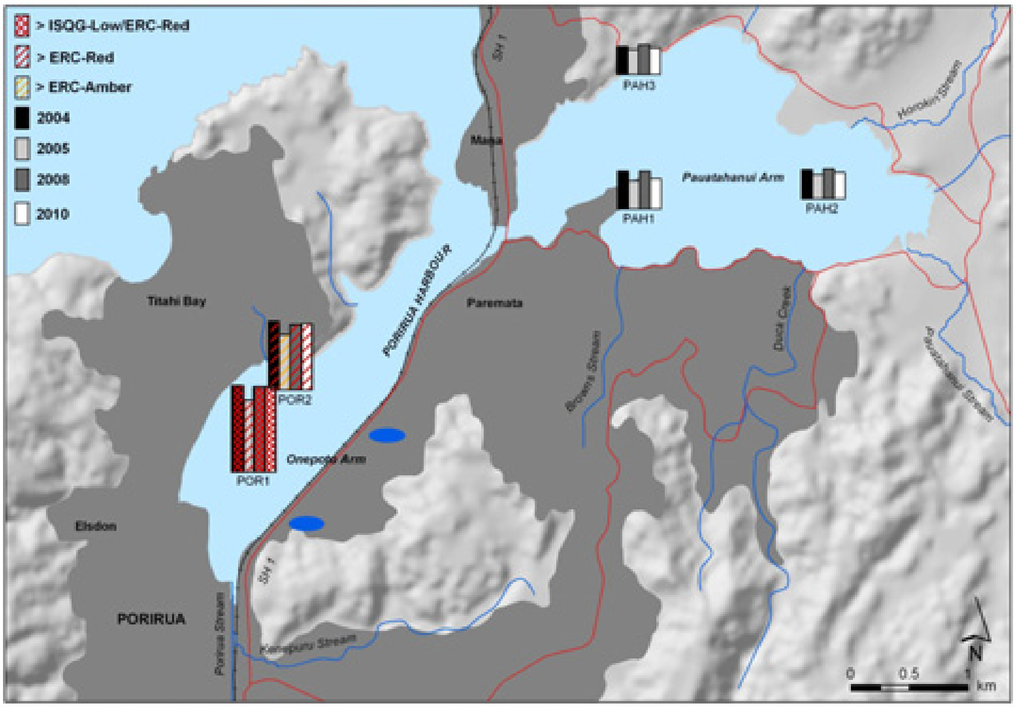
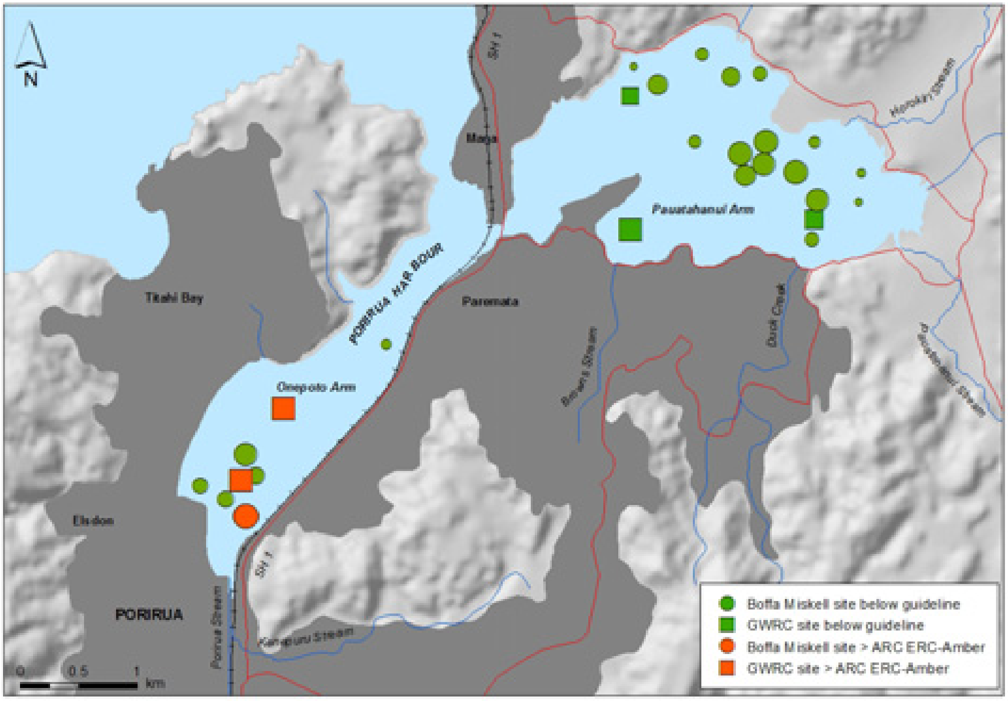


Figure 4.2: Concentrations of total zinc in sediments of five sites sampled in Porirua Harbour in 2004, 2005, 2008 and 2010, based on the <500 mm fraction composite sample from each site. Concentrations exceeding ARC (2004) ERC amber thresholds are indicated by hatching. The length of each bar is proportional to the metal concentration

The organochlorine pesticide DDT exceeds both the ANZECC (2000) ISQG-Low and the ARC (2004) ERC amber trigger values sediment quality guidelines in both arms of the harbour. This is considered a legacy contaminant, resulting from its use as a pesticide until as recently as the 1980s. The dominant breakdown product of DDT is DDE and this is indicative of an agricultural source (Williamson et al. 2005) such as that which characterises the Porirua Harbour catchment (61% and 39% of the sub-catchments that drain into the Pauatahanui and Onepoto arms of the harbour, respectively, are in pasture (Oliver & Milne 2012)).

PAH analyses were restricted to a single site in the Onepoto Arm in 2010 following the results of the 2004 and 2005 surveys which found PAH concentrations to be relatively low at the other four sites. Total PAH and HMW PAH concentrations (normalised at 1% TOC) at site POR1 in the inner Onepoto estuary are well below ANZECC (2000) ISQG-Low sediment quality guidelines and have decreased since the 2004 and 2005 surveys. There are unlikely to be adverse effects on the benthic invertebrate communities due to PAH toxicity and concentrations would have to increase by a factor of 2-3 times to approach sediment quality guidelines.

A)



B)

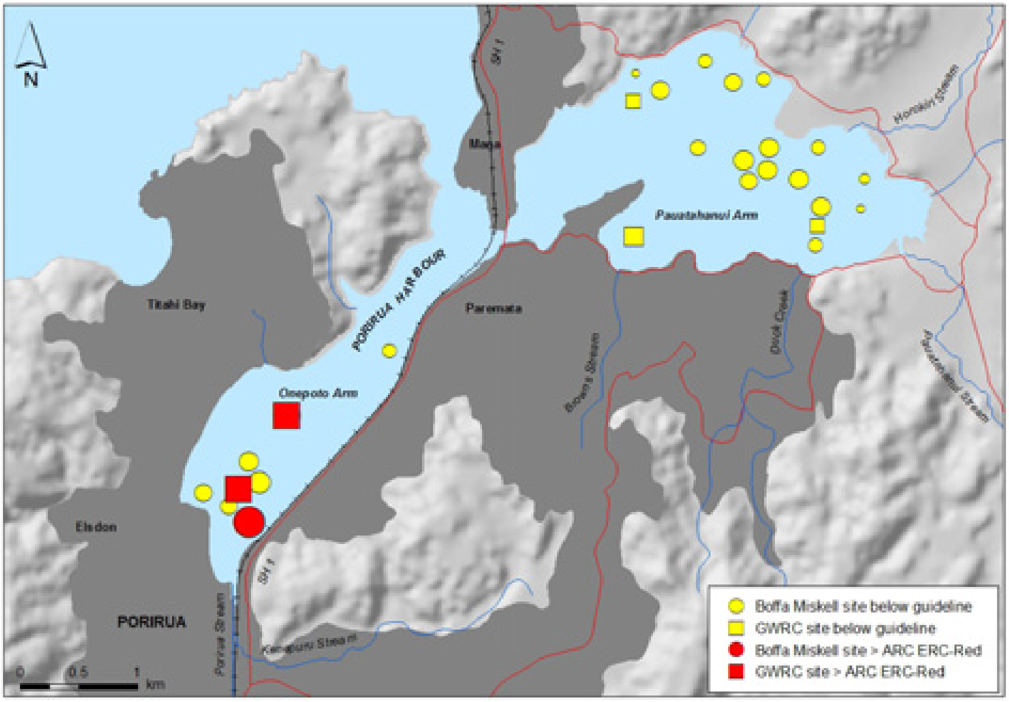


Figure 4.3: Concentrations of total A) lead and B) zinc in sediments of sites sampled by both GWRC and Boffa Miskell Ltd in Porirua Harbour in November/December 2010, based on the <500 µm fraction sample from each site. Concentrations exceeding sediment thresholds are indicated by amber (ARC ERC amber) and red (ARC ERC red) colouring. The size of each shape is proportional to the metal concentration

Multivariate analyses were used to examine changes in benthic community health across the four surveys. The most notable changes in species composition occurred at sites PAH1 and POR2 between the 2005 and 2008 surveys; species diversity and evenness at these two sites decreased and the invertebrate communities became increasingly dominated by only one or two species. The reason for these community changes in unclear – analyses could not attribute the observed changes to any single contaminant or physical property of the sediment. This result is unsurprising given that the concentration, bioavailability and toxicity of contaminants varies according to numerous environmental factors, such as pH, salinity, temperature, the presence of other contaminants and, as mentioned earlier, organic matter (Mayer-Pinto et al. 2010). These factors may interact synergistically or antagonistically with metals, or other contaminants, to influence recruitment, settlement, abundance, competitive success and mortality (Mayer-Pinto et al. 2010).

Although there is no clear evidence that the contaminants measured have resulted in any adverse effects on benthic invertebrate communities at any of the monitoring sites, the combination of heavy metal, mud and organic carbon content appears to be influencing the underlying benthic community structure; community structure or 'health' improves as environmental quality improves. Furthermore, the community 'health', while reasonably stable through time at most sites, has declined at site POR1 over the period of the four surveys. Other studies have also reported a decrease in diversity and animal abundances as a result of anthropogenic contamination but were unable to pinpoint exact drivers of change due to the complex interrelationships of factors (Morrisey et al. 1996; Mayer-Pinto et al. 2010). Adverse ecological effects may result at some Porirua Harbour sites in the future if contaminants continue to accumulate in the harbour sediments. This is considered highly likely as long as stormwater discharges continue in their present form, highlighting the need for further well designed monitoring to evaluate the effects of various contaminants on the benthic invertebrate communities.

A recommendation made following the last Porirua Harbour subtidal sediment survey (Milne et al. 2009) was to undertake a comparison of techniques for measuring sediment particle size following concerns about replicate variability. Subsequently the 2010 survey compared the results of laser particle size distribution with those derived from classic wet sieving techniques at the five benthic collection sites. The results demonstrated very good agreement between the two techniques when comparing the total volume of particles derived from the laser particle sizer with the wet sieve data. Consequently, it is not considered necessary to change from the use of laser particle analysis.

We have now completed four surveys of subtidal sediment quality and in the absence of any substantial environmental changes, a comprehensive review of the Porirua Harbour subtidal sediment quality monitoring programme is recommended. This review should take into account the key issues identified from GWRC's intertidal monitoring programme in Porirua Harbour, particularly the elevated rates of sedimentation, declining levels of sediment oxygenation and increasing sediment mud content (Stevens & Robertson 2012).

5. Conclusions

The fourth subtidal survey of Porirua Harbour has found that the subtidal sediments in parts of the harbour contain copper, lead, zinc, and to a lesser extent mercury, at concentrations above nationally recognised 'early warning' sediment quality guidelines. The general trend across the five sites over the last four surveys has been for zinc concentrations to increase steadily, for lead concentrations to decrease and for copper concentrations to be variable, showing both increases and decreases. Overall, the rates of change are relatively small at around 5–6% per year.

There is currently no clear evidence that any of the subtidal sediment contamination has resulted in significant adverse effects on invertebrate communities, however, the combination of heavy metals, mud and organic carbon content at some sites, is linked with less diverse community structure. Adverse effects may eventuate as long as stormwater discharges continue in their present form and contaminants continue to accumulate in the harbour sediments.

5.1 Recommendations

Undertake a comprehensive review of the Porirua Harbour subtidal sediment quality programme giving consideration to:

- The specific aims of the programme,
- The frequency of sediment chemistry and benthic invertebrate surveys,
- Revising the suite of contaminants sampled, including the potential analyses of emerging contaminants (eg, personal care products) of relevance to Porirua Harbour,
- Reviewing the QA component of the programme and preparing a bulk reference sediment sample to improve assessment of within and between survey analytical variability, and
- The key issues identified in GWRC's intertidal monitoring of Porirua Harbour.

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Appendix 1: Sediment particle size results – sediment quality collection areas

The National Institute of Water and Atmospheric Research Limited (NIWA), Hamilton, carried out both the sample preparation and particle size analyses. A summary of results are presented below and the outputs on the following pages are from the analytical report prepared by Crump et al. (2013).

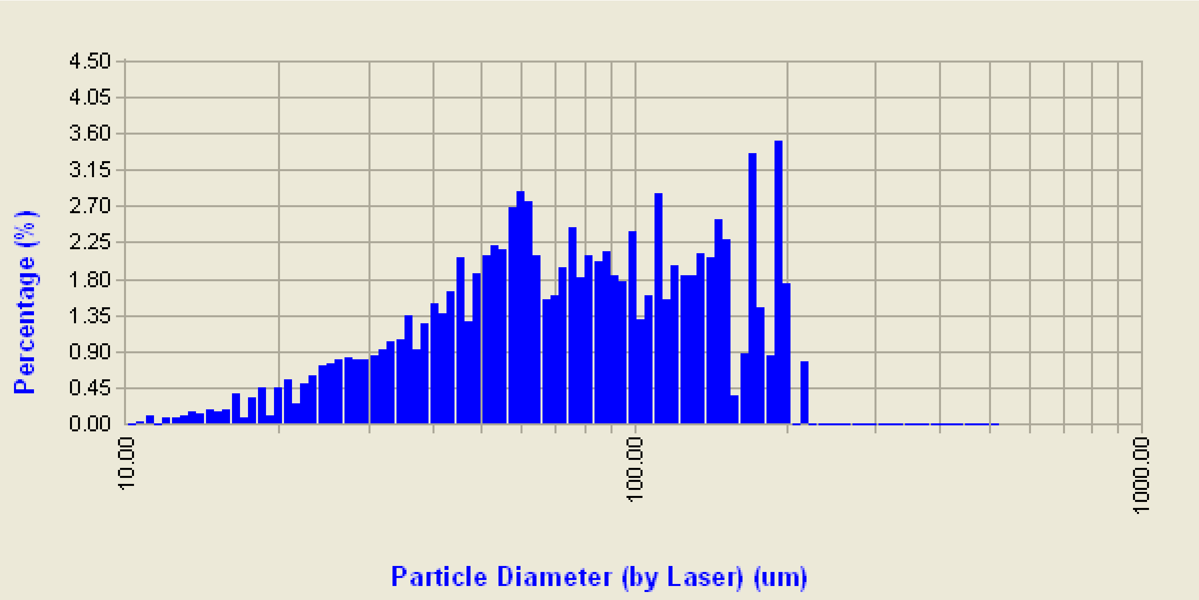
Table A1.1: Summary of particle size results for five replicates from each of five sediment chemistry collection areas in Porirua Harbour in November and December, 2010

NIWA code	GWRC code	Mean (µm)	Standard deviation (µm)	Maximum (µm)	10-62.5 µm '% mud'
OA148/1	PAH 1/16	87.71	51.07	215.07	41.41
OA148/2	PAH 1/17	80.46	43.36	189.30	44.30
OA148/3	PAH 1/18	85.40	48.32	197.23	43.43
OA148/4	PAH 1/19	88.42	48.73	215.41	37.05
OA148/5	PAH 1/20	88.01	50.38	209.89	41.19
OA148/6	PAH 2/16	69.15	30.88	153.31	44.88
OA148/7	PAH 2/17	73.33	36.11	192.56	42.39
OA148/8	PAH 2/18	69.97	31.89	163.19	44.58
OA148/9	PAH 2/19	74.98	35.61	177.33	39.49
OA148/10	PAH 2/20	78.62	38.67	193.06	37.06
OA148/11	PAH 3/16	109.38	53.12	244.78	21.59
OA148/12	PAH 3/17	108.22	52.09	247.46	20.53
OA148/13	PAH 3/18	106.21	51.37	244.78	22.63
OA148/14	PAH 3/19	106.67	53.27	233.20	23.33
OA148/15	PAH 3/20	110.18	54.60	272.48	20.87
OA148/16	POR 1/16	49.08	23.54	116.41	75.28
OA148/17	POR 1/17	54.33	29.50	159.93	68.84
OA148/18	POR 1/18	62.60	41.23	205.13	64.10
OA148/19	POR 1/19	50.04	24.61	121.85	73.30
OA148/20	POR 1/20	50.41	24.54	131.21	72.37
OA148/21	POR 2/16	42.84	22.12	113.14	83.16
OA148/22	POR 2/17	50.51	35.25	158.84	77.29
OA148/23	POR 2/18	45.09	26.25	135.99	81.39
OA148/24	PAH 2/19	43.41	24.38	125.11	83.37
OA148/25	PAH 2/20	40.68	20.72	110.97	86.02

Particle size distribution histograms and tables

Volume Distribution: OA148/1

Volume Histogram : OA148/1
Mean: 87.71 um STD: 51.07 um Conf.: 100.00 %
D10 : 30.12 um D50: 74.72 um D90: 170.46 um



Area Ranges Table : OA148/1

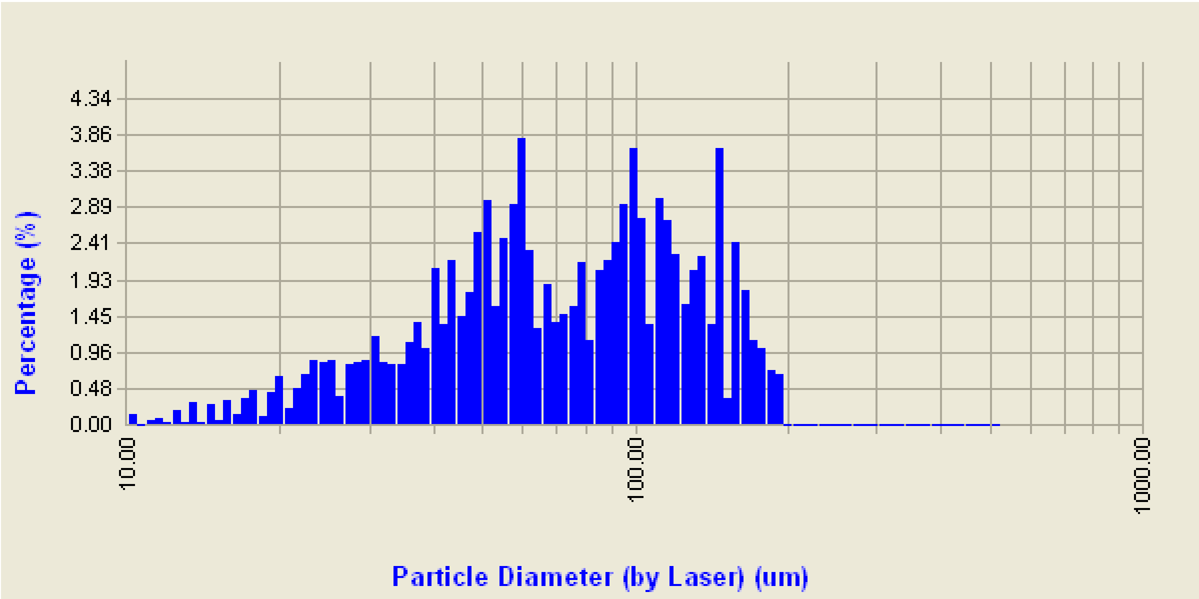
Range	Local(%)	Under(%)
10.0-15.6	5.23	5.91
15.6-31.2	23.02	28.93
31.2-62.5	39.17	68.10
62.5-125.0	23.14	91.24
125.0-250.0	8.76	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/1

Range	Local(%)	Under(%)
10.0-15.6	1.17	1.28
15.6-31.2	9.20	10.48
31.2-62.5	30.93	41.41
62.5-125.0	34.52	75.93
125.0-250.0	24.07	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/2

Volume Histogram : OA148/2
Mean: 80.46 um STD: 43.36 um Conf.: 100.00 %
D10 : 29.37 um D50: 71.80 um D90: 145.78 um



Area Ranges Table : OA148/2

Range	Local(%)	Under(%)
10.0-15.6	5.42	5.59
15.6-31.2	24.73	30.32
31.2-62.5	39.43	69.75
62.5-125.0	23.56	93.31
125.0-250.0	6.69	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/2

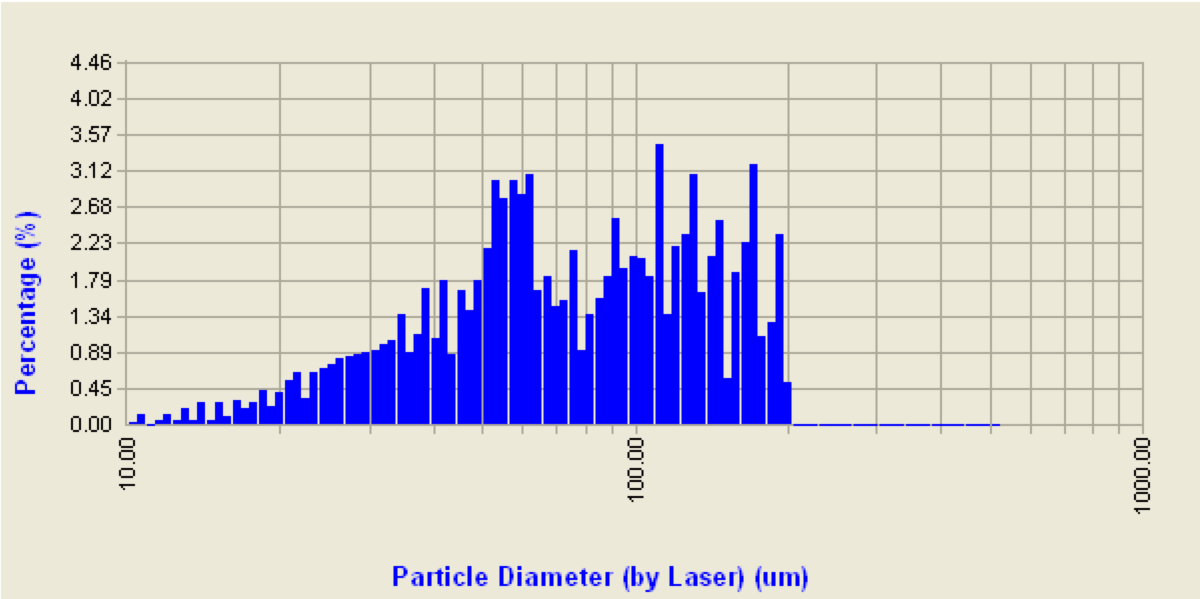
Range	Local(%)	Under(%)
10.0-15.6	1.22	1.25
15.6-31.2	10.23	11.48
31.2-62.5	32.82	44.30
62.5-125.0	37.75	82.05
125.0-250.0	17.95	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/3

Volume Histogram : OA148/3

Mean: 85.40 um STD: 48.32 um Conf.: 100.00 %

D10 : 28.83 um D50: 73.67 um D90: 163.33 um



Area Ranges Table : OA148/3

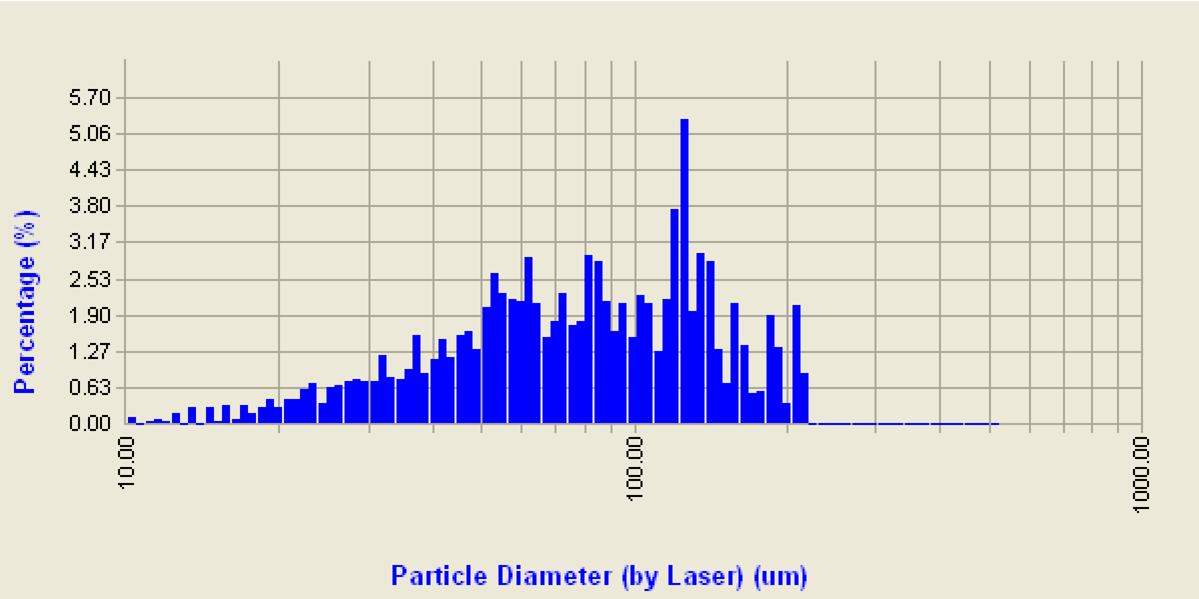
Range	Local(%)	Under(%)
10.0-15.6	5.44	5.99
15.6-31.2	24.35	30.34
31.2-62.5	39.64	69.99
62.5-125.0	21.29	91.28
125.0-250.0	8.72	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/3

Range	Local(%)	Under(%)
10.0-15.6	1.21	1.30
15.6-31.2	9.88	11.18
31.2-62.5	32.26	43.43
62.5-125.0	33.05	76.49
125.0-250.0	23.51	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/4

Volume Histogram : OA148/4
Mean: 88.42 um STD: 48.73 um Conf.: 100.00 %
D10 : 31.71 um D50: 79.82 um D90: 157.46 um



Area Ranges Table : OA148/4

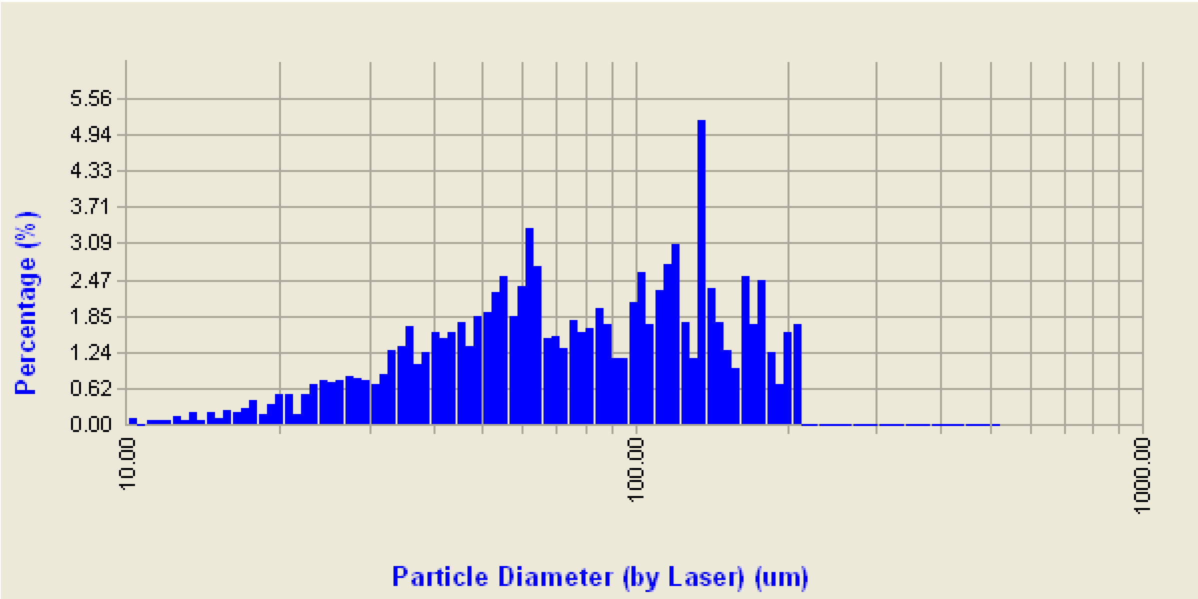
Range	Local(%)	Under(%)
10.0-15.6	5.11	5.22
15.6-31.2	23.06	28.29
31.2-62.5	35.45	63.74
62.5-125.0	27.52	91.26
125.0-250.0	8.74	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/4

Range	Local(%)	Under(%)
10.0-15.6	1.07	1.09
15.6-31.2	8.89	9.98
31.2-62.5	27.07	37.05
62.5-125.0	40.46	77.51
125.0-250.0	22.49	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/5

Volume Histogram : OA148/5
Mean: 88.01 um STD: 50.38 um Conf.: 100.00 %
D10 : 30.21 um D50: 75.67 um D90: 163.35 um



Area Ranges Table : OA148/5

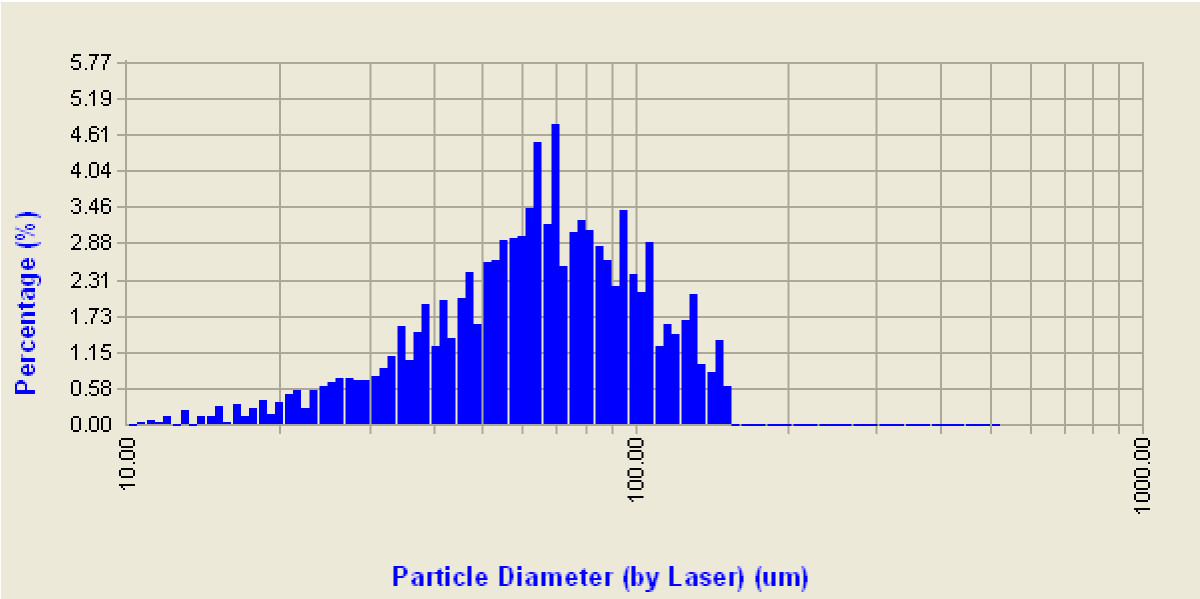
Range	Local(%)	Under(%)
10.0-15.6	5.81	6.07
15.6-31.2	22.59	28.67
31.2-62.5	39.69	68.36
62.5-125.0	22.27	90.62
125.0-250.0	9.38	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/5

Range	Local(%)	Under(%)
10.0-15.6	1.28	1.33
15.6-31.2	8.99	10.32
31.2-62.5	30.87	41.19
62.5-125.0	33.75	74.94
125.0-250.0	25.06	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/6

Volume Histogram : OA148/6
Mean: 69.15 um STD: 30.88 um Conf.: 100.00 %
D10 : 31.00 um D50: 65.64 um D90: 113.26 um



Area Ranges Table : OA148/6

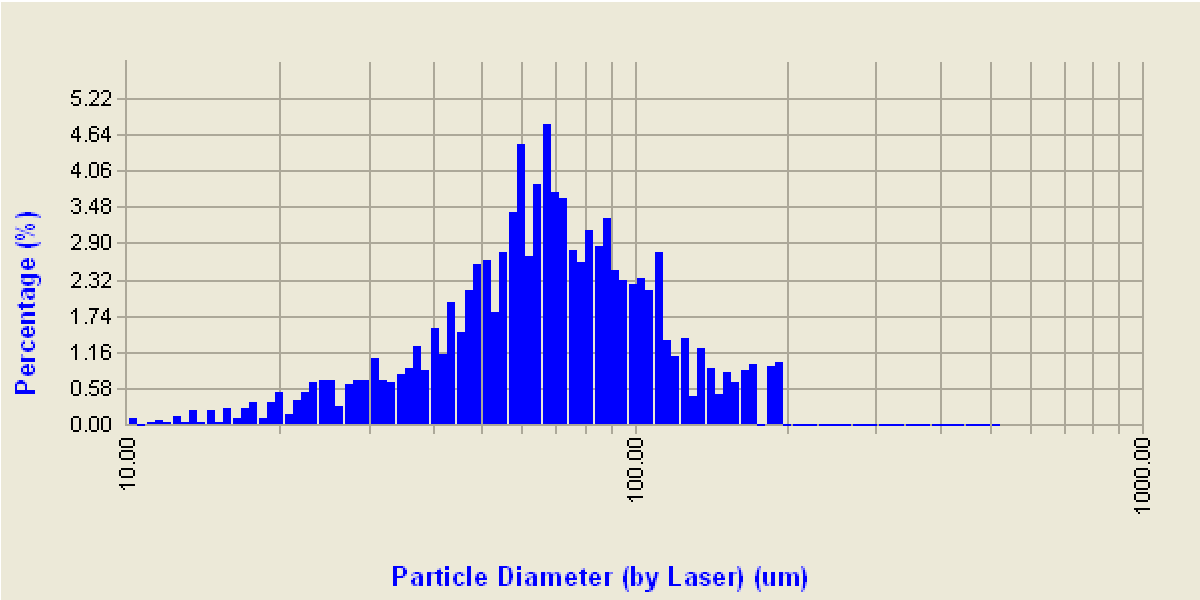
Range	Local(%)	Under(%)
10.0-15.6	4.19	4.69
15.6-31.2	19.40	24.09
31.2-62.5	41.40	65.50
62.5-125.0	32.04	97.54
125.0-250.0	2.46	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/6

Range	Local(%)	Under(%)
10.0-15.6	1.01	1.10
15.6-31.2	8.37	9.46
31.2-62.5	35.42	44.88
62.5-125.0	48.87	93.75
125.0-250.0	6.25	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/7

Volume Histogram : OA148/7
Mean: 73.33 um STD: 36.11 um Conf.: 100.00 %
D10 : 31.55 um D50: 66.36 um D90: 120.76 um



Area Ranges Table : OA148/7

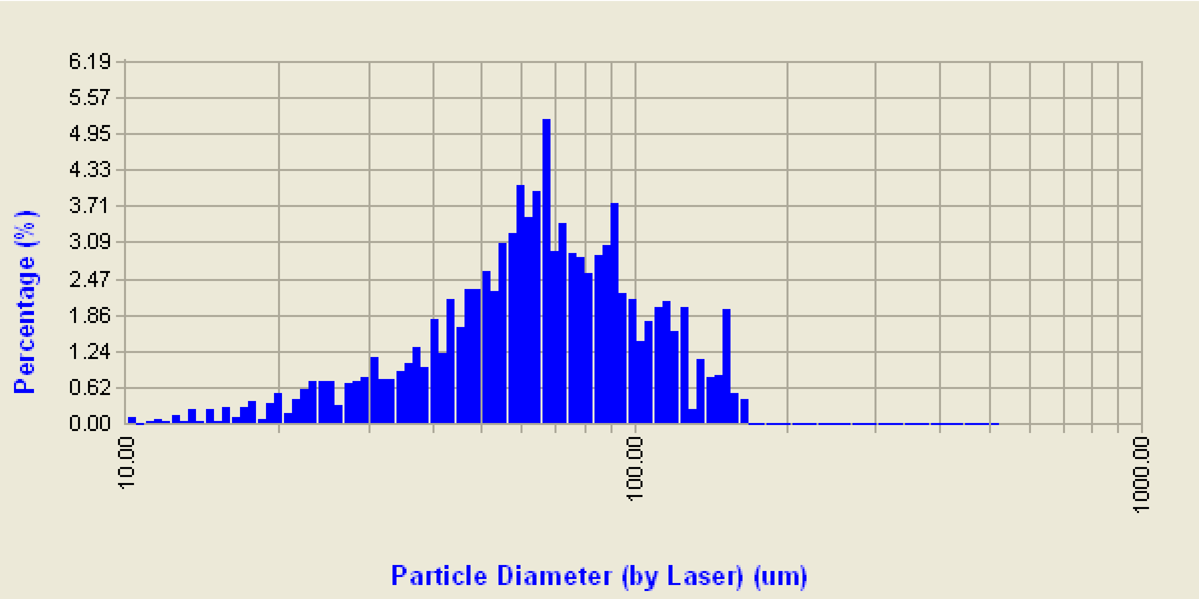
Range	Local(%)	Under(%)
10.0-15.6	4.21	4.34
15.6-31.2	20.06	24.40
31.2-62.5	38.97	63.37
62.5-125.0	33.35	96.71
125.0-250.0	3.29	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/7

Range	Local(%)	Under(%)
10.0-15.6	0.95	0.98
15.6-31.2	8.34	9.32
31.2-62.5	33.07	42.39
62.5-125.0	48.60	90.99
125.0-250.0	9.01	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/8

Volume Histogram : OA148/8
Mean: 69.97 um STD: 31.89 um Conf.: 100.00 %
D10 : 31.55 um D50: 65.28 um D90: 114.23 um



Area Ranges Table : OA148/8

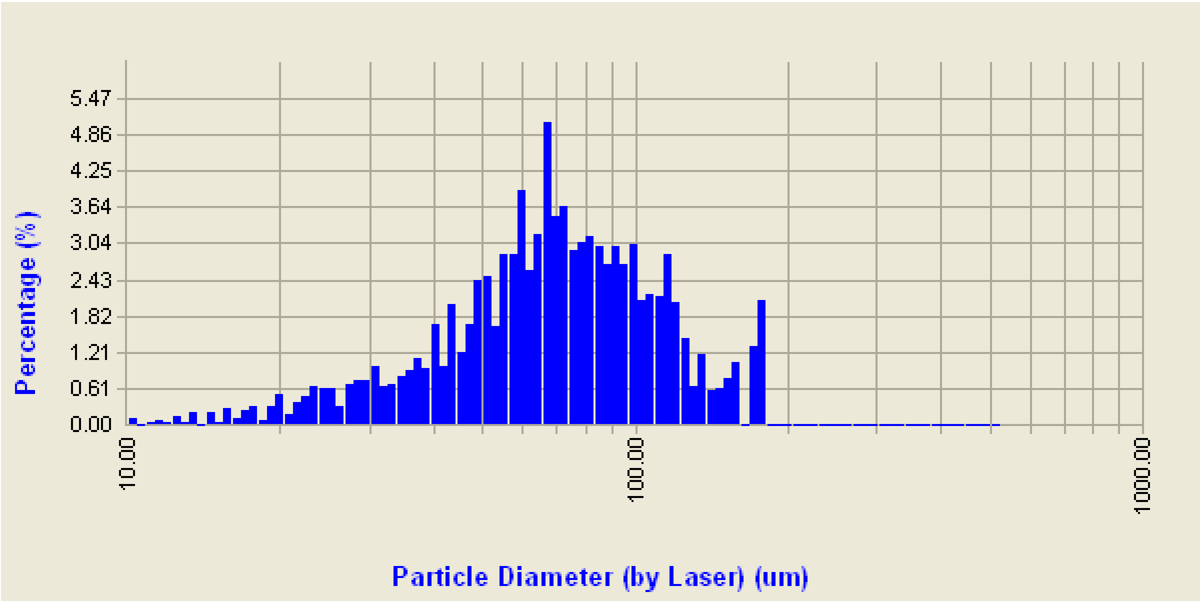
Range	Local(%)	Under(%)
10.0-15.6	4.16	4.29
15.6-31.2	20.74	25.04
31.2-62.5	39.94	64.98
62.5-125.0	32.56	97.54
125.0-250.0	2.46	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/8

Range	Local(%)	Under(%)
10.0-15.6	0.97	0.99
15.6-31.2	8.87	9.86
31.2-62.5	34.72	44.58
62.5-125.0	48.93	93.51
125.0-250.0	6.49	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/9

Volume Histogram : OA148/9
Mean: 74.98 um STD: 35.61 um Conf.: 100.00 %
D10 : 32.64 um D50: 68.54 um D90: 120.76 um



Area Ranges Table : OA148/9

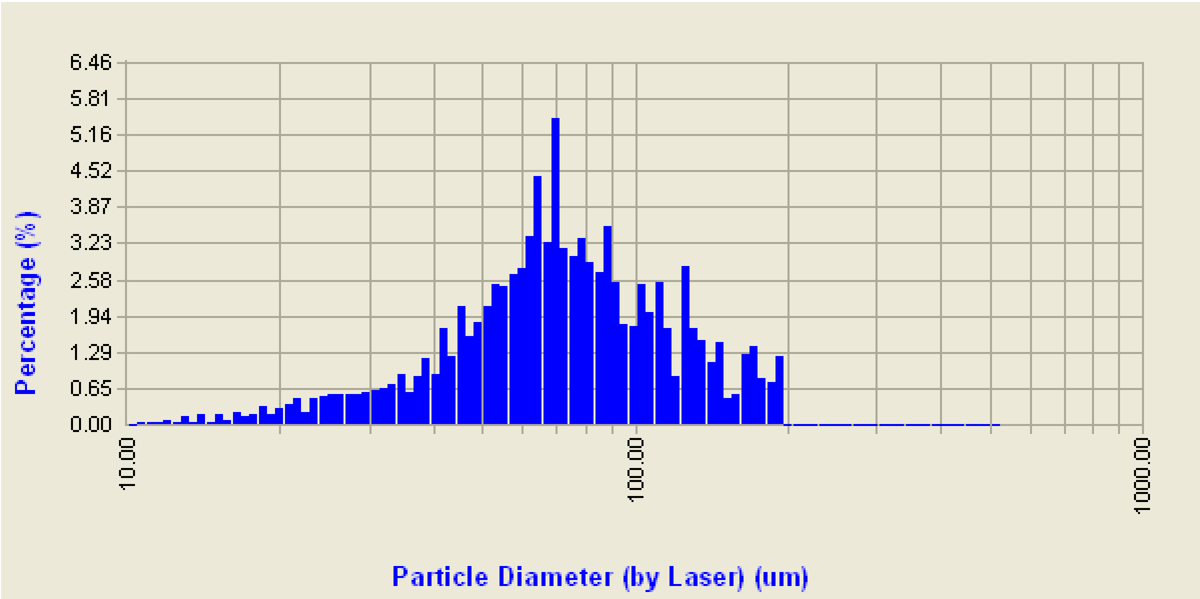
Range	Local(%)	Under(%)
10.0-15.6	4.06	4.19
15.6-31.2	19.53	23.71
31.2-62.5	37.23	60.94
62.5-125.0	35.77	96.71
125.0-250.0	3.29	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/9

Range	Local(%)	Under(%)
10.0-15.6	0.90	0.92
15.6-31.2	7.95	8.86
31.2-62.5	30.63	39.49
62.5-125.0	51.77	91.26
125.0-250.0	8.74	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/10

Volume Histogram : OA148/10
Mean: 78.62 um STD: 38.67 um Conf.: 100.00 %
D10 : 35.31 um D50: 70.13 um D90: 133.23 um



Area Ranges Table : OA148/10

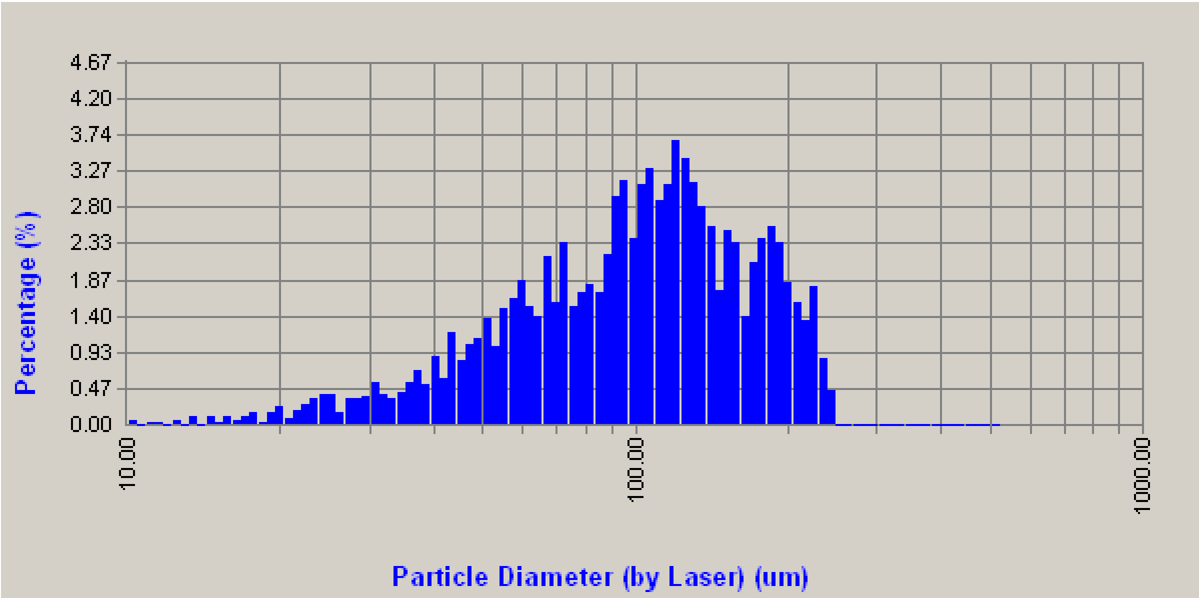
Range	Local(%)	Under(%)
10.0-15.6	3.75	4.17
15.6-31.2	17.36	21.53
31.2-62.5	37.10	58.63
62.5-125.0	35.97	94.60
125.0-250.0	5.40	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/10

Range	Local(%)	Under(%)
10.0-15.6	0.81	0.87
15.6-31.2	6.73	7.60
31.2-62.5	29.46	37.06
62.5-125.0	49.34	86.40
125.0-250.0	13.60	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/11

Volume Histogram : OA148/11
Mean: 109.38 um STD: 53.12 um Conf.: 100.00 %
D10 : 43.52 um D50: 104.44 um D90: 188.21 um



Area Ranges Table : OA148/11

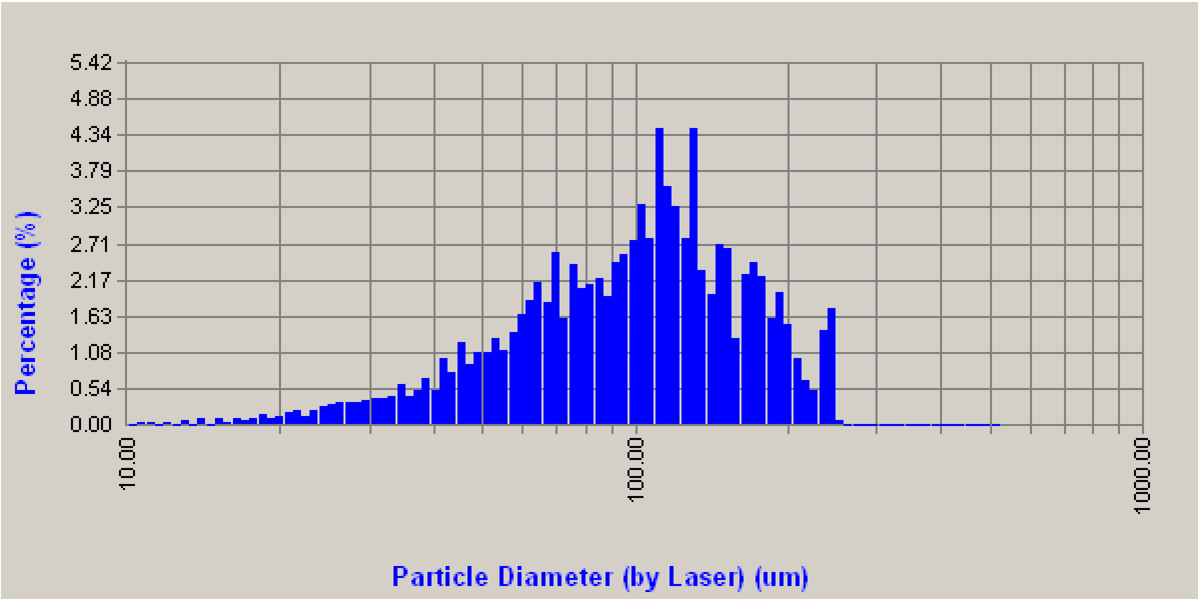
Range	Local(%)	Under(%)
10.0-15.6	2.49	2.56
15.6-31.2	14.10	16.66
31.2-62.5	28.61	45.28
62.5-125.0	37.55	82.82
125.0-250.0	17.18	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/11

Range	Local(%)	Under(%)
10.0-15.6	0.40	0.41
15.6-31.2	4.19	4.60
31.2-62.5	16.99	21.59
62.5-125.0	42.99	64.57
125.0-250.0	35.43	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/12

Volume Histogram : OA148/12
Mean: 108.22 um STD: 52.09 um Conf.: 100.00 %
D10 : 45.11 um D50: 103.85 um D90: 181.10 um



Area Ranges Table : OA148/12

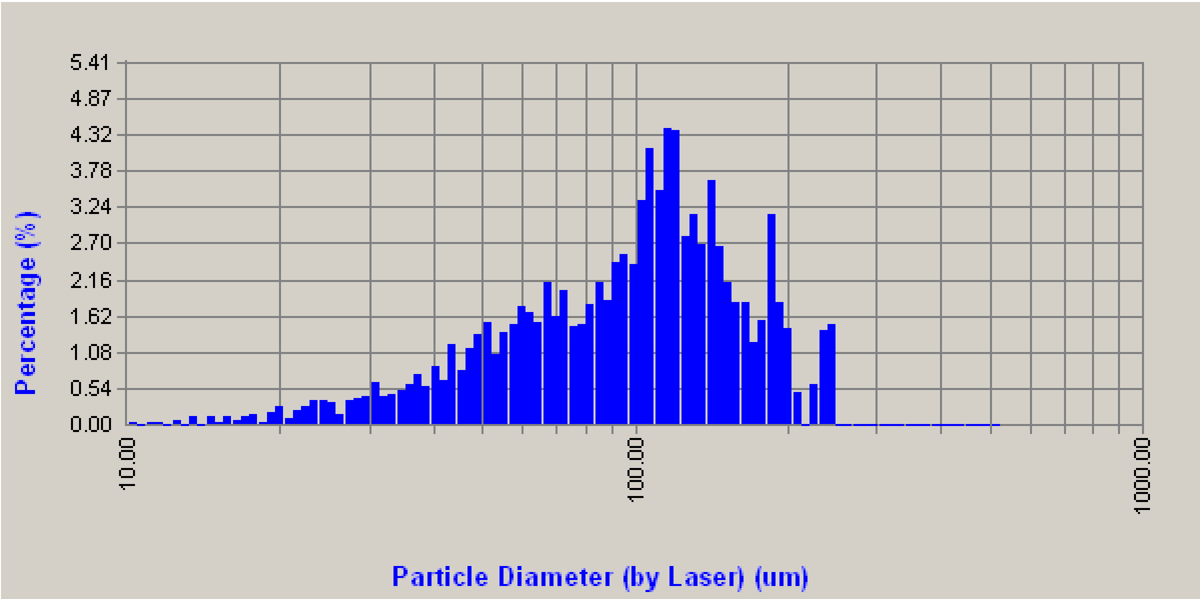
Range	Local(%)	Under(%)
10.0-15.6	2.21	2.45
15.6-31.2	12.30	14.75
31.2-62.5	28.12	42.87
62.5-125.0	40.26	83.13
125.0-250.0	16.87	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/12

Range	Local(%)	Under(%)
10.0-15.6	0.35	0.38
15.6-31.2	3.64	4.02
31.2-62.5	16.51	20.53
62.5-125.0	45.38	65.91
125.0-250.0	34.09	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/13

Volume Histogram : OA148/13
Mean: 106.21 um STD: 51.37 um Conf.: 100.00 %
D10 : 42.43 um D50: 104.44 um D90: 181.68 um



Area Ranges Table : OA148/13

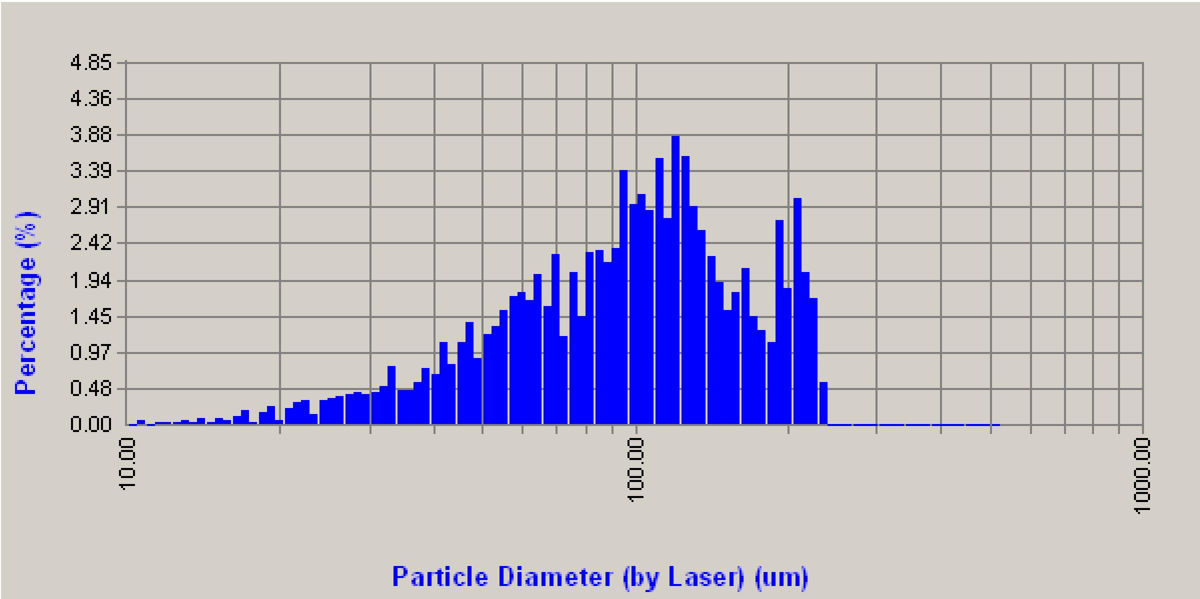
Range	Local(%)	Under(%)
10.0-15.6	2.70	2.78
15.6-31.2	14.57	17.35
31.2-62.5	29.37	46.71
62.5-125.0	37.70	84.42
125.0-250.0	15.58	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/13

Range	Local(%)	Under(%)
10.0-15.6	0.44	0.45
15.6-31.2	4.45	4.90
31.2-62.5	17.73	22.63
62.5-125.0	45.01	67.64
125.0-250.0	32.36	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/14

Volume Histogram : OA148/14
Mean: 106.67 um STD: 53.27 um Conf.: 100.00 %
D10 : 41.73 um D50: 100.48 um D90: 192.95 um



Area Ranges Table : OA148/14

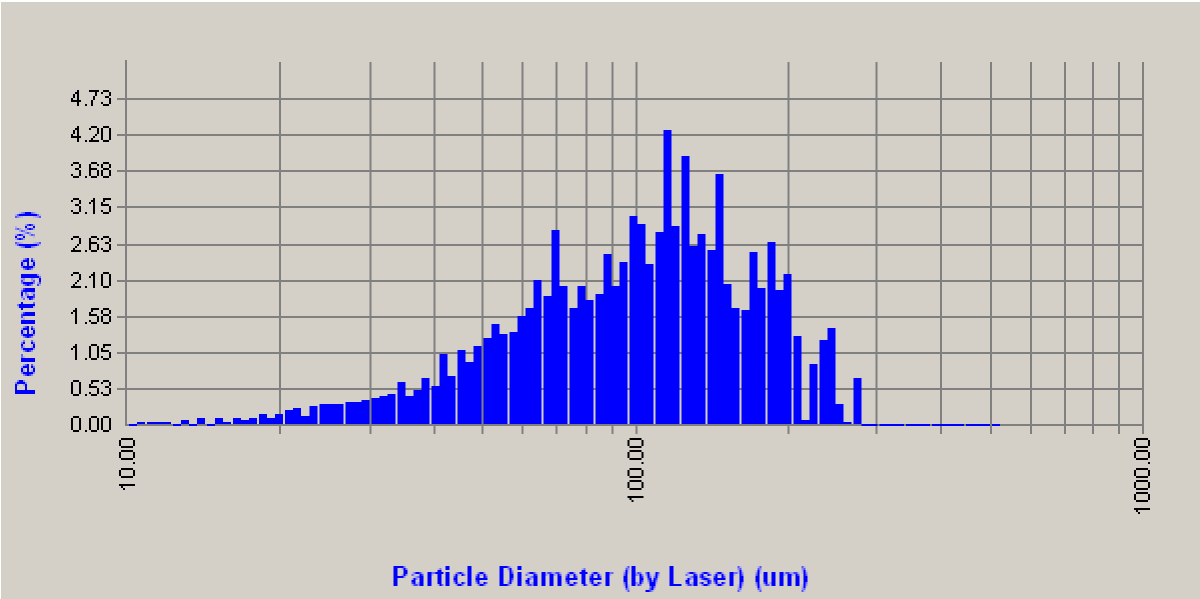
Range	Local(%)	Under(%)
10.0-15.6	2.59	2.88
15.6-31.2	14.91	17.79
31.2-62.5	30.02	47.82
62.5-125.0	37.60	85.42
125.0-250.0	14.58	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/14

Range	Local(%)	Under(%)
10.0-15.6	0.43	0.47
15.6-31.2	4.56	5.03
31.2-62.5	18.31	23.33
62.5-125.0	45.00	68.34
125.0-250.0	31.66	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/15

Volume Histogram : OA148/15
Mean: 110.18 um STD: 54.60 um Conf.: 100.00 %
D10 : 45.11 um D50: 103.85 um D90: 187.62 um



Area Ranges Table : OA148/15

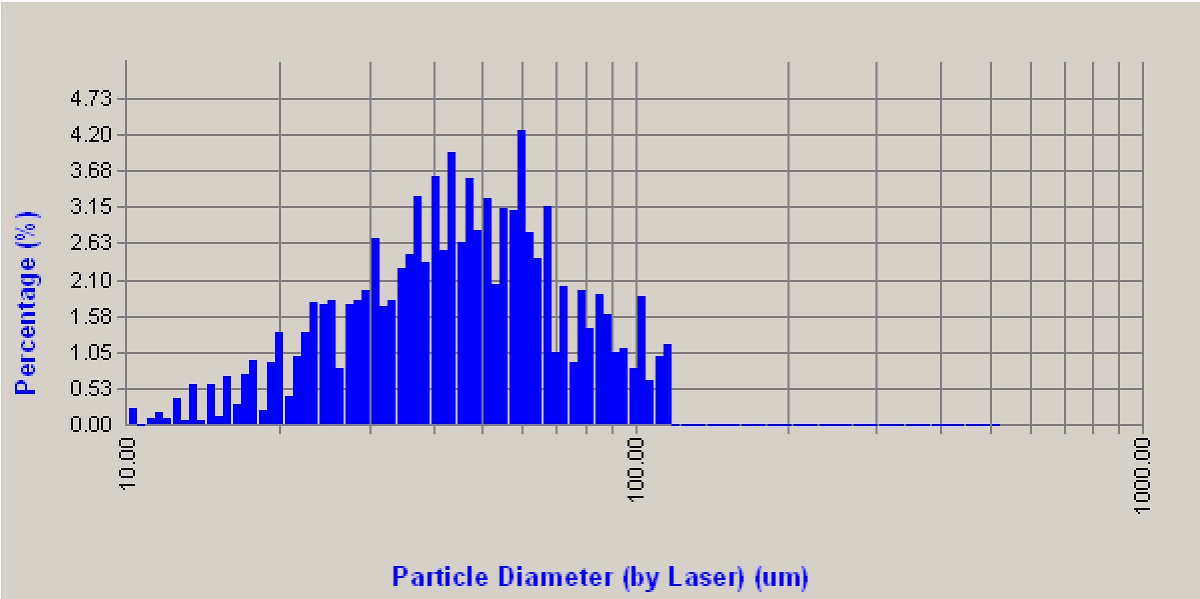
Range	Local(%)	Under(%)
10.0-15.6	2.33	2.58
15.6-31.2	12.95	15.53
31.2-62.5	28.45	43.98
62.5-125.0	38.77	82.74
125.0-250.0	16.96	99.70
250.0-500.0	0.30	100.00

Volume Ranges Table : OA148/15

Range	Local(%)	Under(%)
10.0-15.6	0.37	0.40
15.6-31.2	3.80	4.20
31.2-62.5	16.67	20.87
62.5-125.0	43.65	64.52
125.0-250.0	34.49	99.01
250.0-500.0	0.99	100.00

Volume Distribution: OA148/16

Volume Histogram : OA148/16
Mean: 49.08 um STD: 23.54 um Conf.: 100.00 %
D10 : 21.76 um D50: 44.61 um D90: 83.77 um



Area Ranges Table : OA148/16

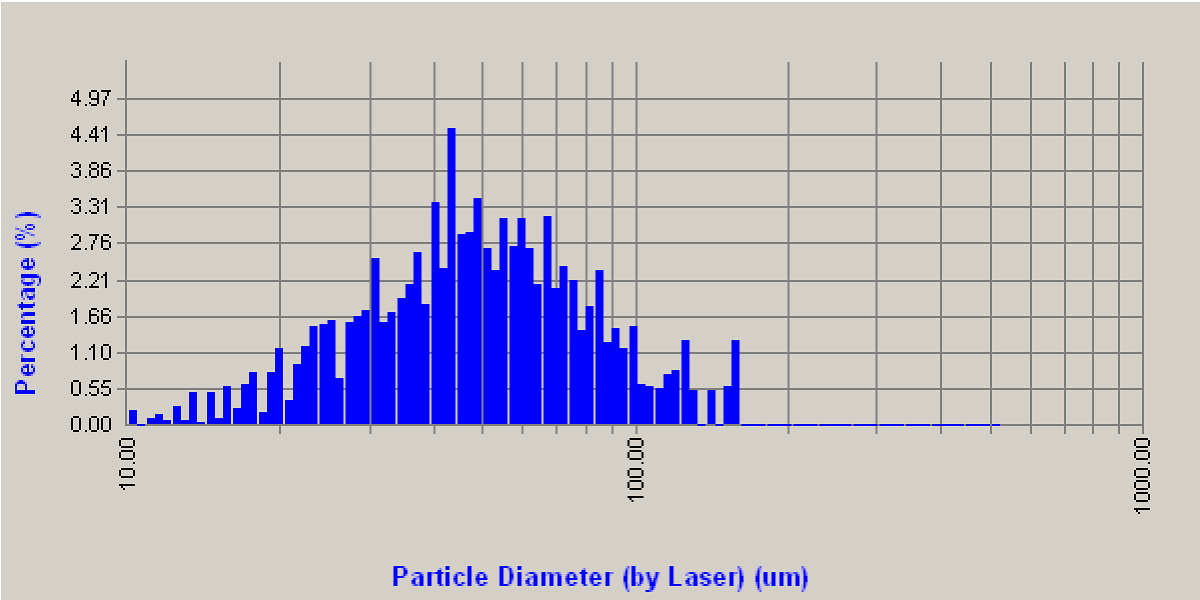
Range	Local(%)	Under(%)
10.0-15.6	7.50	7.71
15.6-31.2	36.29	44.00
31.2-62.5	44.13	88.13
62.5-125.0	11.87	100.00
125.0-250.0	0.00	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/16

Range	Local(%)	Under(%)
10.0-15.6	2.48	2.53
15.6-31.2	21.99	24.52
31.2-62.5	50.76	75.28
62.5-125.0	24.72	100.00
125.0-250.0	0.00	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/17

Volume Histogram : OA148/17
Mean: 54.33 um STD: 29.50 um Conf.: 100.00 %
D10 : 22.85 um D50: 47.87 um D90: 92.47 um



Area Ranges Table : OA148/17

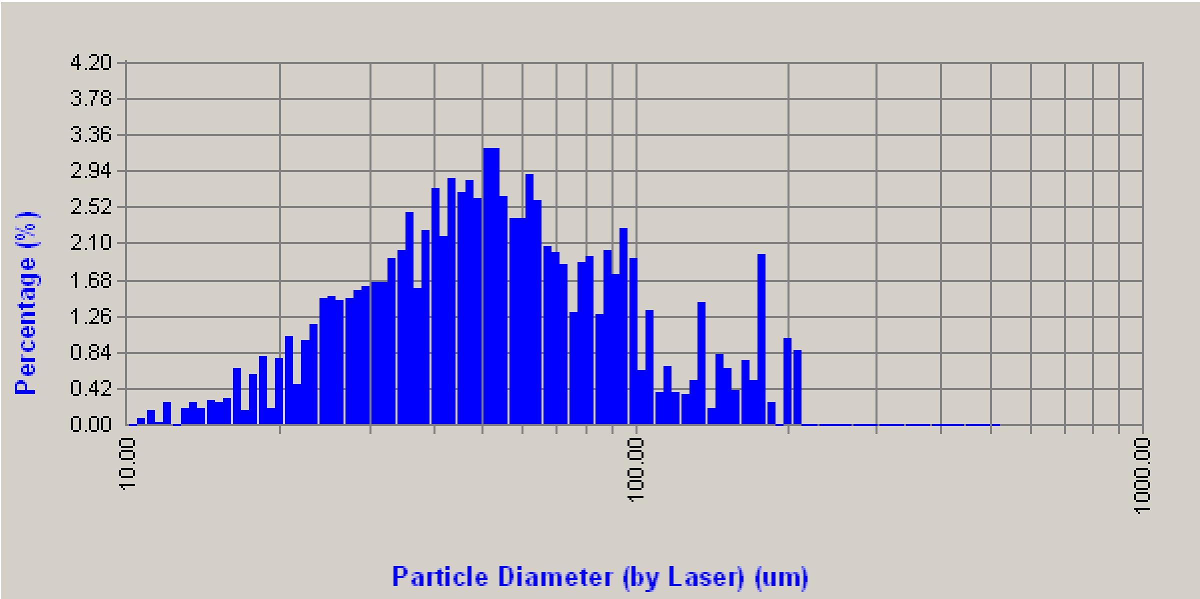
Range	Local(%)	Under(%)
10.0-15.6	6.69	6.88
15.6-31.2	34.14	41.03
31.2-62.5	43.76	84.79
62.5-125.0	14.16	98.95
125.0-250.0	1.05	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/17

Range	Local(%)	Under(%)
10.0-15.6	2.07	2.12
15.6-31.2	19.48	21.60
31.2-62.5	47.24	68.84
62.5-125.0	27.48	96.32
125.0-250.0	3.68	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/18

Volume Histogram : OA148/18
Mean: 62.60 um STD: 41.23 um Conf.: 100.00 %
D10 : 23.61 um D50: 50.95 um D90: 117.65 um



Area Ranges Table : OA148/18

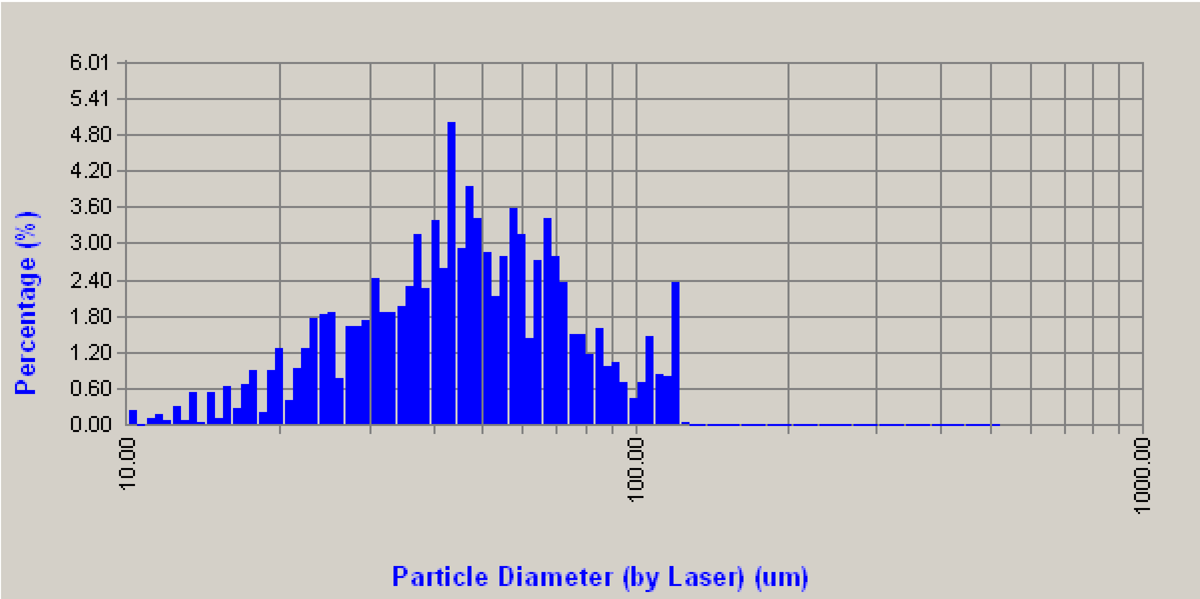
Range	Local(%)	Under(%)
10.0-15.6	6.52	7.29
15.6-31.2	32.27	39.56
31.2-62.5	43.75	83.31
62.5-125.0	14.20	97.51
125.0-250.0	2.49	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/18

Range	Local(%)	Under(%)
10.0-15.6	1.95	2.12
15.6-31.2	17.45	19.56
31.2-62.5	44.53	64.10
62.5-125.0	26.60	90.69
125.0-250.0	9.31	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/19

Volume Histogram : OA148/19
Mean: 50.04 um STD: 24.61 um Conf.: 100.00 %
D10 : 22.85 um D50: 45.69 um D90: 83.77 um



Area Ranges Table : OA148/19

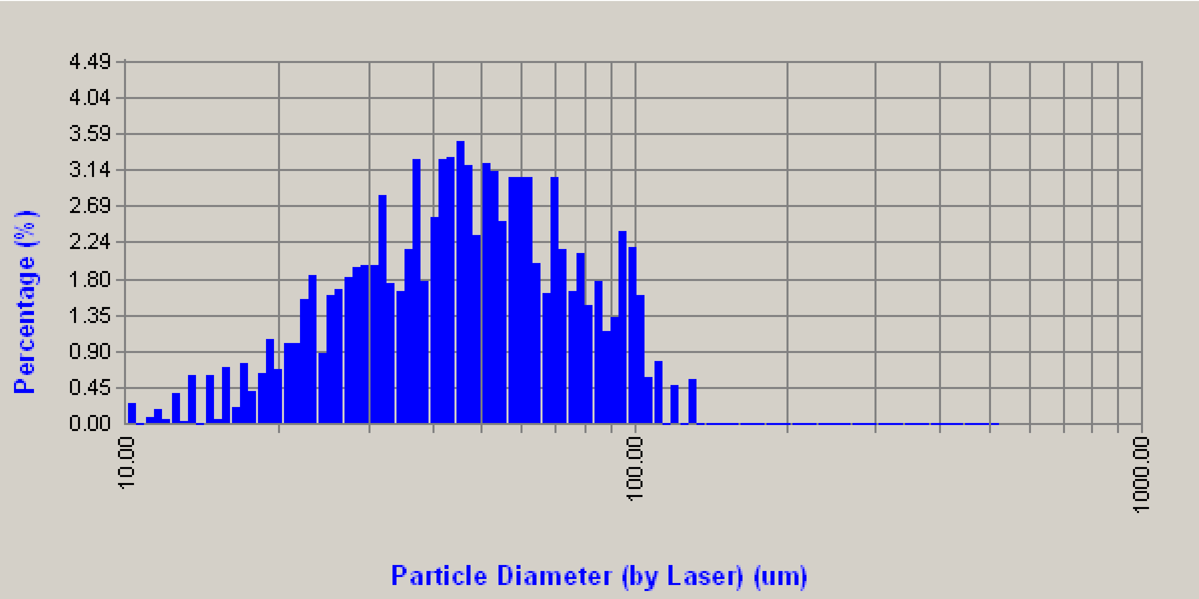
Range	Local(%)	Under(%)
10.0-15.6	7.02	7.23
15.6-31.2	35.07	42.30
31.2-62.5	44.66	86.95
62.5-125.0	13.05	100.00
125.0-250.0	0.00	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/19

Range	Local(%)	Under(%)
10.0-15.6	2.28	2.33
15.6-31.2	20.86	23.19
31.2-62.5	50.11	73.30
62.5-125.0	26.70	100.00
125.0-250.0	0.00	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/20

Volume Histogram : OA148/20
Mean: 50.41 um STD: 24.54 um Conf.: 100.00 %
D10 : 21.87 um D50: 45.93 um D90: 88.57 um



Area Ranges Table : OA148/20

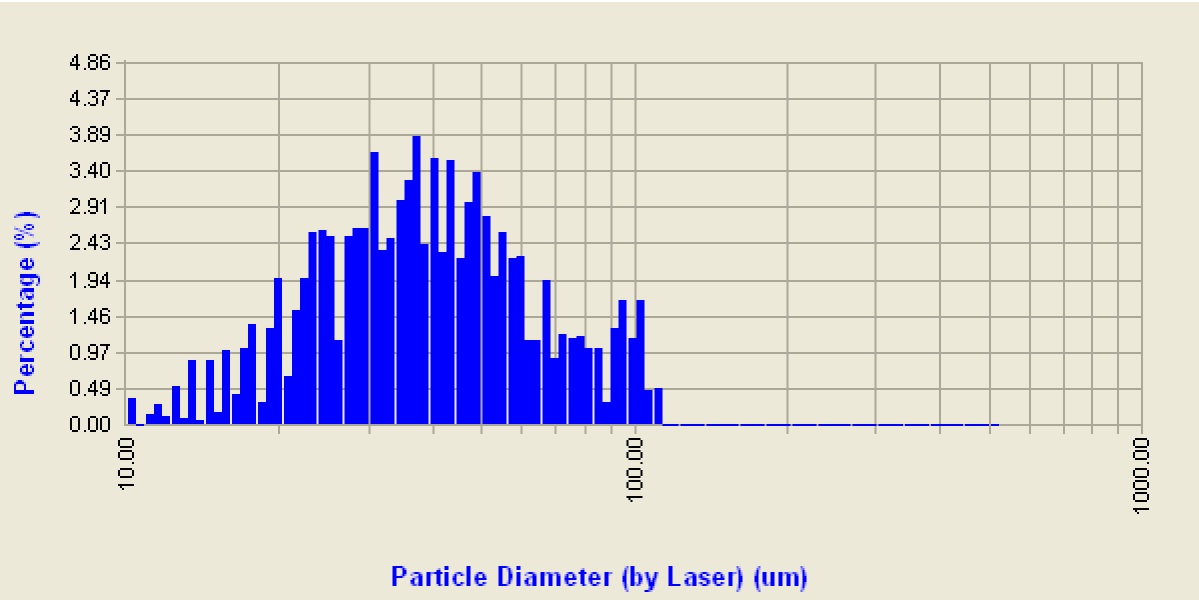
Range	Local(%)	Under(%)
10.0-15.6	7.13	7.30
15.6-31.2	37.26	44.56
31.2-62.5	42.10	86.66
62.5-125.0	13.18	99.84
125.0-250.0	0.16	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/20

Range	Local(%)	Under(%)
10.0-15.6	2.31	2.35
15.6-31.2	22.36	24.72
31.2-62.5	47.65	72.37
62.5-125.0	27.08	99.45
125.0-250.0	0.55	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/21

Volume Histogram : OA148/21
Mean: 42.84 um STD: 22.12 um Conf.: 100.00 %
D10 : 19.58 um D50: 36.99 um D90: 76.16 um



Area Ranges Table : OA148/21

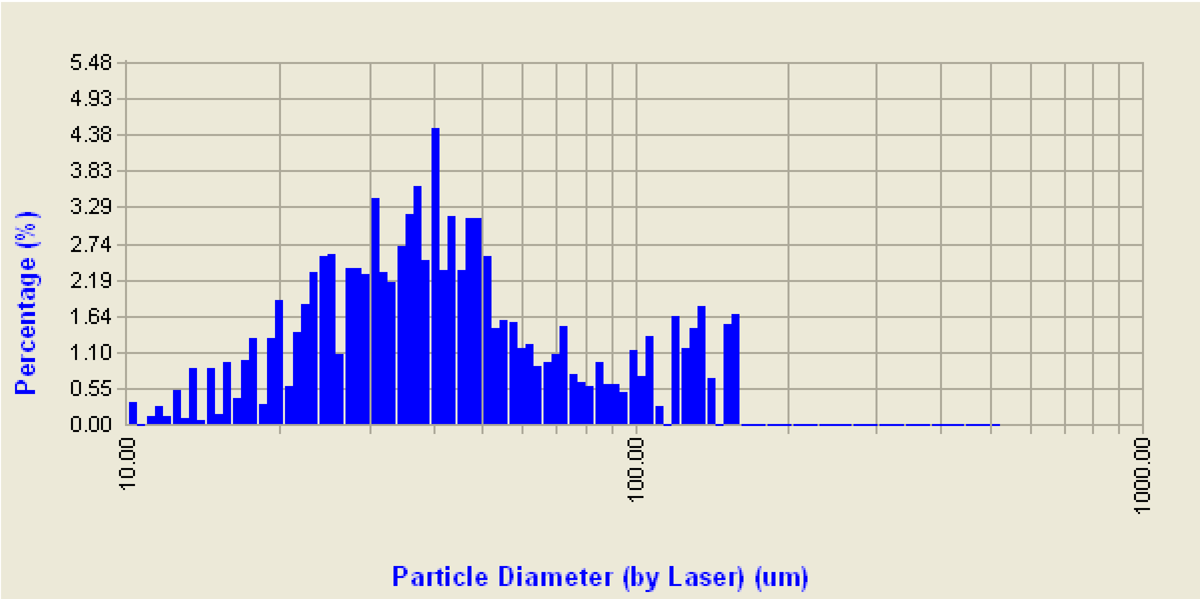
Range	Local(%)	Under(%)
10.0-15.6	9.56	9.85
15.6-31.2	45.24	55.09
31.2-62.5	37.97	93.06
62.5-125.0	6.94	100.00
125.0-250.0	0.00	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/21

Range	Local(%)	Under(%)
10.0-15.6	3.63	3.71
15.6-31.2	31.46	35.17
31.2-62.5	47.99	83.16
62.5-125.0	16.84	100.00
125.0-250.0	0.00	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/22

Volume Histogram : OA148/22
Mean: 50.51 um STD: 35.25 um Conf.: 100.00 %
D10 : 19.58 um D50: 39.17 um D90: 108.79 um



Area Ranges Table : OA148/22

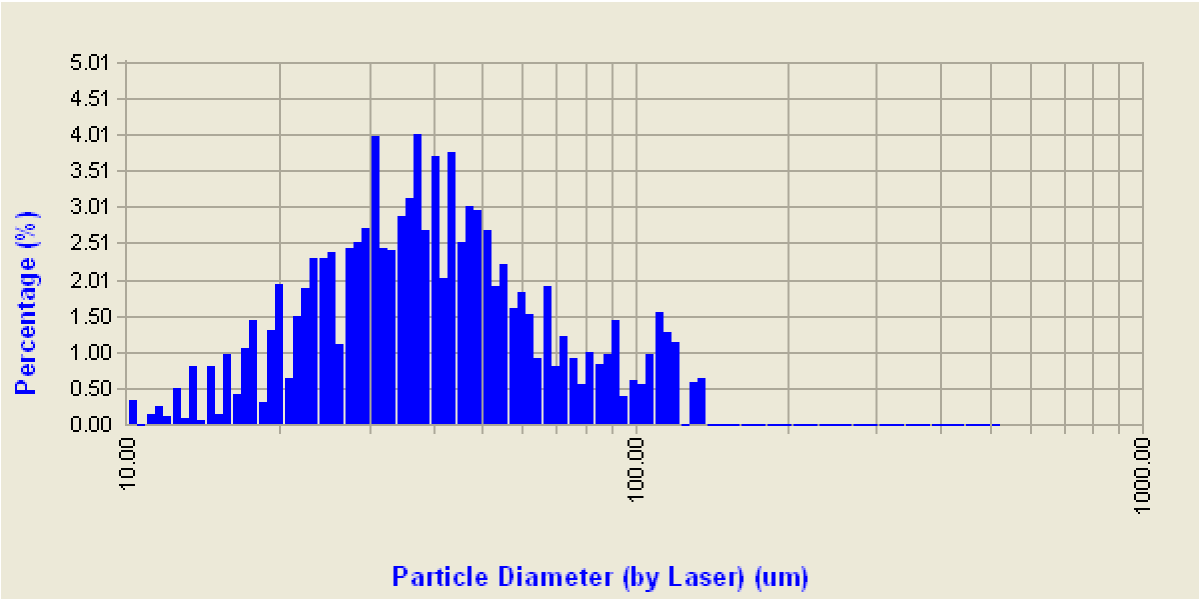
Range	Local(%)	Under(%)
10.0-15.6	9.81	10.08
15.6-31.2	44.75	54.83
31.2-62.5	37.09	91.93
62.5-125.0	6.23	98.16
125.0-250.0	1.84	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/22

Range	Local(%)	Under(%)
10.0-15.6	3.56	3.63
15.6-31.2	29.61	33.25
31.2-62.5	44.04	77.29
62.5-125.0	15.22	92.51
125.0-250.0	7.49	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/23

Volume Histogram : OA148/23
Mean: 45.09 um STD: 26.25 um Conf.: 100.00 %
D10 : 19.58 um D50: 38.08 um D90: 85.95 um



Area Ranges Table : OA148/23

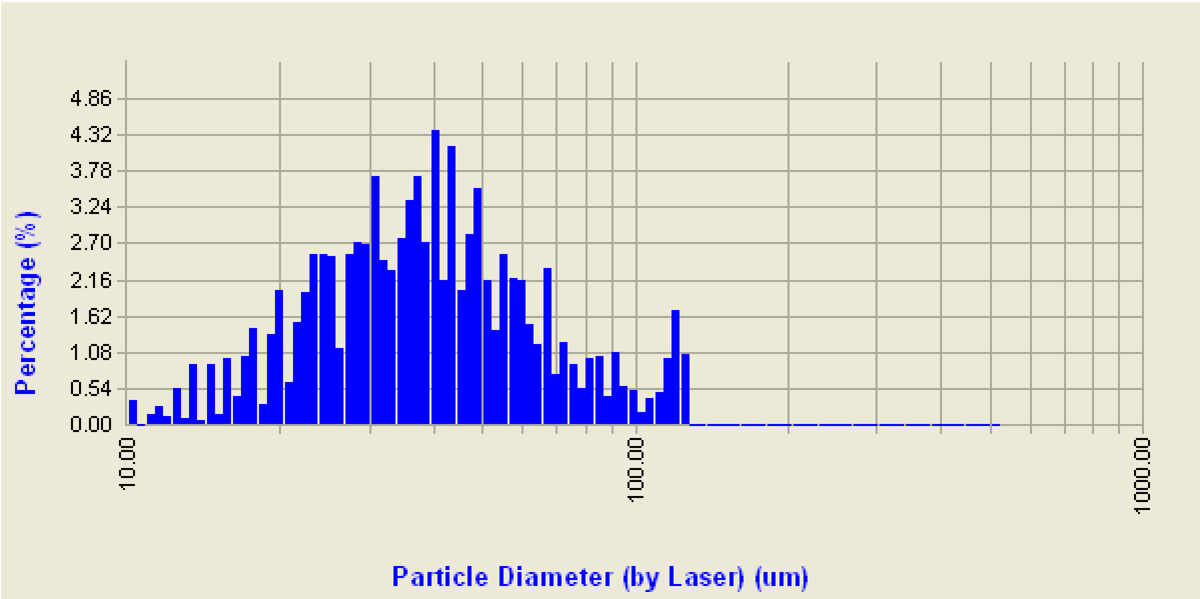
Range	Local(%)	Under(%)
10.0-15.6	9.20	9.47
15.6-31.2	45.23	54.70
31.2-62.5	38.03	92.73
62.5-125.0	6.95	99.69
125.0-250.0	0.31	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/23

Range	Local(%)	Under(%)
10.0-15.6	3.43	3.51
15.6-31.2	30.93	34.44
31.2-62.5	46.95	81.39
62.5-125.0	17.39	98.78
125.0-250.0	1.22	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/24

Volume Histogram : OA148/24
Mean: 43.41 um STD: 24.38 um Conf.: 100.00 %
D10 : 19.58 um D50: 36.99 um D90: 75.07 um



Area Ranges Table : OA148/24

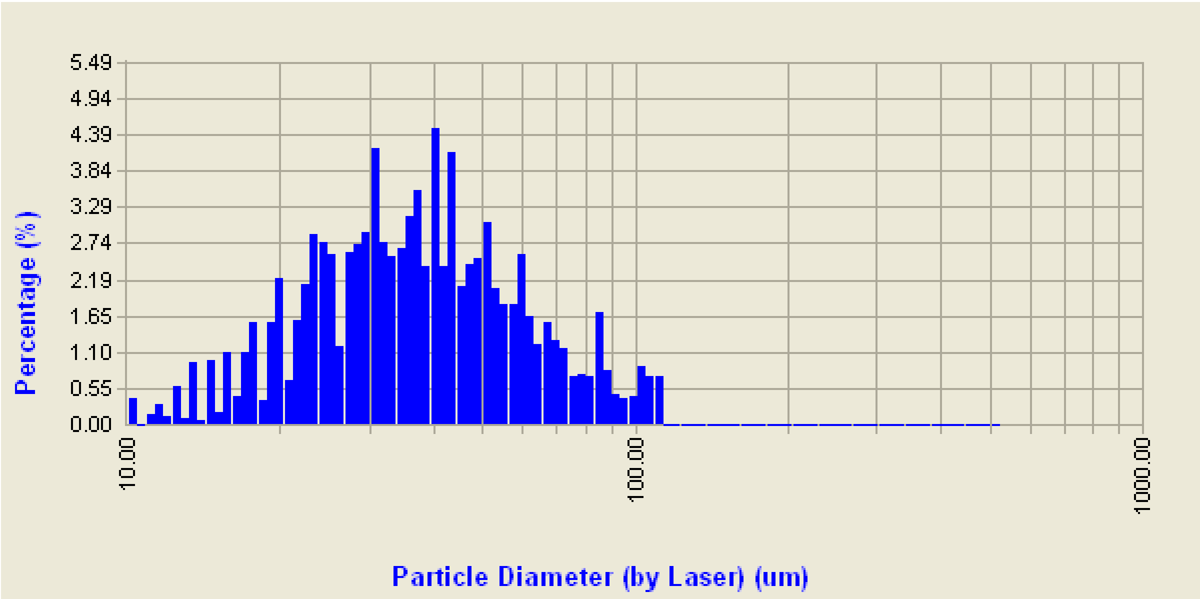
Range	Local(%)	Under(%)
10.0-15.6	9.76	10.04
15.6-31.2	45.47	55.50
31.2-62.5	37.88	93.39
62.5-125.0	6.61	99.99
125.0-250.0	0.01	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/24

Range	Local(%)	Under(%)
10.0-15.6	3.72	3.80
15.6-31.2	31.70	35.50
31.2-62.5	47.87	83.37
62.5-125.0	16.61	99.98
125.0-250.0	0.02	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/25

Volume Histogram : OA148/25
Mean: 40.68 um STD: 20.72 um Conf.: 100.00 %
D10 : 18.49 um D50: 35.90 um D90: 69.63 um



Area Ranges Table : OA148/25

Range	Local(%)	Under(%)
10.0-15.6	10.35	10.67
15.6-31.2	47.31	57.97
31.2-62.5	36.35	94.32
62.5-125.0	5.68	100.00
125.0-250.0	0.00	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/25

Range	Local(%)	Under(%)
10.0-15.6	4.09	4.18
15.6-31.2	34.18	38.36
31.2-62.5	47.66	86.02
62.5-125.0	13.98	100.00
125.0-250.0	0.00	100.00
250.0-500.0	0.00	100.00

Quality control data for particle size analyses – sediment quality collection areas

QA included replicate analyses of seven sediment samples from the 2010 survey to assess 'within-batch' variability.

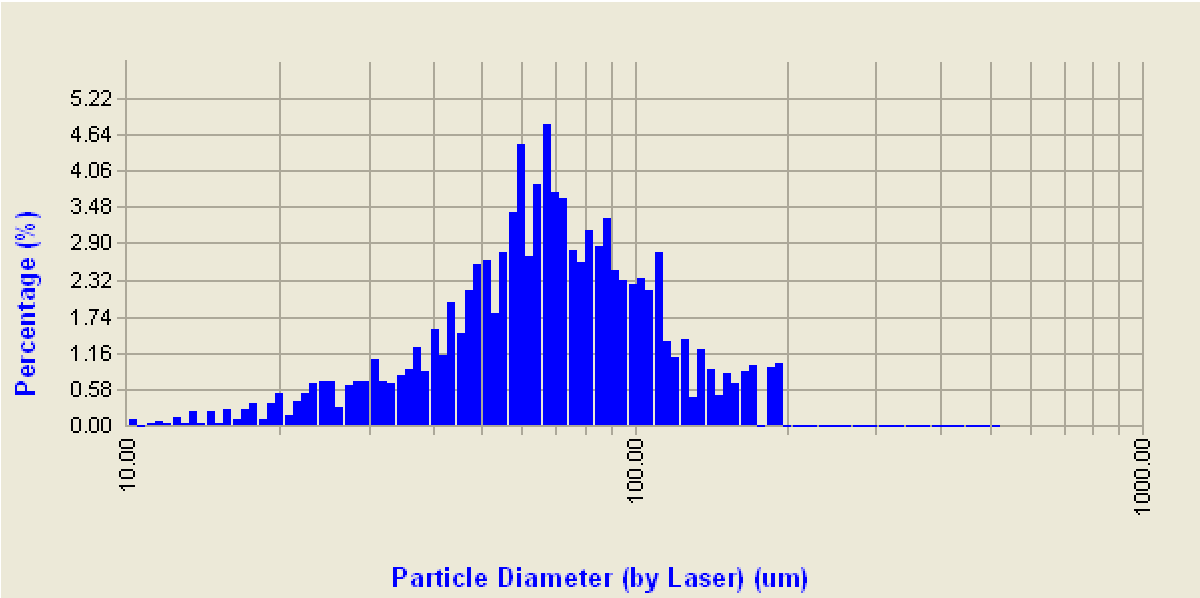
Table A1-2: Summary of QA particle size data for subtidal sediments collected from sediment quality collection areas of Porirua Harbour in 2010

NIWA Code	GWRC Code	Mean (µm)	Standard deviation (µm)	Maximum (µm)	10-62.5 µm '% mud'
OA148/7(a)	PAH 2/17	73.33	36.11	192.56	42.39
OA148/7(b)	PAH 2/17	73.17	36.67	191.93	42.35
OA148/9(a)	PAH 2/19	74.98	35.61	177.33	39.49
OA148/9(b)	PAH 2/19	80.23	39.78	227.74	36.46
OA148/10(a)	PAH 2/20	78.62	38.67	193.06	37.06
OA148/10(b)	PAH 2/20	75.26	34.85	179.51	37.77
OA148/10(c)	PAH 2/20	74.06	34.84	209.29	39.01
OA148/11(a)	PAH 3/16	109.38	53.12	244.78	21.59
OA148/11(b)	PAH 3/16	105.57	51.87	252.70	22.18
OA148/11(c)	PAH 3/16	108.62	51.81	234.99	20.22
OA148/14(a)	PAH 3/19	106.67	53.27	233.20	23.33
OA148/14(b)	PAH 3/19	105.28	47.44	221.25	19.60
OA148/20(a)	POR 1/20	50.41	24.54	131.21	72.37
OA148/20(b)	POR 1/20	49.44	25.00	127.69	74.46
OA148/24(a)	PAH 2/19	43.41	24.38	125.11	83.37
OA148/24(b)	PAH 2/19	51.02	36.69	180.60	76.62

Particle size distribution histograms and tables

Volume Distribution: OA148/7(a)

Volume Histogram : OA148/7(a)
Mean: 73.33 um STD: 36.11 um Conf.: 100.00 %
D10 : 31.55 um D50: 66.36 um D90: 120.76 um



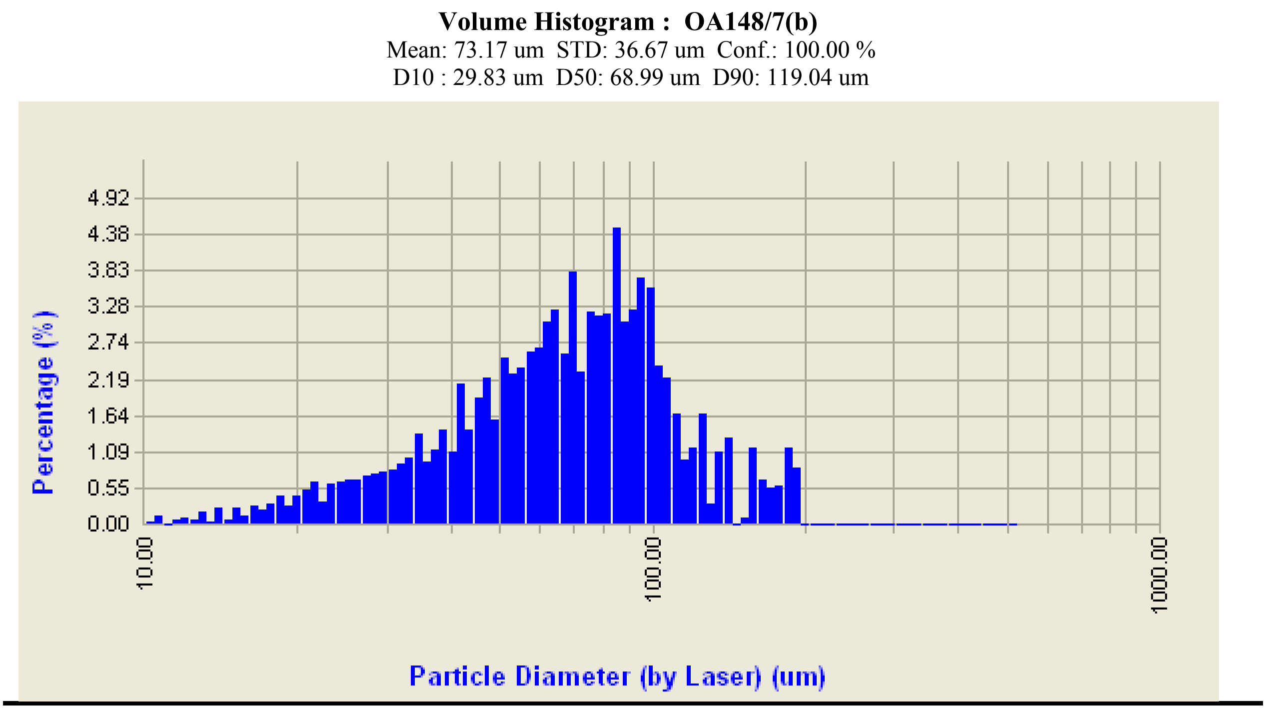
Area Ranges Table : OA148/7(a)

Range	Local(%)	Under(%)
10.0-15.6	4.21	4.34
15.6-31.2	20.06	24.40
31.2-62.5	38.97	63.37
62.5-125.0	33.35	96.71
125.0-250.0	3.29	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/7(a)

Range	Local(%)	Under(%)
10.0-15.6	0.95	0.98
15.6-31.2	8.34	9.32
31.2-62.5	33.07	42.39
62.5-125.0	48.60	90.99
125.0-250.0	9.01	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/7(b)



Area Ranges Table : OA148/7(b)

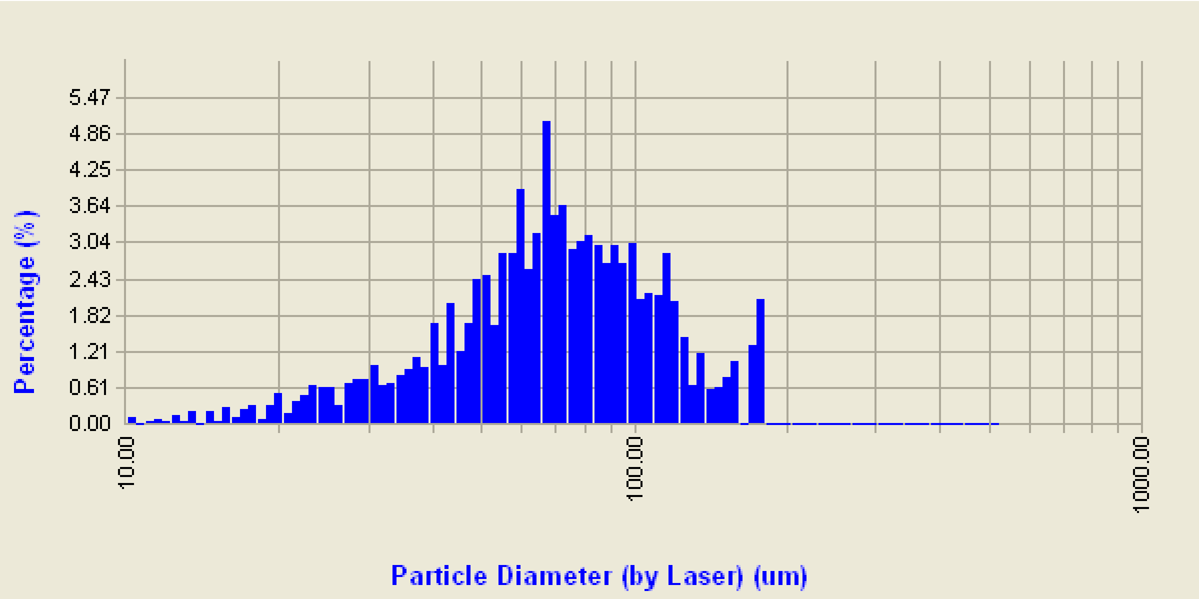
Range	Local(%)	Under(%)
10.0-15.6	4.66	5.15
15.6-31.2	21.93	27.08
31.2-62.5	37.85	64.94
62.5-125.0	32.20	97.14
125.0-250.0	2.86	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/7(b)

Range	Local(%)	Under(%)
10.0-15.6	1.09	1.17
15.6-31.2	9.21	10.39
31.2-62.5	31.96	42.35
62.5-125.0	49.47	91.83
125.0-250.0	8.17	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/9(a)

Volume Histogram : OA148/9(a)
Mean: 74.98 um STD: 35.61 um Conf.: 100.00 %
D10 : 32.64 um D50: 68.54 um D90: 120.76 um



Area Ranges Table : OA148/9(a)

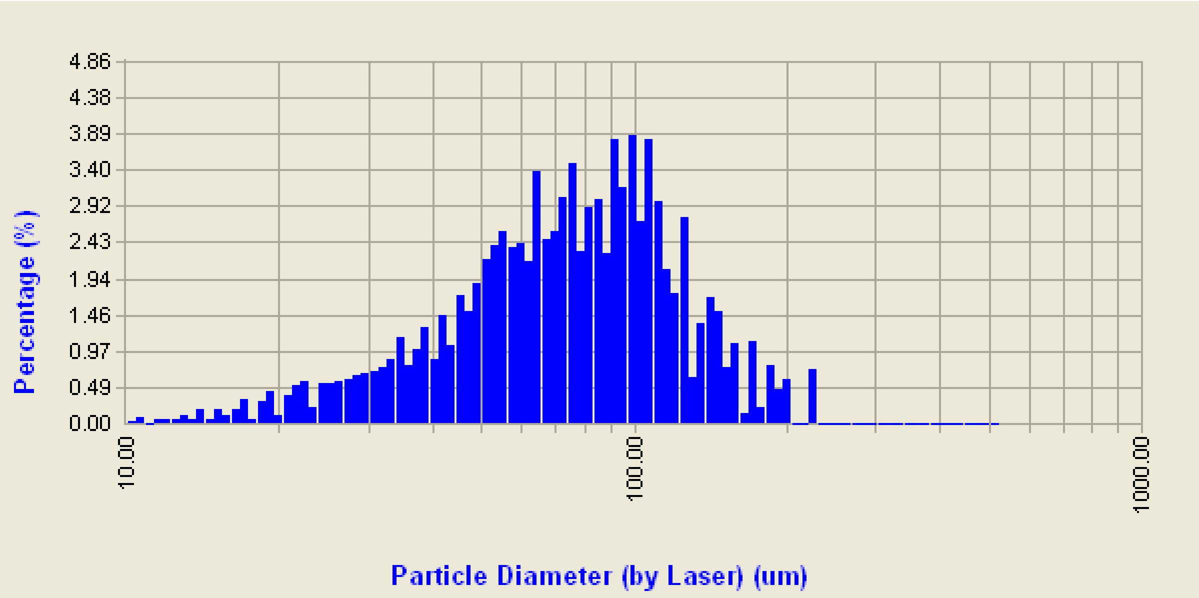
Range	Local(%)	Under(%)
10.0-15.6	4.06	4.19
15.6-31.2	19.53	23.71
31.2-62.5	37.23	60.94
62.5-125.0	35.77	96.71
125.0-250.0	3.29	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/9(a)

Range	Local(%)	Under(%)
10.0-15.6	0.90	0.92
15.6-31.2	7.95	8.86
31.2-62.5	30.63	39.49
62.5-125.0	51.77	91.26
125.0-250.0	8.74	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/9(b)

Volume Histogram : OA148/9(b)
Mean: 80.23 um STD: 39.78 um Conf.: 100.00 %
D10 : 33.11 um D50: 74.66 um D90: 133.71 um



Area Ranges Table : OA148/9(b)

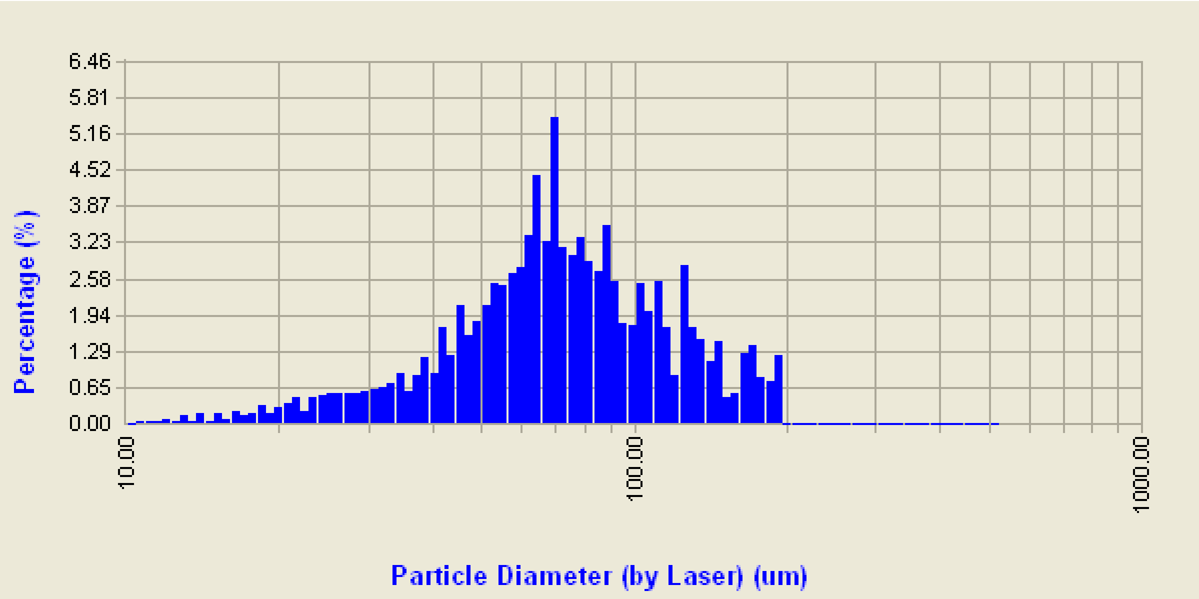
Range	Local(%)	Under(%)
10.0-15.6	4.00	4.41
15.6-31.2	19.24	23.65
31.2-62.5	36.09	59.74
62.5-125.0	35.49	95.23
125.0-250.0	4.77	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/9(b)

Range	Local(%)	Under(%)
10.0-15.6	0.85	0.91
15.6-31.2	7.46	8.37
31.2-62.5	28.08	36.46
62.5-125.0	51.32	87.78
125.0-250.0	12.22	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/10(a)

Volume Histogram : OA148/10(a)
Mean: 78.62 um STD: 38.67 um Conf.: 100.00 %
D10 : 35.31 um D50: 70.13 um D90: 133.23 um



Area Ranges Table : OA148/10(a)

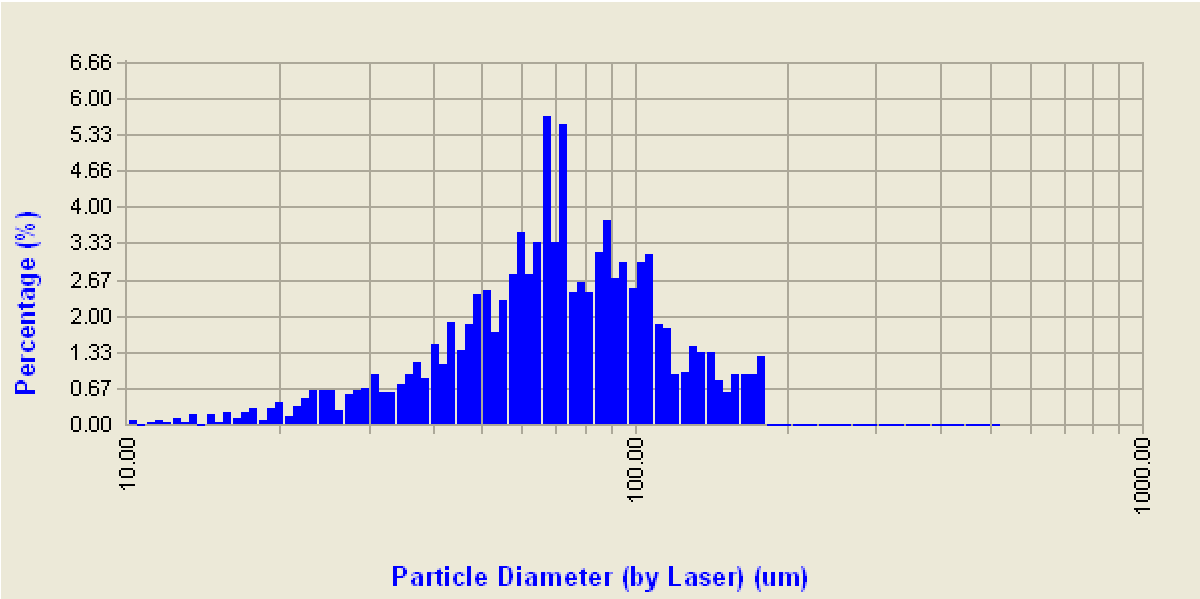
Range	Local(%)	Under(%)
10.0-15.6	3.75	4.17
15.6-31.2	17.36	21.53
31.2-62.5	37.10	58.63
62.5-125.0	35.97	94.60
125.0-250.0	5.40	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/10(a)

Range	Local(%)	Under(%)
10.0-15.6	0.81	0.87
15.6-31.2	6.73	7.60
31.2-62.5	29.46	37.06
62.5-125.0	49.34	86.40
125.0-250.0	13.60	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/10(b)

Volume Histogram : OA148/10(b)
Mean: 75.26 um STD: 34.85 um Conf.: 100.00 %
D10 : 33.73 um D50: 69.63 um D90: 124.02 um



Area Ranges Table : OA148/10(b)

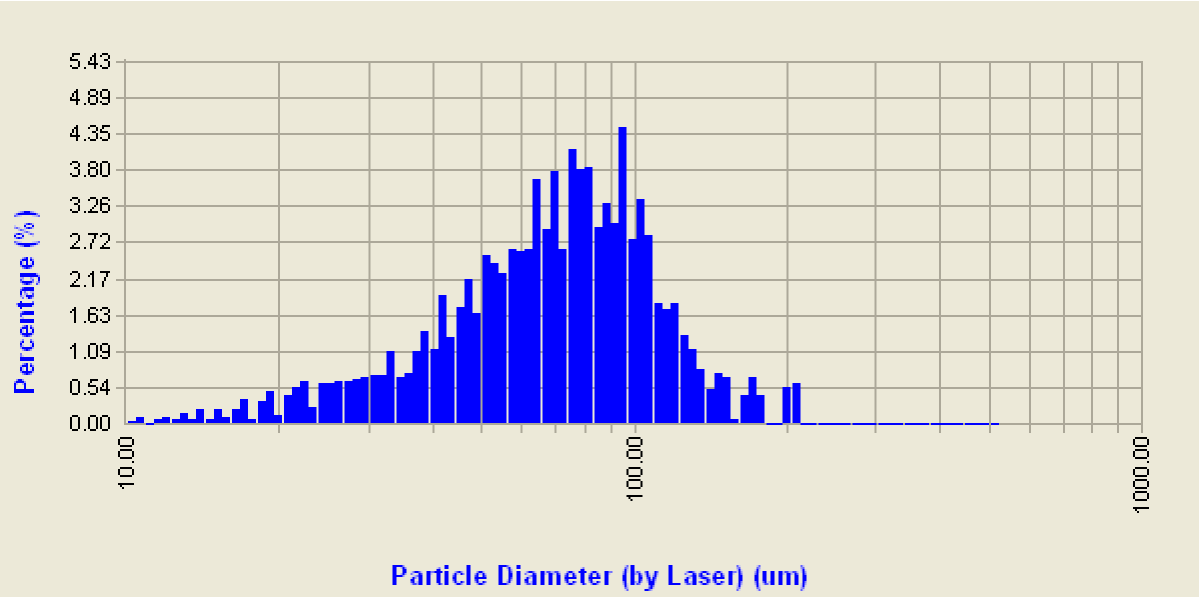
Range	Local(%)	Under(%)
10.0-15.6	3.86	3.98
15.6-31.2	18.39	22.36
31.2-62.5	36.45	58.81
62.5-125.0	37.27	96.08
125.0-250.0	3.92	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/10(b)

Range	Local(%)	Under(%)
10.0-15.6	0.84	0.86
15.6-31.2	7.36	8.21
31.2-62.5	29.55	37.77
62.5-125.0	52.29	90.05
125.0-250.0	9.95	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/10(c)

Volume Histogram : OA148/10(c)
Mean: 74.06 um STD: 34.84 um Conf.: 100.00 %
D10 : 31.95 um D50: 71.12 um D90: 116.81 um



Area Ranges Table : OA148/10(c)

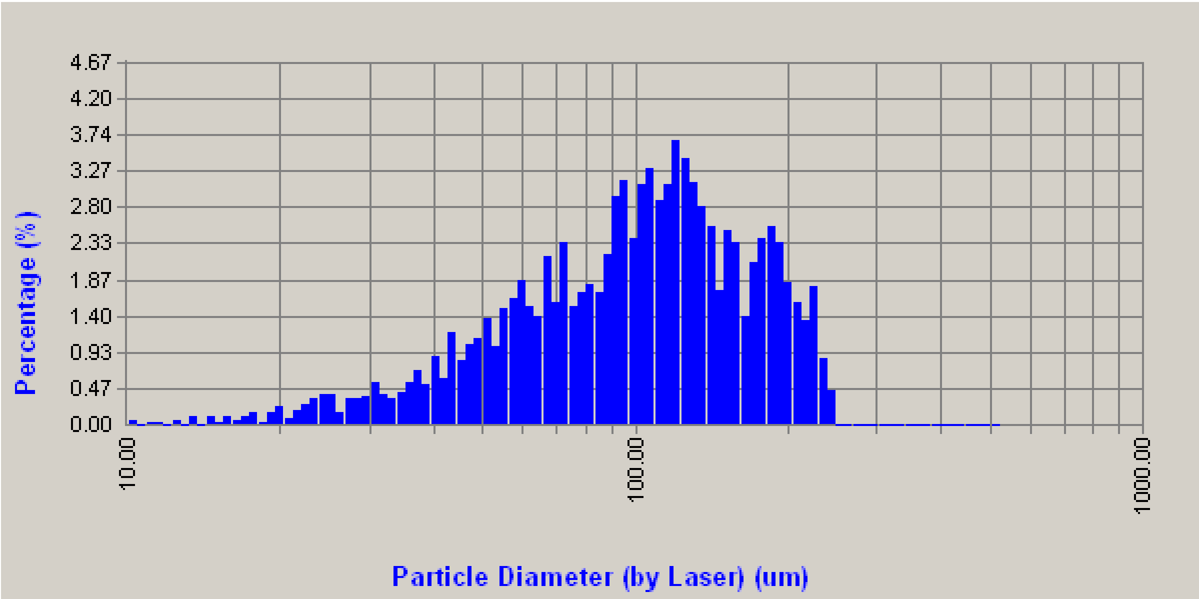
Range	Local(%)	Under(%)
10.0-15.6	4.22	4.66
15.6-31.2	19.78	24.44
31.2-62.5	36.52	60.96
62.5-125.0	36.38	97.34
125.0-250.0	2.66	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/10(c)

Range	Local(%)	Under(%)
10.0-15.6	0.95	1.02
15.6-31.2	8.04	9.05
31.2-62.5	29.96	39.01
62.5-125.0	53.87	92.88
125.0-250.0	7.12	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/11(a)

Volume Histogram : OA148/11(a)
Mean: 109.38 um STD: 53.12 um Conf.: 100.00 %
D10 : 43.52 um D50: 104.44 um D90: 188.21 um



Area Ranges Table : OA148/11(a)

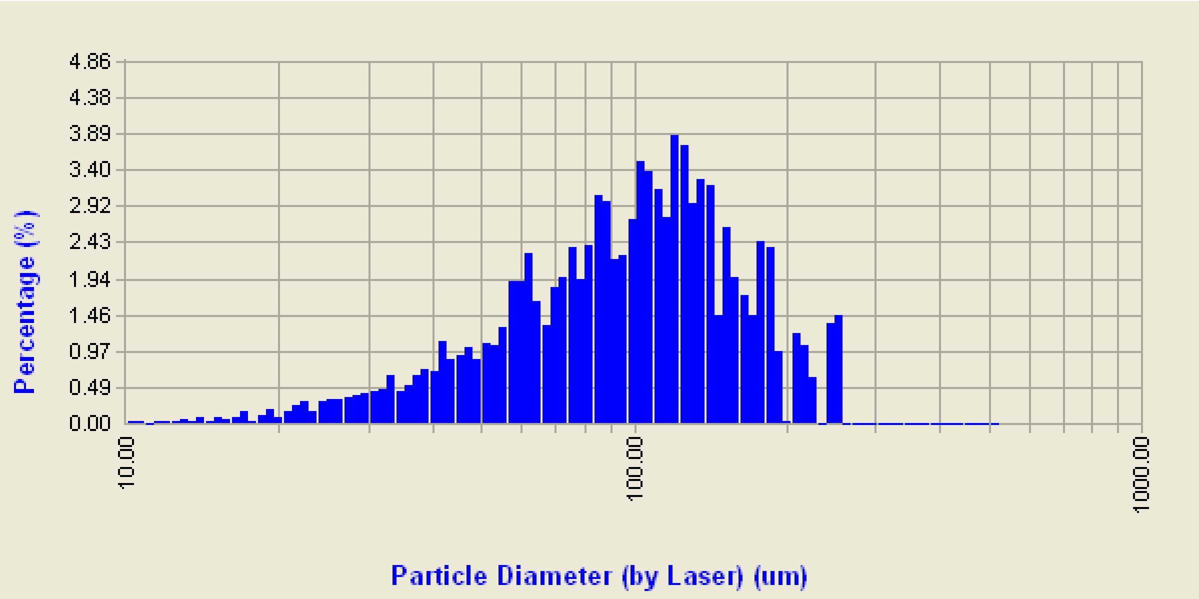
Range	Local(%)	Under(%)
10.0-15.6	2.49	2.56
15.6-31.2	14.10	16.66
31.2-62.5	28.61	45.28
62.5-125.0	37.55	82.82
125.0-250.0	17.18	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/11(a)

Range	Local(%)	Under(%)
10.0-15.6	0.40	0.41
15.6-31.2	4.19	4.60
31.2-62.5	16.99	21.59
62.5-125.0	42.99	64.57
125.0-250.0	35.43	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/11(b)

Volume Histogram : OA148/11(b)
Mean: 105.57 um STD: 51.87 um Conf.: 100.00 %
D10 : 42.73 um D50: 100.39 um D90: 177.64 um



Area Ranges Table : OA148/11(b)

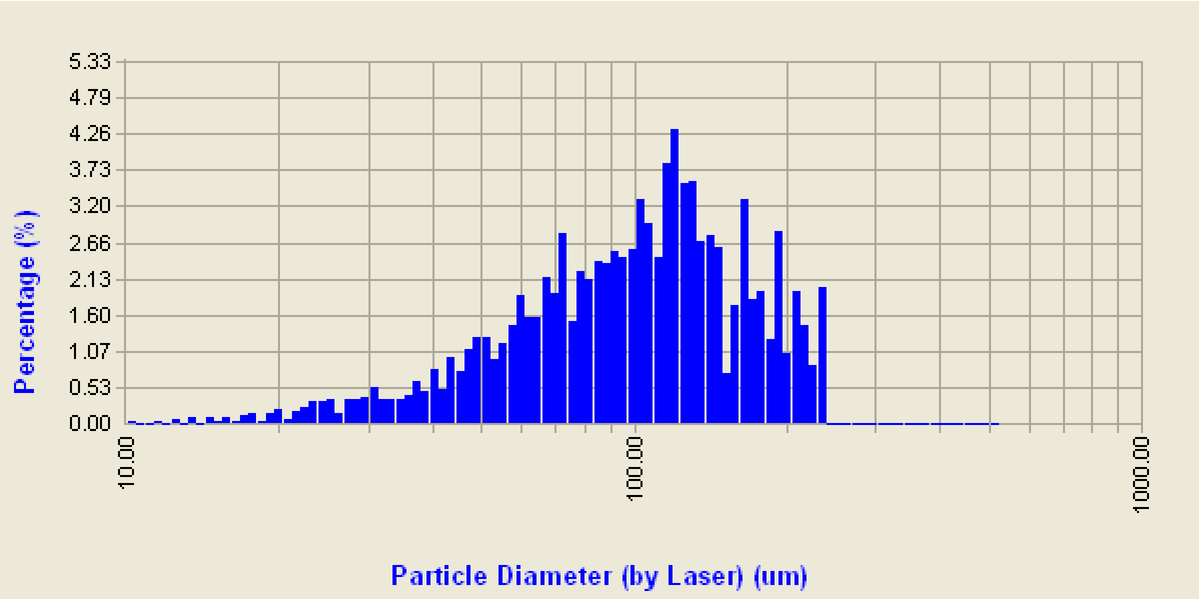
Range	Local(%)	Under(%)
10.0-15.6	2.41	2.65
15.6-31.2	13.63	16.28
31.2-62.5	29.11	45.38
62.5-125.0	39.60	84.98
125.0-250.0	14.80	99.78
250.0-500.0	0.22	100.00

Volume Ranges Table : OA148/11(b)

Range	Local(%)	Under(%)
10.0-15.6	0.39	0.42
15.6-31.2	4.16	4.58
31.2-62.5	17.60	22.18
62.5-125.0	46.52	68.69
125.0-250.0	30.59	99.29
250.0-500.0	0.71	100.00

Volume Distribution: OA148/11(c)

Volume Histogram : OA148/11(c)
Mean: 108.62 um STD: 51.81 um Conf.: 100.00 %
D10 : 45.69 um D50: 103.35 um D90: 188.21 um



Area Ranges Table : OA148/11(c)

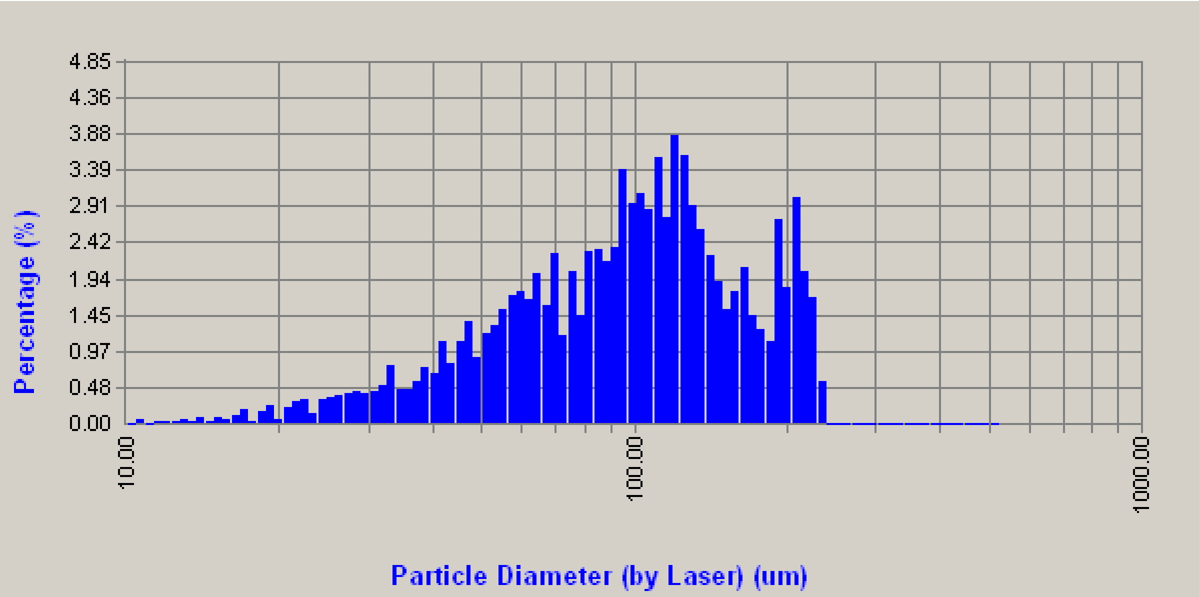
Range	Local(%)	Under(%)
10.0-15.6	2.20	2.27
15.6-31.2	13.57	15.84
31.2-62.5	26.86	42.70
62.5-125.0	40.50	83.20
125.0-250.0	16.80	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/11(c)

Range	Local(%)	Under(%)
10.0-15.6	0.35	0.36
15.6-31.2	4.01	4.37
31.2-62.5	15.85	20.22
62.5-125.0	45.71	65.93
125.0-250.0	34.07	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/14(a)

Volume Histogram : OA148/14(a)
Mean: 106.67 um STD: 53.27 um Conf.: 100.00 %
D10 : 41.73 um D50: 100.48 um D90: 192.95 um



Area Ranges Table : OA148/14(a)

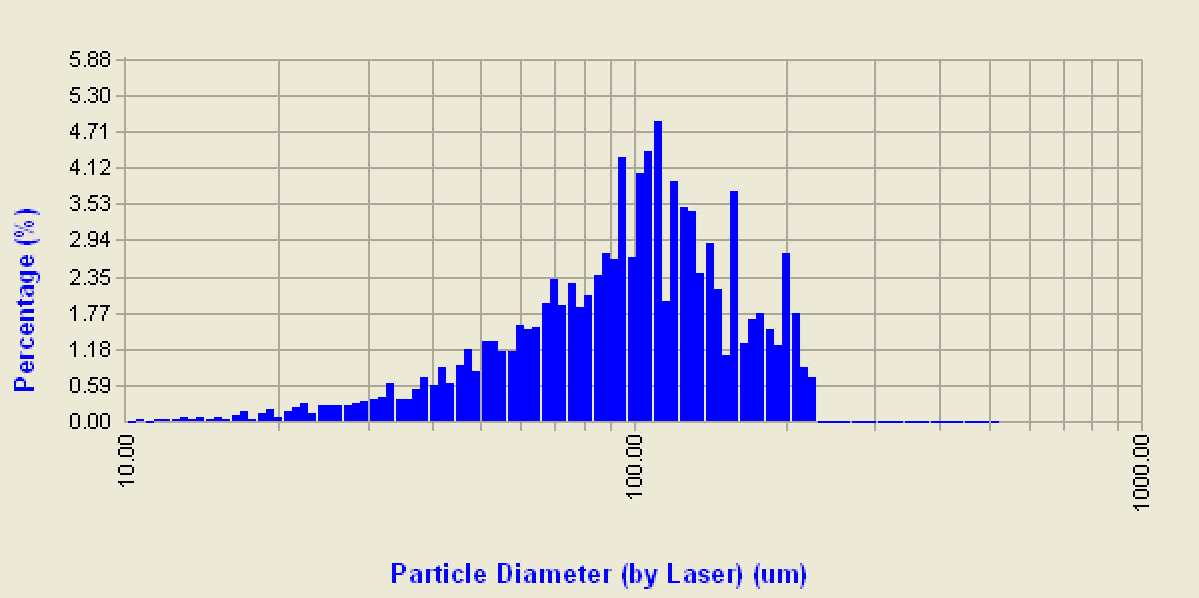
Range	Local(%)	Under(%)
10.0-15.6	2.59	2.88
15.6-31.2	14.91	17.79
31.2-62.5	30.02	47.82
62.5-125.0	37.60	85.42
125.0-250.0	14.58	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/14(a)

Range	Local(%)	Under(%)
10.0-15.6	0.43	0.47
15.6-31.2	4.56	5.03
31.2-62.5	18.31	23.33
62.5-125.0	45.00	68.34
125.0-250.0	31.66	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/14(b)

Volume Histogram : OA148/14(b)
Mean: 105.28 um STD: 47.44 um Conf.: 100.00 %
D10 : 46.10 um D50: 101.58 um D90: 176.65 um



Area Ranges Table : OA148/14(b)

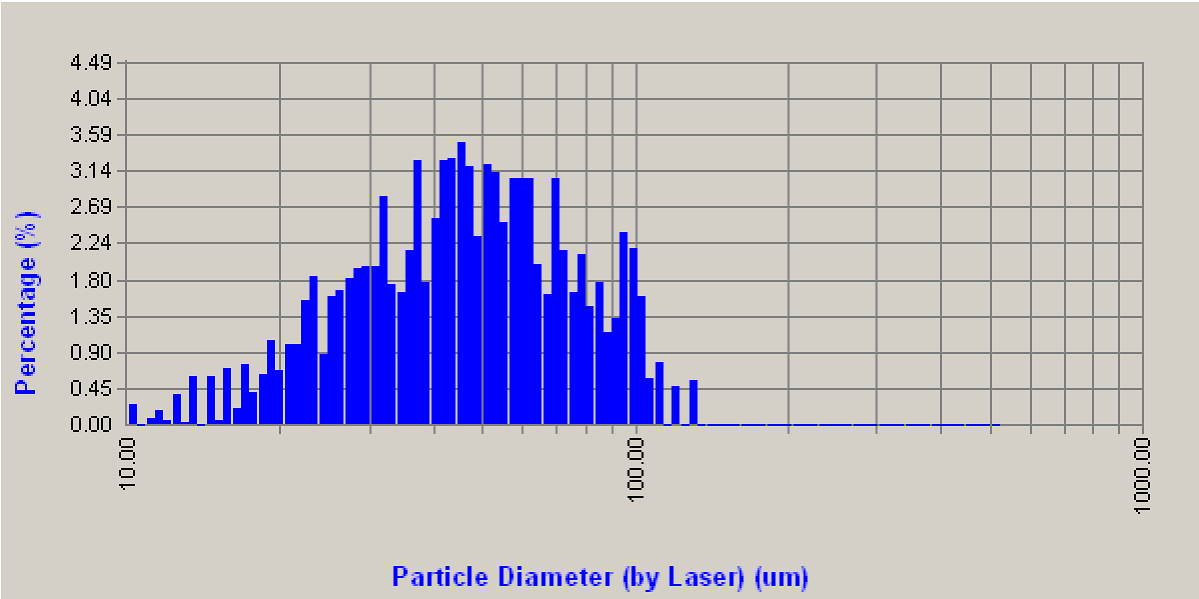
Range	Local(%)	Under(%)
10.0-15.6	2.42	2.65
15.6-31.2	12.18	14.83
31.2-62.5	26.61	41.44
62.5-125.0	43.53	84.97
125.0-250.0	15.03	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/14(b)

Range	Local(%)	Under(%)
10.0-15.6	0.39	0.41
15.6-31.2	3.56	3.98
31.2-62.5	15.62	19.60
62.5-125.0	50.26	69.86
125.0-250.0	30.14	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/20(a)

Volume Histogram : OA148/20(a)
Mean: 50.41 um STD: 24.54 um Conf.: 100.00 %
D10 : 21.87 um D50: 45.93 um D90: 88.57 um



Area Ranges Table : OA148/20(a)

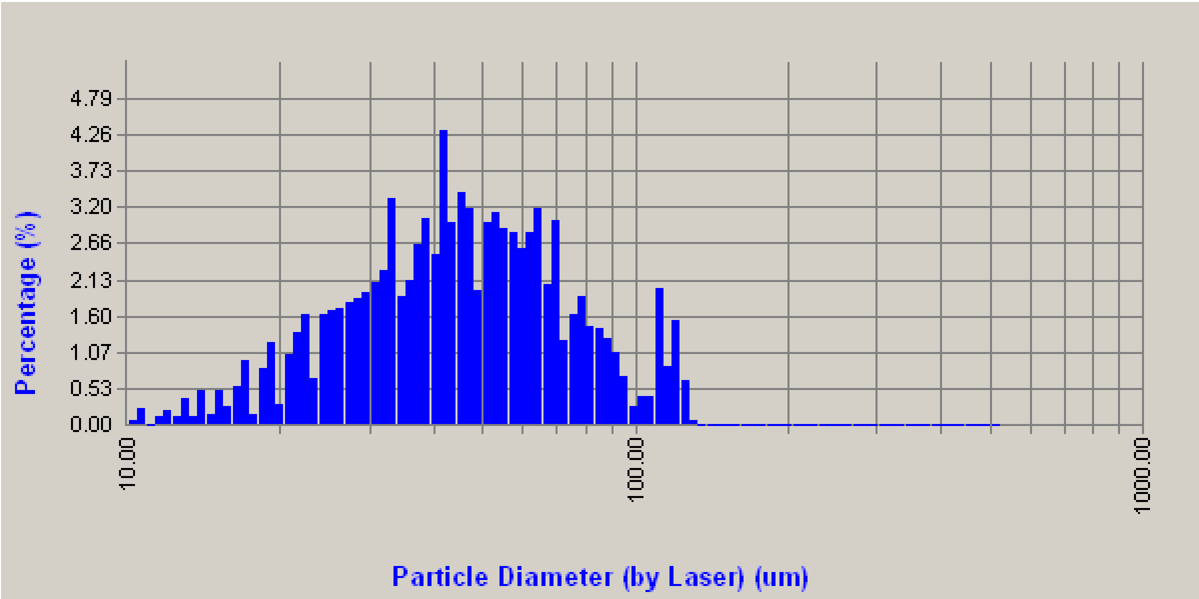
Range	Local(%)	Under(%)
10.0-15.6	7.13	7.30
15.6-31.2	37.26	44.56
31.2-62.5	42.10	86.66
62.5-125.0	13.18	99.84
125.0-250.0	0.16	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/20(a)

Range	Local(%)	Under(%)
10.0-15.6	2.31	2.35
15.6-31.2	22.36	24.72
31.2-62.5	47.65	72.37
62.5-125.0	27.08	99.45
125.0-250.0	0.55	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/20(b)

Volume Histogram : OA148/20(b)
Mean: 49.44 um STD: 25.00 um Conf.: 100.00 %
D10 : 22.16 um D50: 43.92 um D90: 84.17 um



Area Ranges Table : OA148/20(b)

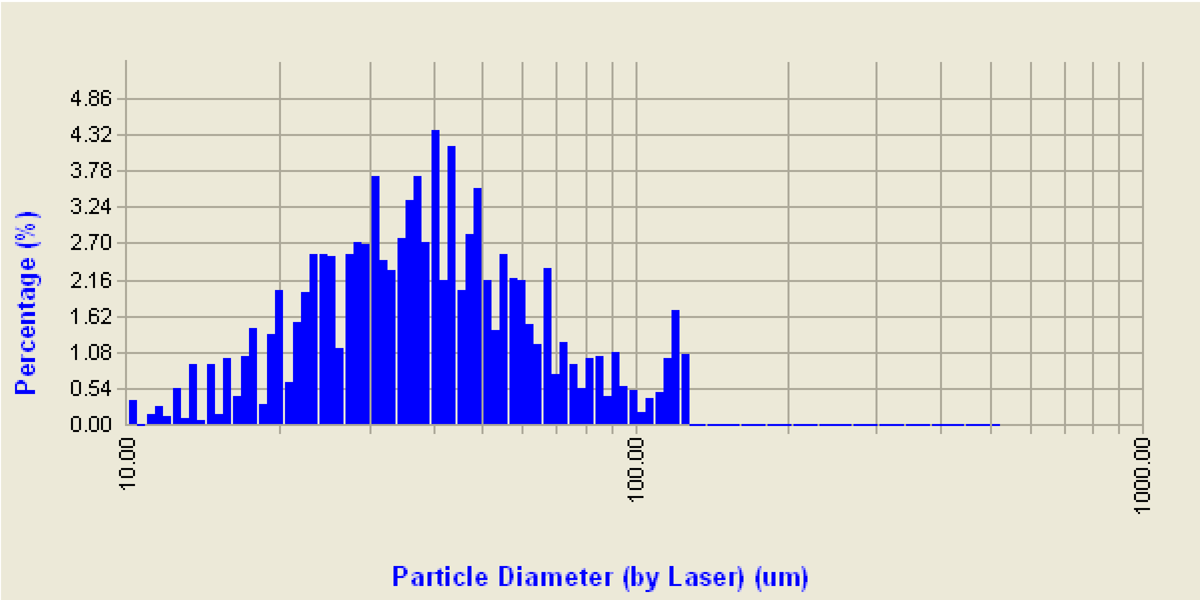
Range	Local(%)	Under(%)
10.0-15.6	7.16	7.91
15.6-31.2	35.79	43.70
31.2-62.5	44.18	87.88
62.5-125.0	11.93	99.81
125.0-250.0	0.19	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/20(b)

Range	Local(%)	Under(%)
10.0-15.6	2.38	2.56
15.6-31.2	21.76	24.32
31.2-62.5	50.14	74.46
62.5-125.0	24.90	99.35
125.0-250.0	0.65	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/24(a)

Volume Histogram : OA148/24(a)
Mean: 43.41 um STD: 24.38 um Conf.: 100.00 %
D10 : 19.58 um D50: 36.99 um D90: 75.07 um



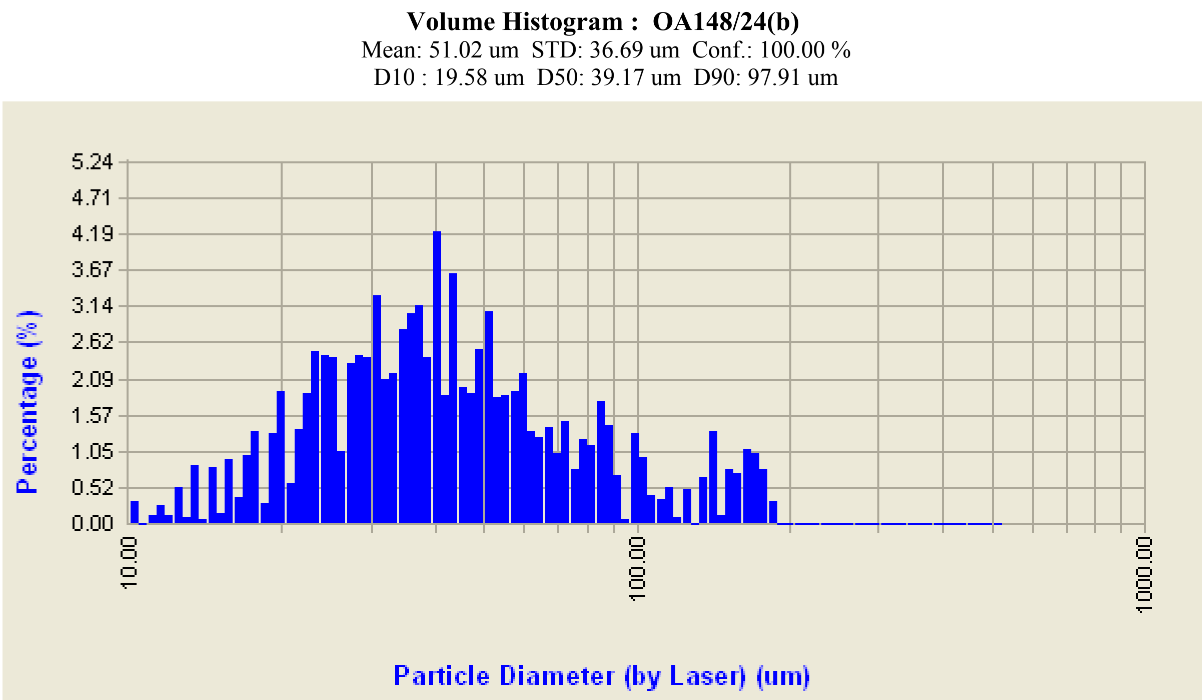
Area Ranges Table : OA148/24(a)

Range	Local(%)	Under(%)
10.0-15.6	9.76	10.04
15.6-31.2	45.47	55.50
31.2-62.5	37.88	93.39
62.5-125.0	6.61	99.99
125.0-250.0	0.01	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/24(a)

Range	Local(%)	Under(%)
10.0-15.6	3.72	3.80
15.6-31.2	31.70	35.50
31.2-62.5	47.87	83.37
62.5-125.0	16.61	99.98
125.0-250.0	0.02	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/24(b)



Area Ranges Table : OA148/24(b)

Range	Local(%)	Under(%)
10.0-15.6	9.68	9.96
15.6-31.2	44.96	54.92
31.2-62.5	36.38	91.30
62.5-125.0	7.18	98.48
125.0-250.0	1.52	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/24(b)

Range	Local(%)	Under(%)
10.0-15.6	3.49	3.56
15.6-31.2	29.52	33.09
31.2-62.5	43.53	76.62
62.5-125.0	16.58	93.19
125.0-250.0	6.81	100.00
250.0-500.0	0.00	100.00

Appendix 2: Sediment particle size and QA results – benthic ecology collection areas

The National Institute of Water and Atmospheric Research Limited (NIWA), Hamilton, carried out both the sample preparation and particle size analyses. The outputs on the following pages are from the analytical report prepared by Olsen and Ovenden (2011).

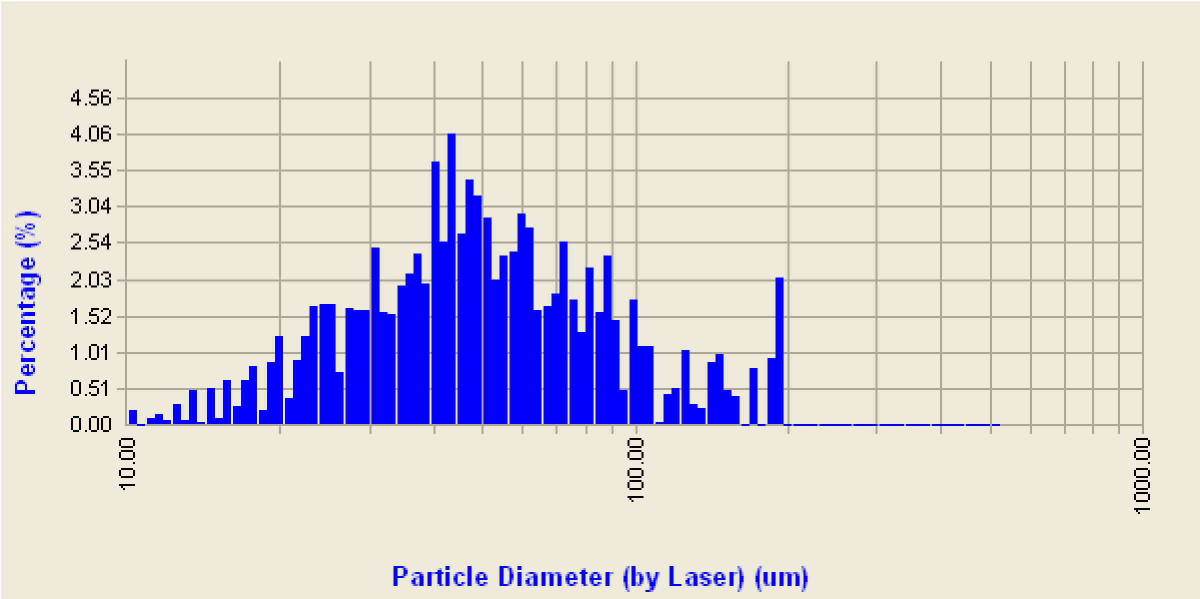
Table A2.1: Summary of particle size results for two (PAH1, PAH2, POR2) or three (POR1, PAH3) replicates from each of five benthic ecology collection areas in Porirua Harbour in November and December, 2010

NIWA Code	GWRC Code	Mean (µm)	Standard deviation (µm)	Maximum (µm)	10-62.5 µm '% mud'
OA148/26	POR 1B/4	58.54	38.21	192.56	67.71
OA148/27	POR 1B/5	53.61	28.89	155.57	70.97
OA148/28	POR 1B/6	62.25	43.62	230.64	64.79
OA148/29	PAH 3B/4	104.82	46.37	218.09	19.58
OA148/30	PAH 3B/5	102.20	47.06	223.38	22.32
OA148/31	PAH 3B/6	111.99	55.28	274.51	19.16
OA148/32	POR 2B/4	57.16	37.41	153.08	68.83
OA148/33	POR 2B/5	44.21	24.15	112.63	81.86
OA148/34	PAH 1B/4	93.70	49.45	212.15	32.64
OA148/35	PAH 1B/5	88.39	48.83	208.85	37.07
OA148/36	PAH 2B/4	82.48	35.58	180.95	31.24
OA148/37	PAH 2B/5	81.93	35.47	187.53	31.70

Particle size distribution histograms and tables

Volume Distribution: OA148/26

Volume Histogram : OA148/26
Mean: 58.54 um STD: 38.21 um Conf.: 100.00 %
D10 : 22.85 um D50: 47.87 um D90: 104.44 um



Area Ranges Table : OA148/26

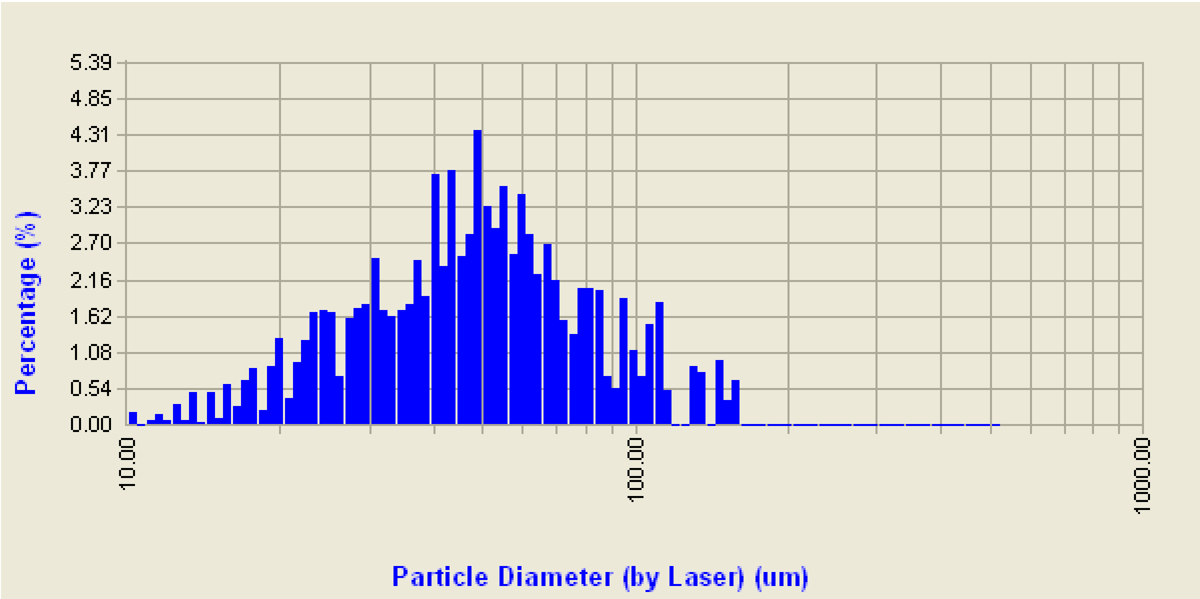
Range	Local(%)	Under(%)
10.0-15.6	6.69	6.88
15.6-31.2	35.51	42.39
31.2-62.5	42.95	85.34
62.5-125.0	12.80	98.15
125.0-250.0	1.85	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/26

Range	Local(%)	Under(%)
10.0-15.6	2.06	2.10
15.6-31.2	19.94	22.04
31.2-62.5	45.66	67.71
62.5-125.0	25.06	92.77
125.0-250.0	7.23	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/27

Volume Histogram : OA148/27
Mean: 53.61 um STD: 28.89 um Conf.: 99.99 %
D10 : 22.85 um D50: 47.87 um D90: 95.74 um



Area Ranges Table : OA148/27

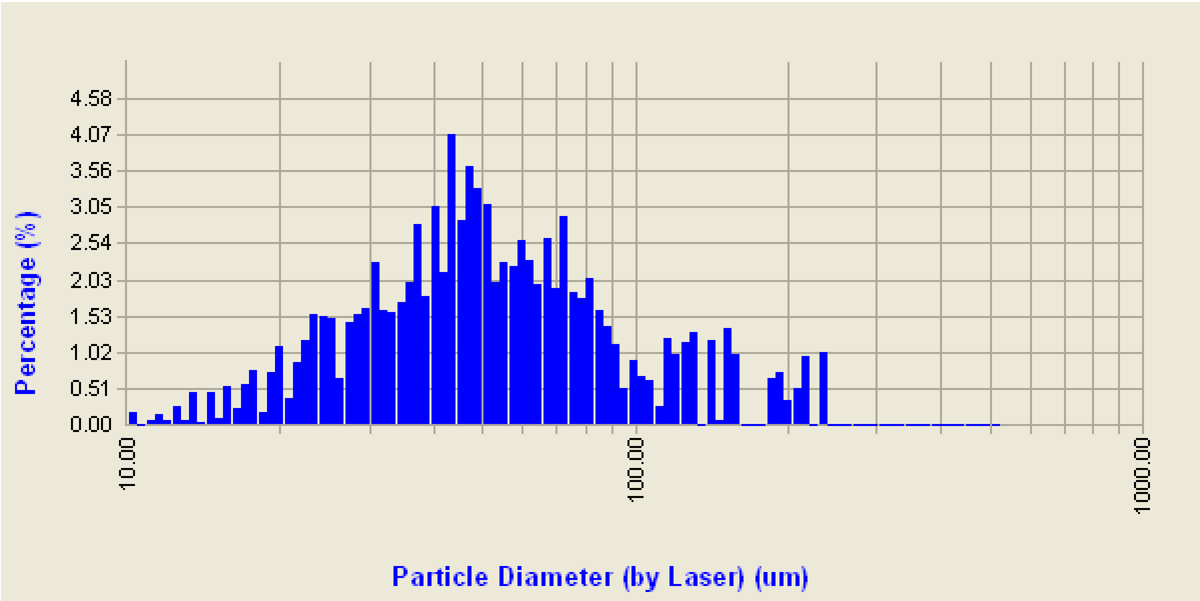
Range	Local(%)	Under(%)
10.0-15.6	6.38	6.56
15.6-31.2	35.48	42.04
31.2-62.5	44.03	86.07
62.5-125.0	12.90	98.97
125.0-250.0	1.03	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/27

Range	Local(%)	Under(%)
10.0-15.6	2.00	2.05
15.6-31.2	20.37	22.42
31.2-62.5	48.55	70.97
62.5-125.0	25.44	96.41
125.0-250.0	3.59	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/28

Volume Histogram : OA148/28
Mean: 62.25 um STD: 43.62 um Conf.: 100.00 %
D10 : 23.93 um D50: 48.96 um D90: 124.02 um



Area Ranges Table : OA148/28

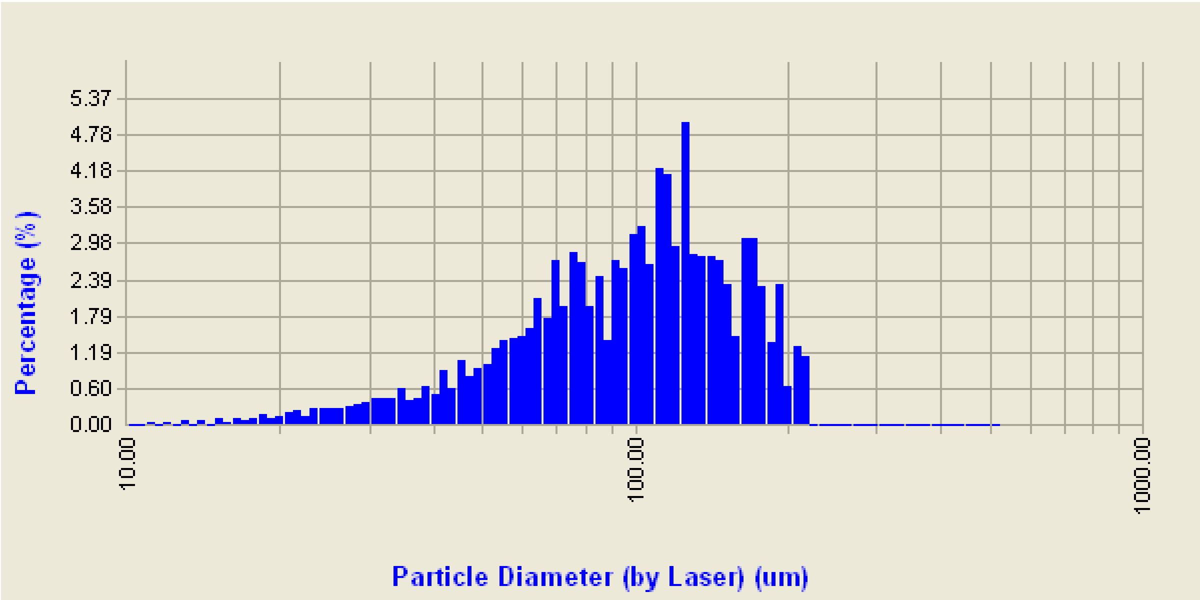
Range	Local(%)	Under(%)
10.0-15.6	6.32	6.50
15.6-31.2	33.82	40.32
31.2-62.5	43.40	83.72
62.5-125.0	13.71	97.43
125.0-250.0	2.57	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/28

Range	Local(%)	Under(%)
10.0-15.6	1.88	1.92
15.6-31.2	18.41	20.33
31.2-62.5	44.46	64.79
62.5-125.0	25.41	90.20
125.0-250.0	9.80	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/29

Volume Histogram : OA148/29
Mean: 104.82 um STD: 46.37 um Conf.: 100.00 %
D10 : 46.19 um D50: 102.77 um D90: 171.31 um



Area Ranges Table : OA148/29

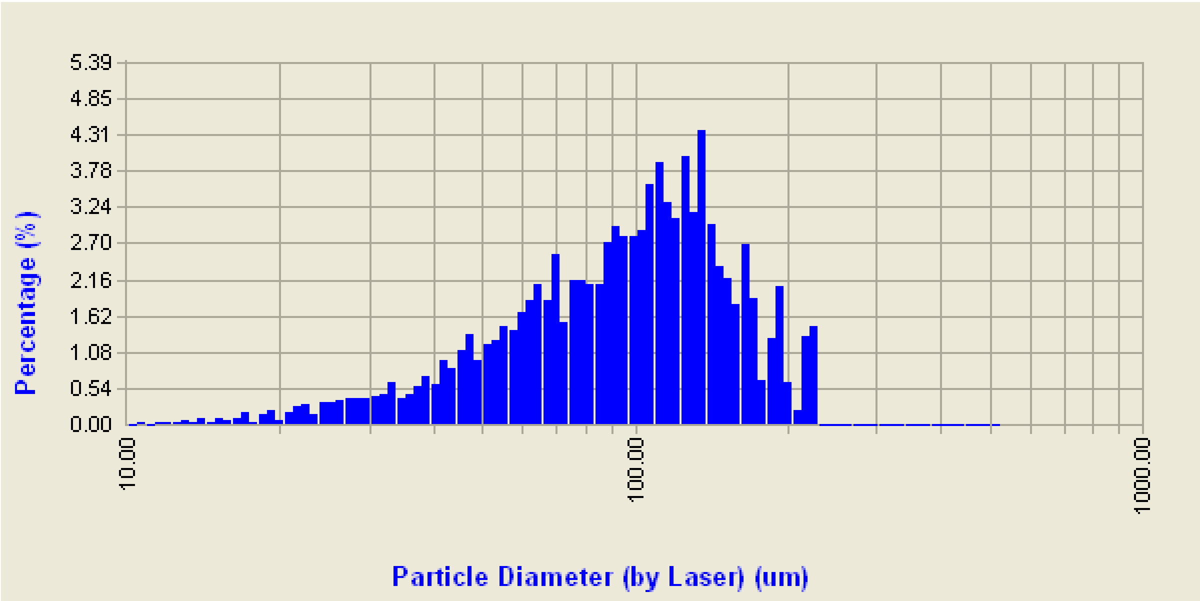
Range	Local(%)	Under(%)
10.0-15.6	2.11	2.32
15.6-31.2	12.58	14.90
31.2-62.5	26.26	41.17
62.5-125.0	42.04	83.21
125.0-250.0	16.79	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/29

Range	Local(%)	Under(%)
10.0-15.6	0.34	0.37
15.6-31.2	3.72	4.09
31.2-62.5	15.49	19.58
62.5-125.0	47.62	67.20
125.0-250.0	32.80	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/30

Volume Histogram : OA148/30
Mean: 102.20 um STD: 47.06 um Conf.: 100.00 %
D10 : 42.78 um D50: 99.36 um D90: 165.72 um



Area Ranges Table : OA148/30

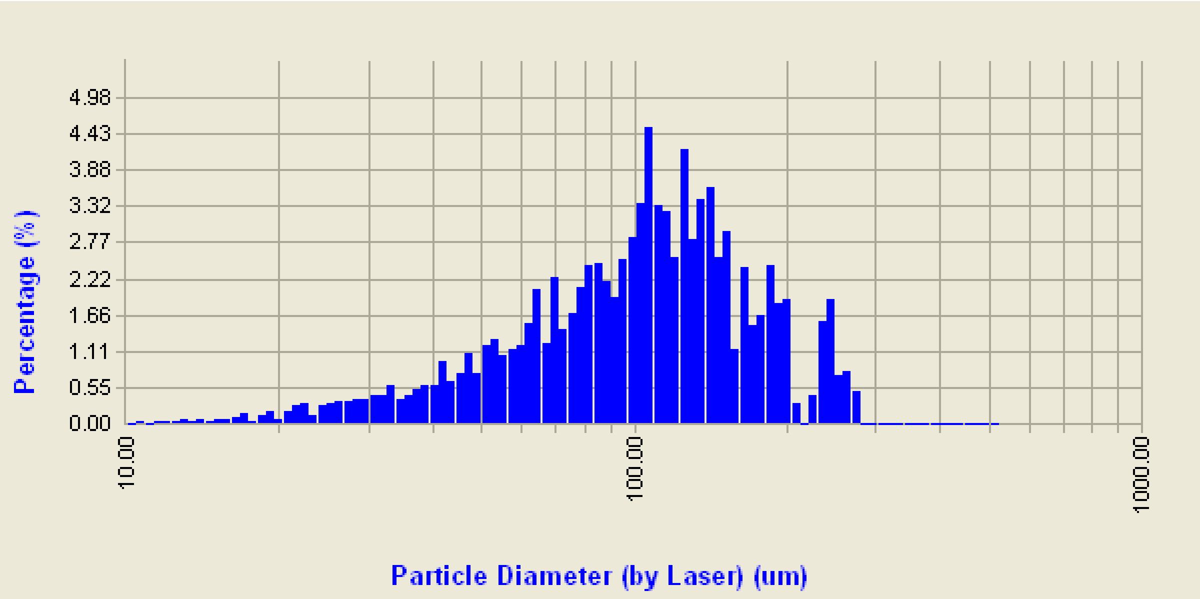
Range	Local(%)	Under(%)
10.0-15.6	2.56	2.80
15.6-31.2	14.14	16.95
31.2-62.5	28.46	45.40
62.5-125.0	39.49	84.90
125.0-250.0	15.10	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/30

Range	Local(%)	Under(%)
10.0-15.6	0.43	0.46
15.6-31.2	4.34	4.80
31.2-62.5	17.52	22.32
62.5-125.0	47.00	69.32
125.0-250.0	30.68	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/31

Volume Histogram : OA148/31
Mean: 111.99 um STD: 55.28 um Conf.: 100.00 %
D10 : 44.96 um D50: 106.97 um D90: 187.48 um



Area Ranges Table : OA148/31

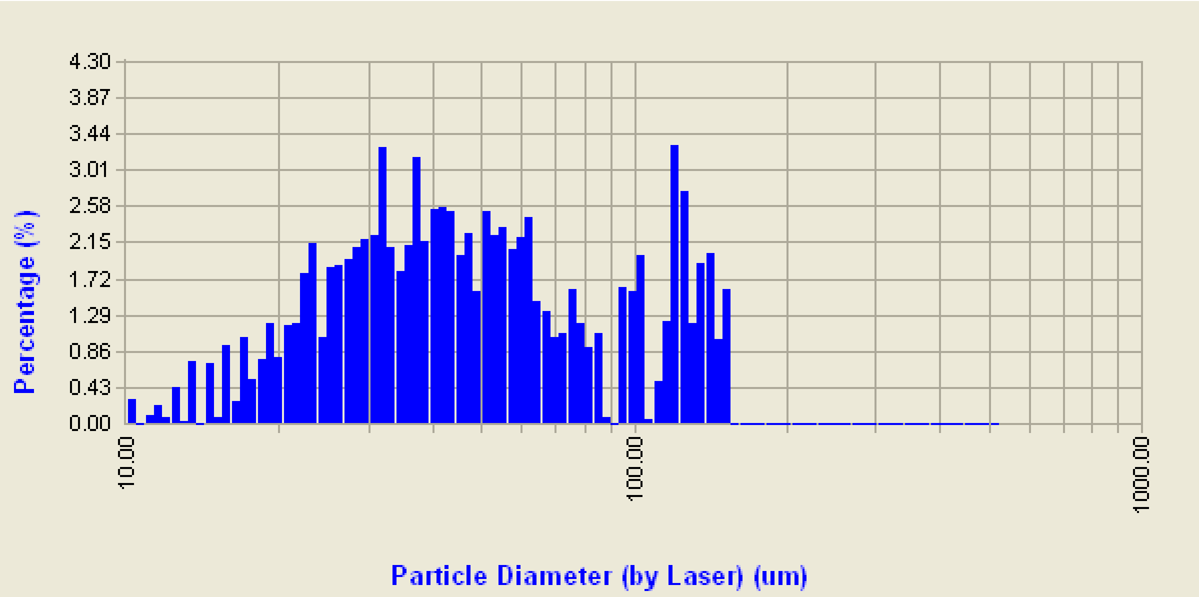
Range	Local(%)	Under(%)
10.0-15.6	2.14	2.33
15.6-31.2	13.98	16.31
31.2-62.5	25.93	42.24
62.5-125.0	39.87	82.10
125.0-250.0	17.30	99.41
250.0-500.0	0.59	100.00

Volume Ranges Table : OA148/31

Range	Local(%)	Under(%)
10.0-15.6	0.34	0.36
15.6-31.2	4.04	4.39
31.2-62.5	14.77	19.16
62.5-125.0	44.83	63.99
125.0-250.0	34.10	98.08
250.0-500.0	1.92	100.00

Volume Distribution: OA148/32

Volume Histogram : OA148/32
Mean: 57.16 um STD: 37.41 um Conf.: 99.99 %
D10 : 20.78 um D50: 43.74 um D90: 122.47 um



Area Ranges Table : OA148/32

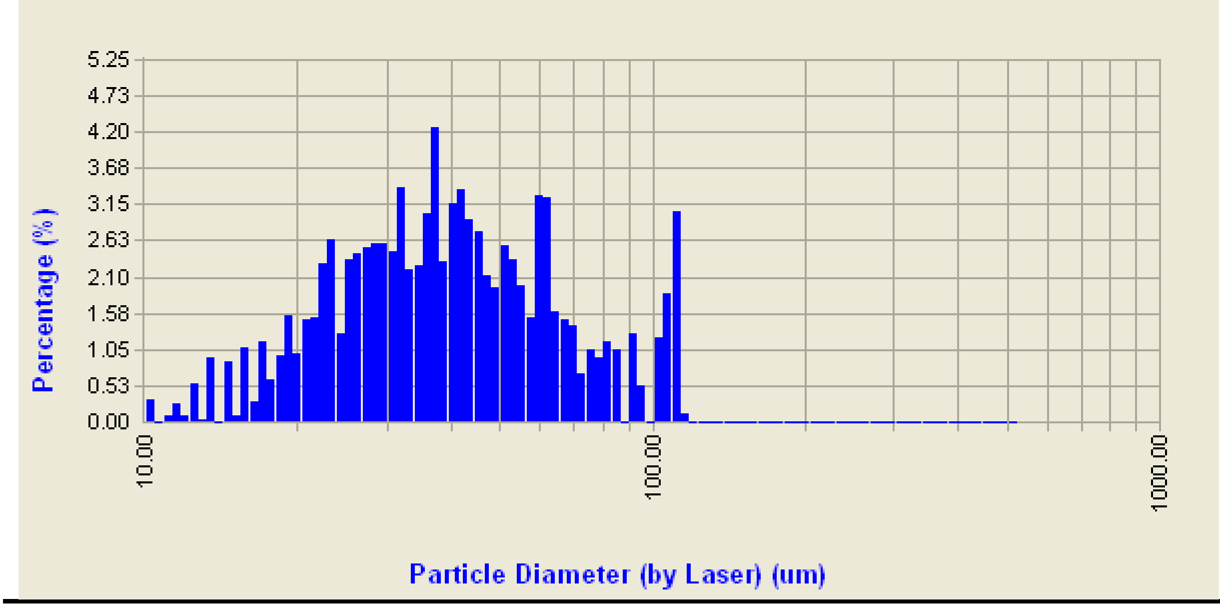
Range	Local(%)	Under(%)
10.0-15.6	8.59	8.78
15.6-31.2	43.06	51.84
31.2-62.5	35.91	87.75
62.5-125.0	9.66	97.41
125.0-250.0	2.59	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/32

Range	Local(%)	Under(%)
10.0-15.6	2.83	2.88
15.6-31.2	25.95	28.83
31.2-62.5	40.00	68.83
62.5-125.0	21.95	90.77
125.0-250.0	9.23	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/33

Volume Histogram : OA148/33
Mean: 44.21 um STD: 24.15 um Conf.: 100.00 %
D10 : 19.68 um D50: 38.27 um D90: 79.82 um



Area Ranges Table : OA148/33

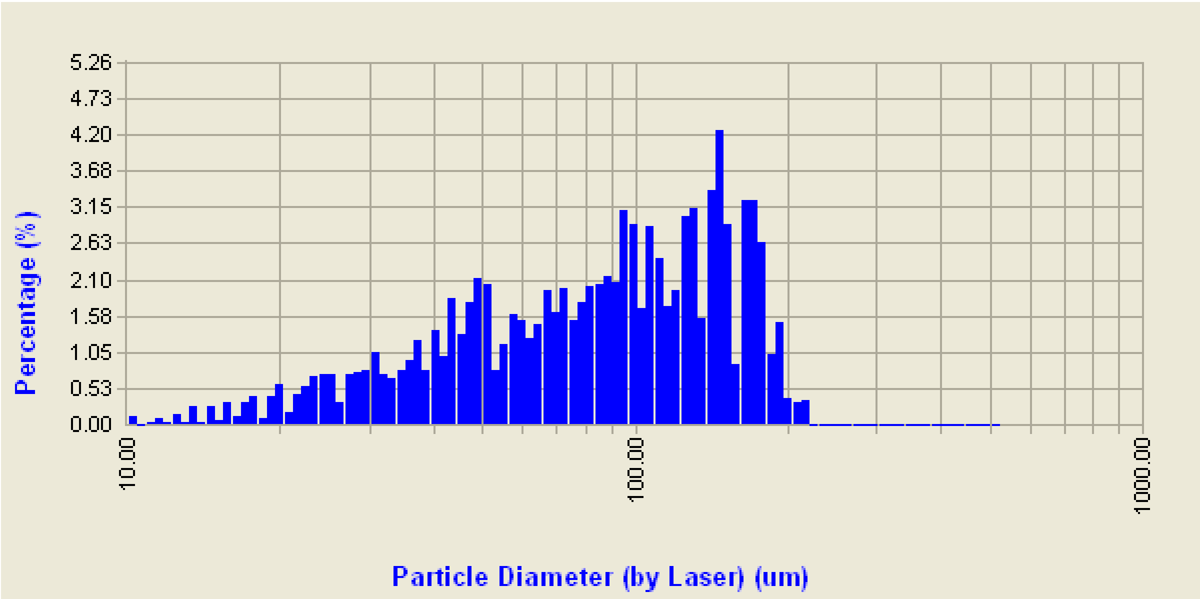
Range	Local(%)	Under(%)
10.0-15.6	9.17	9.37
15.6-31.2	46.36	55.73
31.2-62.5	36.88	92.60
62.5-125.0	7.40	100.00
125.0-250.0	0.00	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/33

Range	Local(%)	Under(%)
10.0-15.6	3.45	3.51
15.6-31.2	31.78	35.29
31.2-62.5	46.57	81.86
62.5-125.0	18.14	100.00
125.0-250.0	0.00	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/34

Volume Histogram : OA148/34
Mean: 93.70 um STD: 49.45 um Conf.: 100.00 %
D10 : 30.46 um D50: 89.21 um D90: 166.45 um



Area Ranges Table : OA148/34

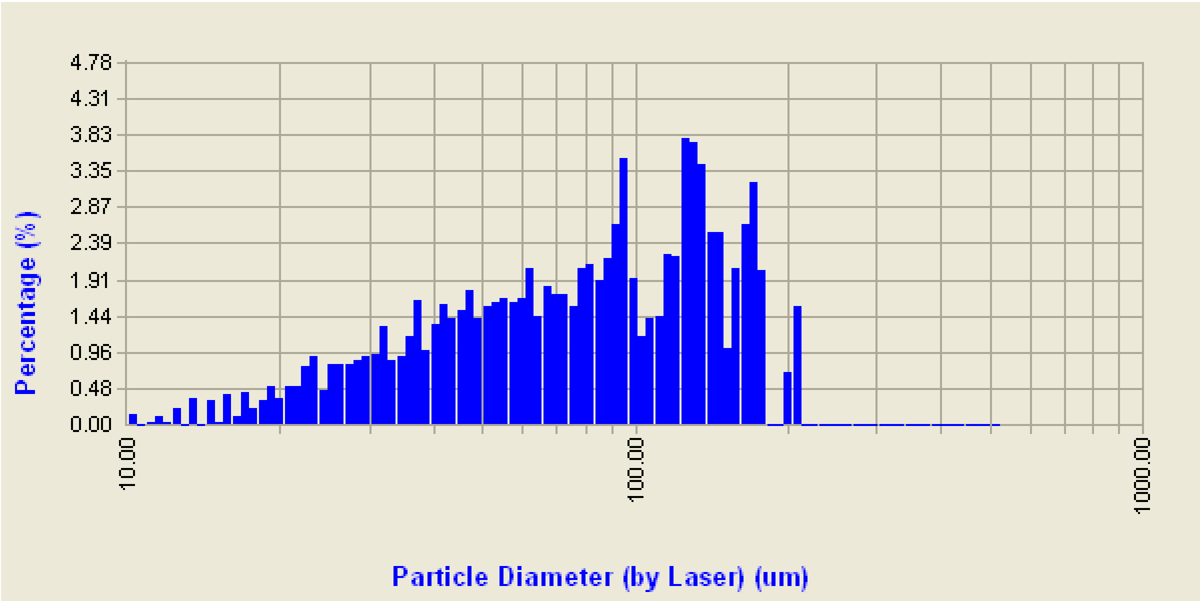
Range	Local(%)	Under(%)
10.0-15.6	5.36	5.51
15.6-31.2	24.59	30.10
31.2-62.5	31.36	61.46
62.5-125.0	26.36	87.82
125.0-250.0	12.18	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/34

Range	Local(%)	Under(%)
10.0-15.6	1.09	1.11
15.6-31.2	9.08	10.19
31.2-62.5	22.46	32.64
62.5-125.0	37.37	70.02
125.0-250.0	29.98	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/35

Volume Histogram : OA148/35
Mean: 88.39 um STD: 48.83 um Conf.: 100.00 %
D10 : 28.43 um D50: 82.01 um D90: 160.74 um



Area Ranges Table : OA148/35

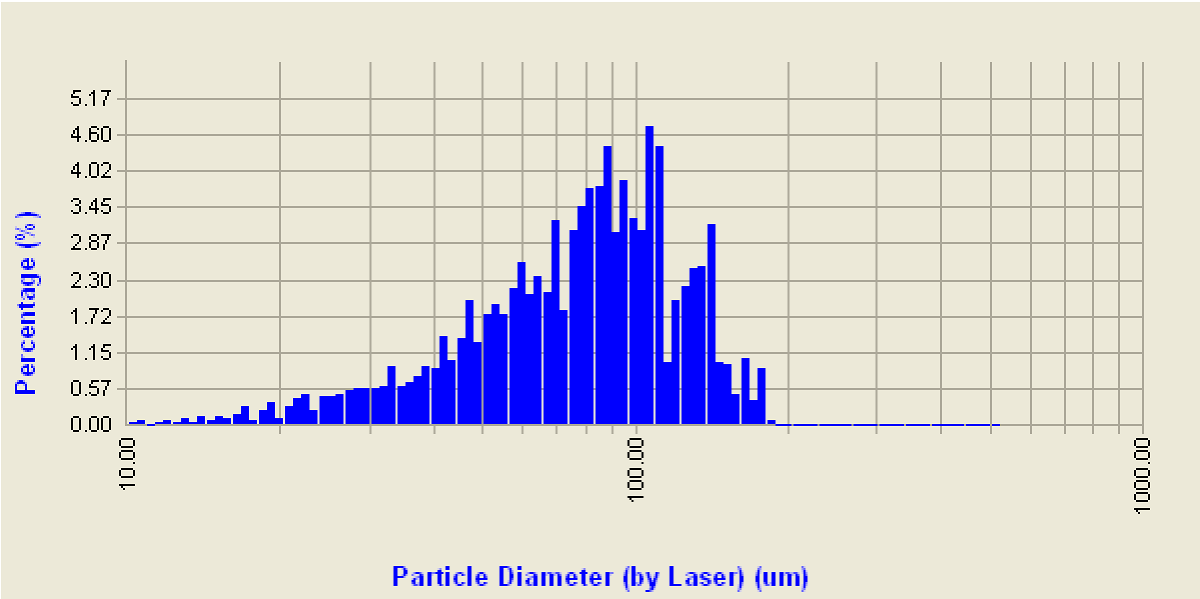
Range	Local(%)	Under(%)
10.0-15.6	5.84	5.97
15.6-31.2	27.42	33.40
31.2-62.5	32.44	65.84
62.5-125.0	23.87	89.71
125.0-250.0	10.29	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/35

Range	Local(%)	Under(%)
10.0-15.6	1.27	1.29
15.6-31.2	10.91	12.20
31.2-62.5	24.87	37.07
62.5-125.0	36.17	73.24
125.0-250.0	26.76	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/36

Volume Histogram : OA148/36
Mean: 82.48 um STD: 35.58 um Conf.: 100.00 %
D10 : 36.26 um D50: 80.86 um D90: 131.99 um



Area Ranges Table : OA148/36

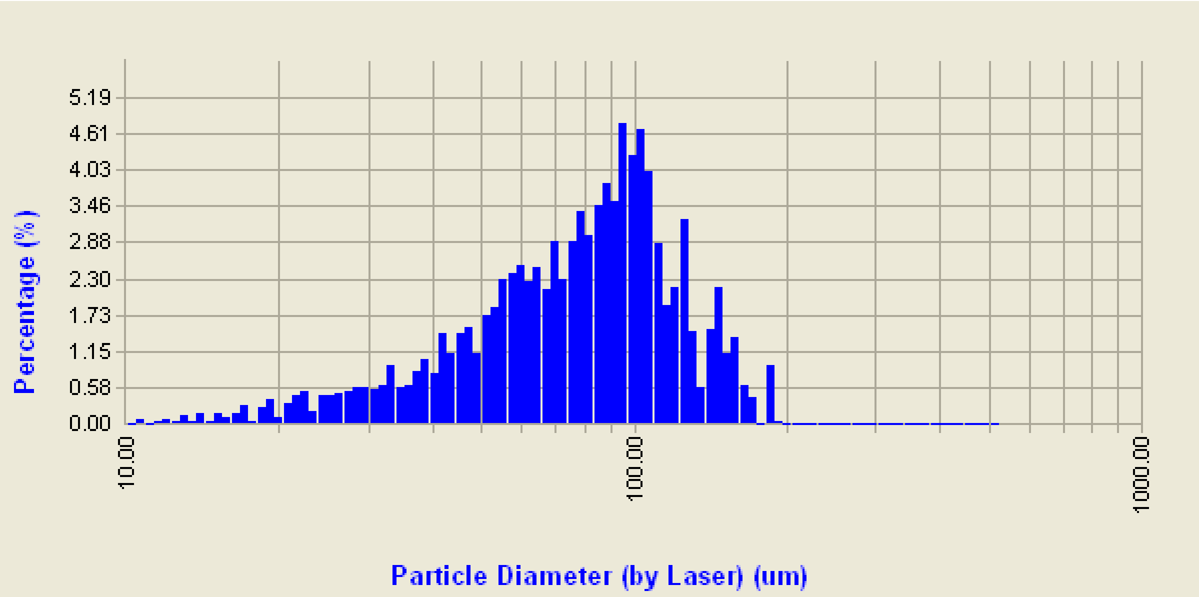
Range	Local(%)	Under(%)
10.0-15.6	3.38	3.69
15.6-31.2	17.36	21.05
31.2-62.5	32.87	53.92
62.5-125.0	40.19	94.12
125.0-250.0	5.88	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/36

Range	Local(%)	Under(%)
10.0-15.6	0.67	0.72
15.6-31.2	6.33	7.05
31.2-62.5	24.18	31.24
62.5-125.0	55.52	86.76
125.0-250.0	13.24	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/37

Volume Histogram : OA148/37
Mean: 81.93 um STD: 35.47 um Conf.: 100.00 %
D10 : 36.30 um D50: 80.91 um D90: 127.69 um



Area Ranges Table : OA148/37

Range	Local(%)	Under(%)
10.0-15.6	3.54	3.89
15.6-31.2	17.43	21.32
31.2-62.5	33.02	54.33
62.5-125.0	40.91	95.24
125.0-250.0	4.76	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/37

Range	Local(%)	Under(%)
10.0-15.6	0.72	0.77
15.6-31.2	6.37	7.14
31.2-62.5	24.56	31.70
62.5-125.0	57.26	88.96
125.0-250.0	11.04	100.00
250.0-500.0	0.00	100.00

Quality control data for particle size analyses – benthic ecology collection areas

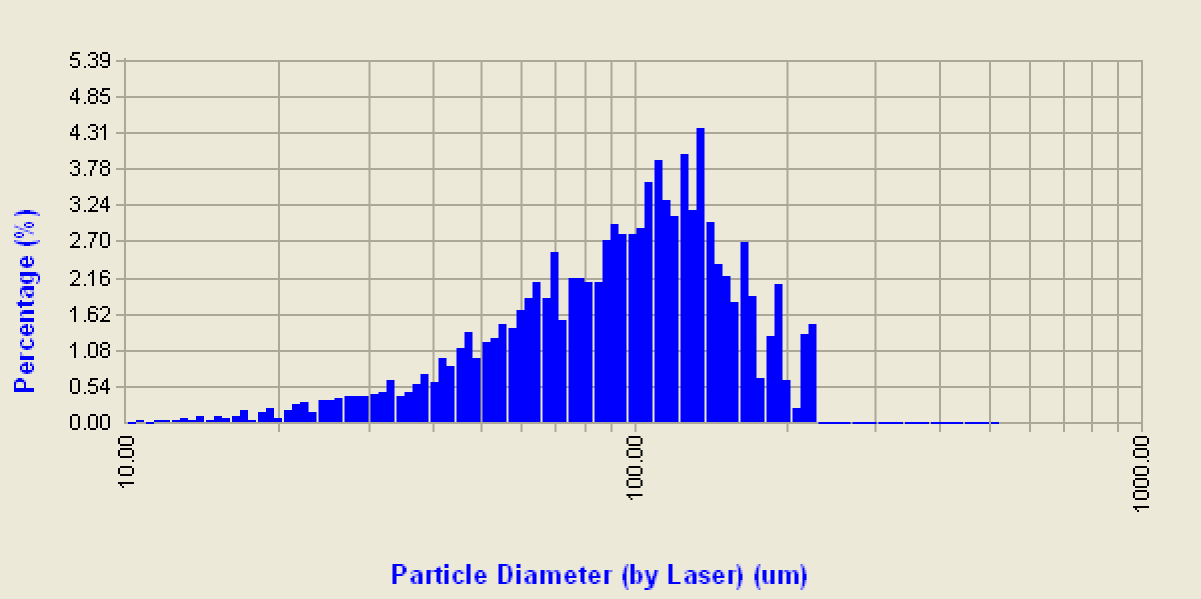
QA included replicate analyses of two sediment samples from the 2010 survey to assess 'within-batch' variability.

Table A2-1: Summary of QA particle size data for subtidal sediments collected from the benthic ecology collection areas of Porirua Harbour in 2010

NIWA Code	GWRC Code	Mean (µm)	Standard deviation (µm)	Maximum (µm)	10-62.5 µm '% mud'
OA148/30(a)	PAH 3B/5	102.20	47.06	223.38	22.32
OA148/30(b)	PAH 3B/5	106.47	52.75	243.40	24.00
OA148/37(a)	PAH 2B/5	81.93	35.47	187.53	31.70
OA148/37(b)	PAH 2B/5	80.82	37.60	202.76	33.26

Volume Distribution: OA148/30(a)

Volume Histogram : OA148/30(a)
Mean: 102.20 um STD: 47.06 um Conf.: 100.00 %
D10 : 42.78 um D50: 99.36 um D90: 165.72 um



Area Ranges Table : OA148/30(a)

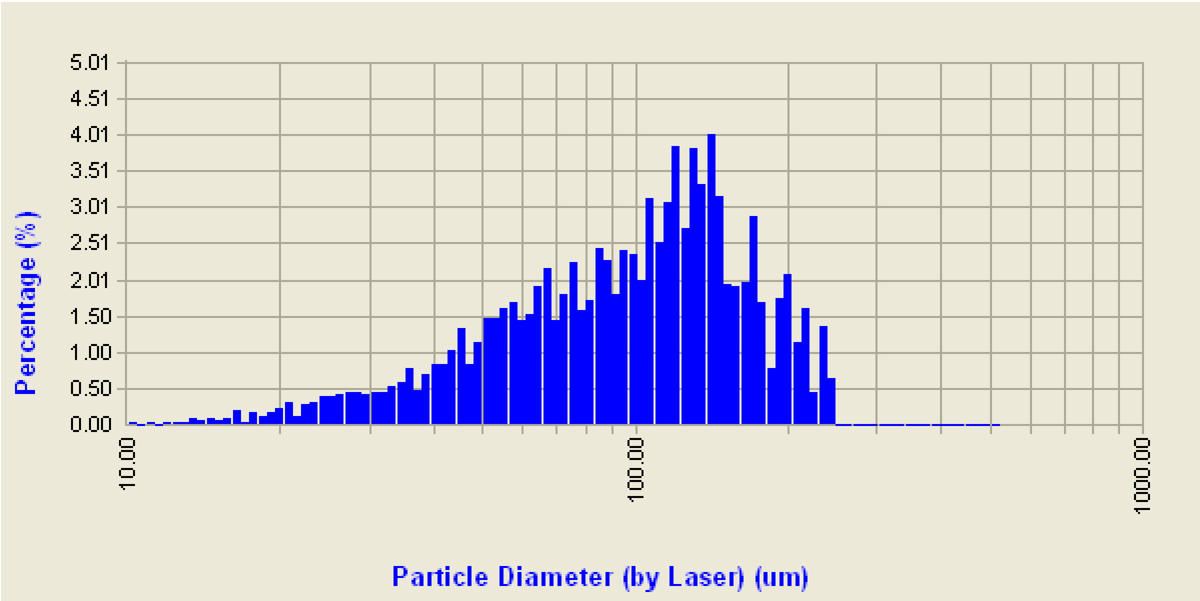
Range	Local(%)	Under(%)
10.0-15.6	2.56	2.80
15.6-31.2	14.14	16.95
31.2-62.5	28.46	45.40
62.5-125.0	39.49	84.90
125.0-250.0	15.10	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/30(a)

Range	Local(%)	Under(%)
10.0-15.6	0.43	0.46
15.6-31.2	4.34	4.80
31.2-62.5	17.52	22.32
62.5-125.0	47.00	69.32
125.0-250.0	30.68	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/30(b)

Volume Histogram : OA148/30(b)
Mean: 106.47 um STD: 52.75 um Conf.: 100.00 %
D10 : 41.05 um D50: 104.15 um D90: 178.13 um



Area Ranges Table : OA148/30(b)

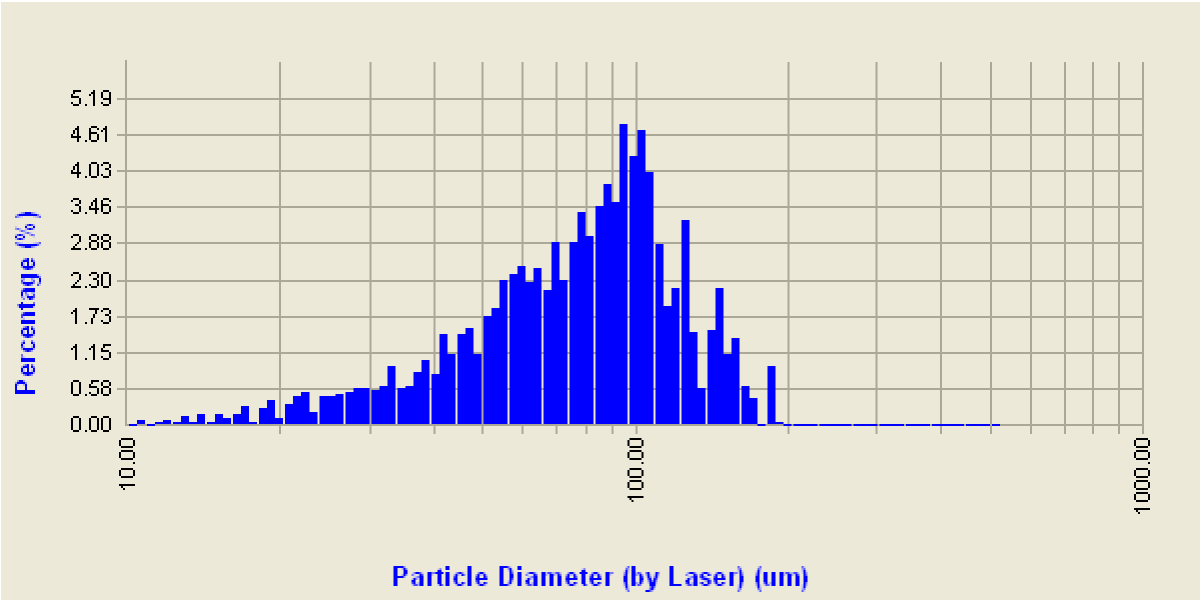
Range	Local(%)	Under(%)
10.0-15.6	3.07	3.23
15.6-31.2	15.47	18.69
31.2-62.5	30.38	49.08
62.5-125.0	33.76	82.84
125.0-250.0	17.16	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/30(b)

Range	Local(%)	Under(%)
10.0-15.6	0.53	0.55
15.6-31.2	4.80	5.34
31.2-62.5	18.66	24.00
62.5-125.0	40.02	64.02
125.0-250.0	35.98	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/37(a)

Volume Histogram : OA148/37(a)
Mean: 81.93 um STD: 35.47 um Conf.: 100.00 %
D10 : 36.30 um D50: 80.91 um D90: 127.69 um



Area Ranges Table : OA148/37(a)

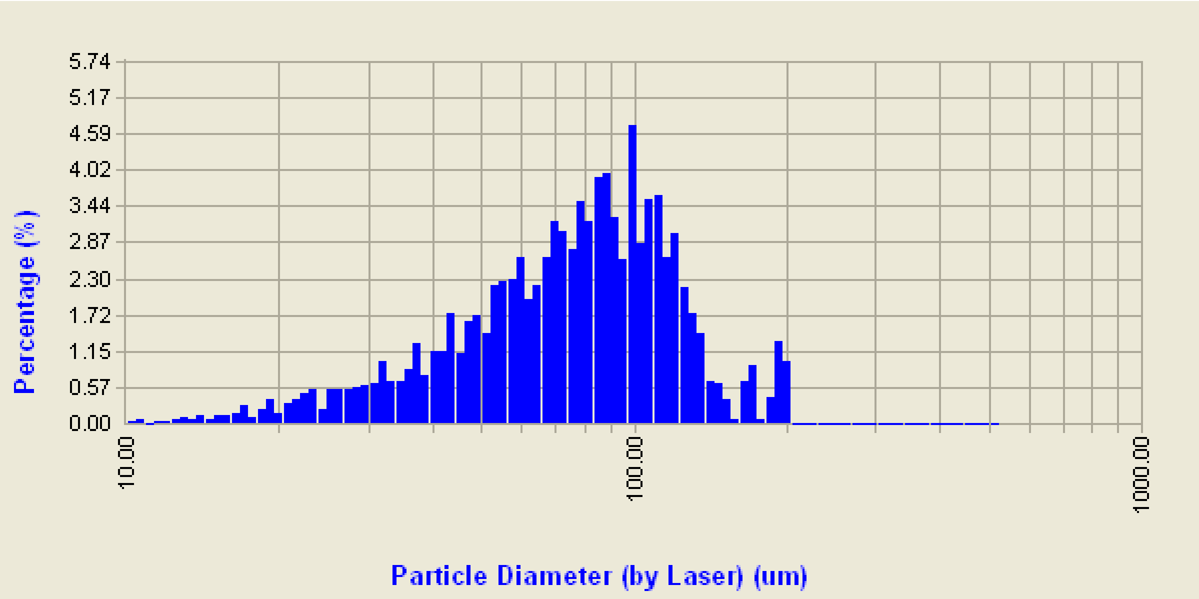
Range	Local(%)	Under(%)
10.0-15.6	3.54	3.89
15.6-31.2	17.43	21.32
31.2-62.5	33.02	54.33
62.5-125.0	40.91	95.24
125.0-250.0	4.76	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/37(a)

Range	Local(%)	Under(%)
10.0-15.6	0.72	0.77
15.6-31.2	6.37	7.14
31.2-62.5	24.56	31.70
62.5-125.0	57.26	88.96
125.0-250.0	11.04	100.00
250.0-500.0	0.00	100.00

Volume Distribution: OA148/37(b)

Volume Histogram : OA148/37(b)
Mean: 80.82 um STD: 37.60 um Conf.: 100.00 %
D10 : 34.99 um D50: 78.29 um D90: 124.83 um



Area Ranges Table : OA148/37(b)

Range	Local(%)	Under(%)
10.0-15.6	3.40	3.72
15.6-31.2	18.13	21.86
31.2-62.5	34.14	56.00
62.5-125.0	39.71	95.71
125.0-250.0	4.29	100.00
250.0-500.0	0.00	100.00

Volume Ranges Table : OA148/37(b)

Range	Local(%)	Under(%)
10.0-15.6	0.70	0.75
15.6-31.2	6.82	7.57
31.2-62.5	25.69	33.26
62.5-125.0	56.21	89.46
125.0-250.0	10.54	100.00
250.0-500.0	0.00	100.00

Wet sieving particle size distribution

Table A2.3: Summary of particle size results (%) for subtidal sediments collected from benthic ecology collection areas in Porirua Harbour in 2010

GWRC Site Code		POR 1B/4	POR 1B/5	POR 1B/6	PAH 3B/4	PAH 3B/5	PAH 3B/6	POR 2B/4	PAH 2B/4	POR 2B/5
NIWA Sample Code		148/26	148/27	148/28	148/29	148/30	148/31	148/32	148/QA1	148/33
Particle size range (mm)	Fraction									
>2	Gravel	0.52	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
2.0-0.5	Coarse Sand	0.01	0.04	0.07	0.11	0.17	0.09	0.03	0.15	0.03
0.5-0.25	Medium Sand	0.16	0.16	0.16	0.78	0.61	0.57	0.11	0.09	0.06
0.25-0.125	Fine Sand	0.54	0.47	0.65	9.09	6.87	7.94	0.47	0.46	0.50
0.125-0.063	Very Fine Sand	4.54	4.81	4.98	32.06	28.84	29.40	1.99	2.29	2.48
< 0.063	Mud	94.23	94.53	94.14	57.96	63.47	62.00	97.41	97.00	96.93
0.063-0.031	Silt	65.62	72.36	71.72	46.92	50.32	51.43	73.87	65.24	77.85
<0.031	Clay	28.60	22.16	22.41	11.04	13.15	10.57	23.54	31.76	19.08

GWRC Site Code		PAH 1B/4	PAH 1B/5	PAH 2B/4	PAH 2B/5
NIWA Sample Code		148/34	148/35	148/36	148/37
Particle size range (mm)	Fraction				
>2	Gravel	0.00	0.00	0.00	0.00
2.0-0.5	Coarse Sand	0.23	0.19	0.19	0.17
0.5-0.25	Medium Sand	0.54	0.46	0.19	0.15
0.25-0.125	Fine Sand	3.58	3.55	0.72	0.56
0.125-0.063	Very Fine Sand	14.79	14.81	28.76	27.68
< 0.063	Mud	80.87	80.98	70.14	71.45
0.063-0.031	Silt	57.89	65.15	64.69	58.09
<0.031	Clay	22.97	15.83	5.45	13.35

Appendix 3: Sediment chemistry and QA results

The National Institute of Water and Atmospheric Research Limited (NIWA), Hamilton, prepared and processed all sediment samples collected from Porirua Harbour in late 2010. Specifically, NIWA undertook the analyses of polycyclic aromatic hydrocarbons (PAHs), and organochlorine pesticides (OCPs). NIWA managed the analyses of organic carbon, weak acid-extractable metals and total recoverable metals undertaken by Hill Laboratories Limited, Hamilton.

Table A3.1: Total organic carbon, metals, and organochlorine pesticide content in replicate composite sediment samples collected at site PAH1 in November and December, 2010

Site Replicate (GWRC Code)	PAH1/16	PAH1/17	PAH1 PAH1/18	PAH1/19	PAH1/20
Total organic carbon (%,<63μm):	1.38	1.40	1.37		
Total organic carbon (%,<500μm):	1.57	1.57	1.53		
Metals (mg/kg, weak acid, <63μm):					
Copper	9.3	9.6	9.4	9.2	8.7
Lead	20	19.6	20	20	19.5
Zinc	72	73	75	71	70
			PAH1/16-20 composite		
Metals (mg/kg, strong acid, <500μm):					
Silver			0.07		
Mercury			0.109		
Arsenic			8.6		
Cadmium			0.029		
Chromium			16.9		
Copper			10.4		
Nickel			11.4		
Lead			21		
Zinc			71		
DDTs					
o,p-DDE	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
p,p'-DDE	4.4	4.3	4.4	4.3	4.3
o,p-DDD	0.2	0.1	0.2	0.1	0.1
p,p-DDD	0.7	0.6	0.8	0.7	0.7
o,p-DDT	< 0.1	< 0.1	0.1	< 0.1	< 0.1
p,p'-DDT	0.8	0.8	1.0	0.6	0.9
Total DDT	6.2	6.0	6.4	5.8	6.0
Chlordanes					
heptachlor	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
heptachlor epox	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
trans-chlordane	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
cis-chlordane	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
trans-nonachlor	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
cis-nonachlor	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Total Chlordane	<0.5	<0.5	<0.5	<0.5	<0.5

Table A3.2: Total organic carbon, metals, and organochlorine pesticides in replicate composite sediment samples collected at site PAH2 in November and December, 2010

Site Replicate (GWRC Code)	PAH2/16	PAH2/17	PAH2 PAH2/18	PAH2/19	PAH2/20
Total organic carbon (%,<63µm):	1.51	1.43	1.55		
Total organic carbon (%,<500µm):	1.73	1.65	1.63		
Metals (mg/kg, weak acid, <63µm):					
Copper	9.1	8.5	9.4	8.8	9.4
Lead	17.4	16.2	17.4	16.7	18.1
Zinc	60	58	61	60	65
			PAH2/16-20 composite		
Metals (mg/kg, strong acid, <500µm):					
Silver			0.07		
Mercury			0.077		
Arsenic			5.8		
Cadmium			0.063		
Chromium			13.1		
Copper			8.7		
Nickel			8.9		
Lead			17.2		
Zinc			62		
DDTs					
o,p-DDE	0.1	< 0.1	0.1	< 0.1	0.1
p,p'-DDE	6.5	6.5	6.2	6.0	6.4
o,p-DDD	0.2	0.2	0.2	0.3	0.2
p,p-DDD	1.1	1.1	1.0	1.0	1.0
o,p-DDT	< 0.1	< 0.1	< 0.1	< 0.1	0.2
p,p'-DDT	1.1	1.4	1.0	1.0	0.8
Total DDT	9.0	9.3	8.6	8.2	8.7
Chlordanes					
heptachlor	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
heptachlor epox	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
trans-chlordane	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
cis-chlordane	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
trans-nonachlor	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
cis-nonachlor	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Total Chlordane	<0.5	<0.5	<0.5	<0.5	<0.5

Table A3.3: Total organic carbon, metals, and organochlorine pesticides in replicate composite sediment samples collected at site PAH3 in November and December, 2010

Site Replicate (GWRC Code)	PAH3/16	PAH3/17	PAH3 PAH3/18	PAH3/19	PAH3/20
Total organic carbon (%,<63µm):	1.12	1.08	1.13		
Total organic carbon (%,<500µm):	0.97	0.94	1.02		
Metals (mg/kg, weak acid, <63µm):					
Copper	8.3	8.4	8.3	8	8.6
Lead	17	16.9	17.4	16.4	17.1
Zinc	62	61	60	59	61
			PAH3/16-20 composite		
Metals (mg/kg, strong acid, <500µm):					
Silver			0.05		
Mercury			0.063		
Arsenic			7.0		
Cadmium			0.041		
Chromium			14.1		
Copper			7.7		
Nickel			9.6		
Lead			15.6		
Zinc			62		
DDTs					
o,p-DDE	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
p,p'-DDE	2.7	2.8	2.7	2.7	2.8
o,p-DDD	< 0.1	0.1	< 0.1	0.1	0.2
p,p-DDD	0.6	0.5	0.5	0.5	0.7
o,p-DDT	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
p,p'-DDT	0.8	0.4	0.8	0.4	0.6
Total DDT	4.1	3.8	4.0	3.7	4.2
Chlordanes					
heptachlor	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
heptachlor epox	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
trans-chlordane	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
cis-chlordane	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
trans-nonachlor	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
cis-nonachlor	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Total Chlordane	<0.5	<0.5	<0.5	<0.5	<0.5

Table A3.4: Total organic carbon, metals, and organochlorine pesticides in replicate composite sediment samples collected at site POR1 in November and December, 2010

Site Replicate (GWRC Code)	POR1/16	POR1/17	POR1 POR1/18	POR1/19	POR1/20
Total organic carbon (%,<63µm):	1.57	1.62	1.62		
Total organic carbon (%,<500µm):	2.50	2.40	2.30		
Metals (mg/kg, weak acid, <63µm):					
Copper	16.3	16.4	17	16.9	14.6
Lead	32	33	33	33	30
Zinc	148	153	155	154	143
POR1/16-20 composite					
Metals (mg/kg, strong acid, <500µm):					
Silver			0.16		
Mercury			0.122		
Arsenic			10.7		
Cadmium			0.138		
Chromium			20		
Copper			23		
Nickel			12.6		
Lead			40		
Zinc			200		
USEPA PAHs (ng/g)					
naphthalene	7.4	7.7	7.4	7.4	7.7
acenaphthene	2.3	2.1	1.9	2.1	1.7
acenaphthylene	4.4	5.0	4.8	5.0	4.7
fluorene	4.4	4.5	4.4	4.4	4.1
phenanthrene	38.8	38.3	33.1	36.0	32.5
anthracene	7.5	8.2	7.7	7.9	7.5
fluoranthene	97.0	97.1	82.1	94.8	83.1
pyrene	99.9	101.0	91.5	99.1	89.0
benz[a]anthracene	48.2	49.8	44.2	49.4	43.4
chrysene	61.7	62.7	57.3	61.8	55.7
benzo[b]fluoranthene	71.7	74.0	70.0	73.4	67.5
benzo[k]fluoranthene	31.0	32.2	30.0	31.3	29.4
benzo[a]pyrene	88.8	94.0	86.2	92.4	84.2
indeno[123-cd]pyrene	54.4	55.4	51.9	57.0	51.5
dibenz[ah]anthracene	3.0	3.4	3.3	3.6	3.1
benzo[ghi]perylene	46.6	47.9	45.3	47.6	45.8
TOTAL PAH	667	684	621	673	611
DDTs					
o,p-DDE	0.1	0.1	< 0.1	< 0.1	< 0.1
p,p'-DDE	7.7	6.1	6.7	6.3	6.4
o,p-DDD	0.6	0.6	0.5	0.5	0.4
p,p-DDD	2.2	2.2	2.0	1.9	1.9
o,p-DDT	0.2	0.2	0.1	0.1	0.1
p,p'-DDT	2.5	1.0	2.9	1.4	2.2
Total DDT	13.4	10.3	12.1	10.1	11.1

Table A3.4 *continued*: Total organic carbon, metals, and organochlorine pesticides in replicate composite sediment samples collected at site POR1 in November and December, 2010

Site			**POR1**		
Replicate (GWRC Code)	**POR1/16**	**POR1/17**	**POR1/18**	**POR1/19**	**POR1/20**
Chlordanes					
heptachlor	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
heptachlor epox	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
trans-chlordane	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
cis-chlordane	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
trans-nonachlor	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
cis-nonachlor	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Total Chlordane	<0.5	<0.5	<0.5	<0.5	<0.5

Table A3.5: Total organic carbon, metals, and organochlorine pesticides in replicate composite sediment samples collected at site POR2 in November and December, 2010

Site **Replicate (GWRC Code)**	**POR2/16**	**POR2/17**	**POR2** **POR2/18**	**POR2/19**	**POR2/20**
Total organic carbon (%,<63µm):	1.58	1.63	1.52		
Total organic carbon (%,<500µm):	1.96	1.93	1.85		
Metals (mg/kg, weak acid, <63µm):					
Copper	13.3	13.6	13.5	13.4	12.4
Lead	33	32	32	32	31
Zinc	128	127	126	126	123
			POR2/16-20 composite		
Metals (mg/kg, strong acid, <500µm):					
Silver			0.12		
Mercury			0.141		
Arsenic			12.8		
Cadmium			0.04		
Chromium			22		
Copper			19.2		
Nickel			13.8		
Lead			38		
Zinc			153		
DDTs					
o,p-DDE	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
p,p'-DDE	4.1	4.2	4.0	4.0	4.1
o,p-DDD	0.3	0.2	0.3	0.3	0.2
p,p-DDD	1.0	1.1	1.1	1.1	1.2
o,p-DDT	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
p,p'-DDT	1.1	0.8	1.0	0.9	1.0
Total DDT	6.5	6.3	6.5	6.3	6.5
Chlordanes					
heptachlor	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
heptachlor epox	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
trans-chlordane	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
cis-chlordane	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
trans-nonachlor	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
cis-nonachlor	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Total Chlordane	<0.5	<0.5	<0.5	<0.5	<0.5

Analytical quality assurance results

The results of the within-batch (duplicate) and between-batch (archive) comparisons carried out as quality assurance (QA) for the Nov/Dec 2010 Porirua Harbour subtidal sediment quality survey are presented in Tables A3.1–A3.4. Archived Porirua Harbour subtidal sediment samples from the 2008 survey have been used for the between-batch comparisons. Results from these sample analyses are shown in the shaded sections of the tables. For all tables, any difference (%) between the new result (denoted with a "2") and the original result (denoted with a "1") is expressed as:

100 x (new result – original result)/mean of the two results

In summary, the analytical QA results (reported in Olsen et al. 2011) show:

Good precision (<6%) for all TOC data for both the <500 µm-fraction and the <63 µm-fraction (Tables A3.6, A3.7).

Good precision for archived replicate total metals (<500mm fraction) with differences between 0 – 8.7%. The exception was nickel (-14.4%) which was lower in 2010 (Tables A3.8). The data may still be used for temporal assessments, but the variability must be considered when comparing data for different years.

Good precision for weak acid-extractable metals, with differences in the results of both the within-batch and between-batch comparisons ranging from -1.2% and 7.4% (Table A3.9).

Surrogate recoveries for PAH analyses were generally good (78-95%) with the exception of naphthalene-d8 (40%) which was typically low (Table A3.10). There was also good agreement for the analyses of PAHs in the archived replicates and SRM material (Table A3.11).

Surrogate recoveries for OC analyses were very good (ca.88%) and there was good agreement for the within-batch replicate and the archived replicate.

Table A3.6: Within-batch and between-batch comparisons for total organic carbon in <500 µm fraction

Site	PAH2/16 (2010 sample)			POR2/11 (2008 sample)		
Result Number	1	2	Diff (%)	1	2	Diff (%)
Total Organic Carbon (%)	1.64	1.73	-5.3	1.94	1.96	-1.0

Table A3.7: Within-batch and between-batch comparisons for total organic carbon in <63 µm fraction

Site	PAH2/16 (2010 sample)			POR2/11 (2008 sample)		
Result Number	1	2	Diff (%)	1	2	Diff (%)
Total Organic Carbon (%)	1.13	1.13	0	1.70	1.72	-1.2

Table A3.8: Comparison of total metals in a 2008 sediment sample from Porirua Harbour analysed in 2008 and 2010 (<500 µm fraction, mg/kg dry weight)

Site	POR2/11-15 (2008 sample)		
Analytical date	2008	2010	Diff (%)
Arsenic	13	12.7	-2.7
Cadmium	0.043	0.041	-4.8
Chromium	23.9	21.9	-8.7
Copper	20.6	19.6	-5.0
Lead	37.2	37	-0.5
Mercury	0.14	0.138	-1.4
Nickel	16	13.9	-14.4
Silver	0.13	0.12	-8.0
Zinc	150	153	2.0

Table A3.9: Within-batch and between-batch comparisons for weak acid extractable metals in the <63 µm fraction (mg/kg dry weight)

Site	PAH3/18 (2010 sample)			POR2/11(2008 sample)		
Result Number	1	2	Diff (%)	1	2	Diff (%)
Copper	8.3	8.3	0	13	14	7.4
Lead	17.4	17.2	-1.2	34	34	0
Zinc	60	60	0	130	132	1.5

Table A3.10: Surrogate percentage recoveries for PAHs

Surrogate	Mean	cv (%)
naphthalene-d8	40	12
acenaphthene-d10	89.3	5.3
phenanthrene-d10	95.3	2.3
fluoranthene-d10	94.7	1.7
pyrene-d10	91.5	1.2
benz[a]anthracene-d12	86.8	3.7
perylene-d12	78.9	3.0
ideno[123-cd]pyrene-d12	85.4	2.4
benzo[ghi]perylene-d12	86.9	2.2

Table A3.11: Replicate analyses of PAHs in a Wellington Harbour sediment sample (WH16/4) and in standard reference material (SRM) (ng/g dry weight, <500 µm fraction)

Site	WH16/4			SRM 1941b		
Result Number	2007	2010	Diff (%)	1	2	Diff (%)
Total PAH (ng/g dry weight)	510	558	9.1	5318	5287	0.6

Table A3.12: Surrogate percentage recoveries for organochlorine pesticides

Surrogate	Mean	cv (%)
DBOFBP	87.8	6.2
PCB103	88.8	2.8
fluoranthene-d10	89.1	2.7

Table A3.13: Replicate analyses for the organochlorine pesticides in the <500 µm fraction (ng/g dry weight)

Site	PAH2/17			PAH2/8		
Analyte	**1**	**2**	**Diff (%)**	**2005**	**2010**	**Diff (%)**
Hexachlorobenzene	<0.1	<0.1	–	<0.1	<0.1	–
Lindane (gamma BHC)	<0.2	<0.2	–	<0.2	<0.2	–
Heptachlor	<0.2	<0.2	–	<0.2	<0.2	–
Heptachlor epoxide	<0.1	<0.1	–	<0.2	<0.2	–
Aldrin	<0.1	<0.1	–	<0.1	<0.1	–
Dieldrin	0.4	0.3	-28.6	<0.2	0.2	66.7
Endrin	<0.1	<0.1	–	<0.1	<0.1	–
DDTs						
2,4' DDE	0.2	<0.1	-120	<0.1	<0.1	–
4,4'-DDE	6.7	6.5	-3.03	7.6	7.7	1.31
2,4'-DDD	0.2	0.2	0	0.2	0.2	0
4,4'-DDD	1.0	1.1	9.52	0.8	1.2	40
2,4'-DDT	<0.1	<0.1	–	<0.1	<0.1	–
4,4'DDT	1.5	1.4	-6.90	0.7	0.8	13.3
Total DDT	9.7	9.3	-4.21	9.3	9.9	6.25
Chlordanes						
trans-Chlordane	<0.1	<0.1	–	<0.1	<0.1	–
cis-Chlordane	<0.1	<0.1	–	<0.1	<0.1	–
trans-Nonachlor	<0.1	<0.1	–	<0.1	<0.1	–
cis-Nonachlor	<0.1	<0.1	–	<0.1	<0.1	–
Total Chlordane (cis+trans)*100/42	<0.5	<0.5	–	<0.5	<0.5	–

Table A3.14: Organochlorine pesticides in a standard reference material (SRM 1941b) sourced from the National Institute of Standards and Technology, Gaithersburg, MD, USA (ng/g dry weight), and minimum detection limits

Analyte	Certified	SRM 1942b	Minimum detection limts (MDL) at NIWA at March 2011
Hexachlorobenzene	5.83	6.4	<0.1
Lindane (gamma BHC)		<0.2	<0.2
Heptachlor		<0.2	<0.2
Heptachlor epoxide		<0.1	<0.1
Aldrin		<0.1	<0.1
Dieldrin		<0.2	<0.2
Endrin		<0.1	<0.1
DDTs			
2,4' DDE	(0.4)[a]	0.3	<0.1
4,4'-DDE	3.2	3.1	<0.1
2,4'-DDD		0.4	<0.1
4,4'-DDD		4.6	<0.1
2,4'-DDT		0.2	<0.1
4,4'DDT	(1.1)	1.2	<0.1
Total DDT	9.3	9.8	
Chlordanes			
trans-Chlordane	0.6	0.9	<0.1
cis-Chlordane	0.9	0.8	<0.1
trans-Nonachlor	0.4	0.4	<0.1
cis-Nonachlor	0.4	0.4	<0.1
Total Chlordane (cis+trans)*100/42	3.4	3.9	

[a] Values in brackets represent data which has not been certified but may be used for comparison only.

Appendix 4: List of species in the subtidal benthos

A list of the species identified in the subtidal samples collected during the 2010 Porirua Harbour sediment quality survey is presented in Table A4.1. Where genus and species names could not be assigned with certainty due to damage to the specimens, small size, immaturity, or taxonomic difficulties, the species are designated “#1”, “#2”, “#3”, etc., following the class, family, or generic name as appropriate.

Table A4.1: List of species identified during the November/December 2010 Porirua Harbour subtidal sediment quality survey. For feeding mode: P = predator, Sc = scavenger, SDF = surface deposit feeder, SSDF = subsurface deposit feeder, SF = suspension feeder, U = unknown

Species	Onepoto Arm	Pauatahanui Arm	Feeding mode(s)
Phylum COELENTERATA (1 species)			
Class ANTHOZOA			
Edwardsia sp.#1[1]	+	+	P
Phylum NEMERTEA (2 species)			
Nemertea sp.#2	+	+	P
Nemertea sp.#3		+	P
Phylum ASCHELMINTHES			
Class PRIAPULIDA (1 species)			
Priapulopsis australis	+	+	P
Class NEMATODA (1 species)			
Nematoda sp.#1		+	U
Phylum ANNELIDA			
Class POLYCHAETA (27 species)			
Aglaophamus macroura		+	P
Armandia maculata	+	+	SSDF
Asychis sp.#1	+	+	SSDF
Boccardia (Paraboccardia) syrtis	+	+	SF, SDF
Cirriformia sp.#1		+	SDF
Cossura consimilis	+	+	SSDF
Dorvilleidae sp.#1		+	P
Euclymene sp.#1		+	SSDF
Glycinde sp.#1	+	+	P
Goniada sp.#1 [a]		+	P
Hesionidae sp.#2		+	P
Hesionidae sp.#3		+	P
Heteromastus filiformis	+	+	SSDF
Magelona sp.#1 [a]		+	SSDF
Nicon aestuariensis	+	+	SDF, Sc
Owenia fusiformis [a]		+	SF, SDF
Paraonidae sp.#1	+	+	SDF
Paraonidae sp.#2		+	SDF
Phylo novazealandiae	+		SSDF
Polynoidae sp.#1		+	P
Polynoidae sp.#2		+	P
Prionospio sp.#2	+	+	SDF
Scolecolepides benhami	+		SDF, SF

Table A4.1 *cont*: List of species identified during the November/December 2010 Porirua Harbour subtidal sediment quality survey. For feeding mode: P = predator, Sc = scavenger, SDF = surface deposit feeder, SSDF = subsurface deposit feeder, SF = suspension feeder, U = unknown

Species	Onepoto Arm	Pauatahanui Arm	Feeding mode(s)
Class POLYCHAETA *continued*			
Sphaerosyllis hirsuta	+	+	P
Terebellidae sp.#1		+	SDF
Terebellides sp.#1	+	+	SDF
Class OLIGOCHAETA (1 species)			
Oligochaeta sp.#1	+	+	SSDF
Phylum MOLLUSCA			
Class GASTROPODA (2 species)			
Cominella glandiformis		+	P, Sc
Xymene plebeius		+	P
Class BIVALVIA (7 species)			
Arthritica sp.#1	+	+	SF
Austrovenus stutchburyi		+	
Cyclomactra ovata	+	+	SF
Macomona liliana		+	SDF
Mysella hounselli		+	SF
Linucula hartvigiana	+	+	SDF
Theora lubrica[2]	+	+	SF
Phylum ARTHROPODA			
Class CRUSTACEA (14 species)			
Amphipoda sp.#1		+	U
Amphipoda sp.#2	+	+	U
Acutigebia danai [a]	+		
Colurostylis lemurum		+	
Macrophthalmus hirtipes	+	+	SDF
Ostracoda sp.#2	+	+	U
Ostracoda sp.#3		+	U
Ostracoda sp.#4		+	U
Ostracoda sp.#6 [a]		+	U
Phoxocephalidae sp.#1	+	+	P, Sc
Phoxocephalidae sp.#2	+	+	P, Sc
Pontophilus australis		+	P, Sc
Tanaidacea sp.#1	+	+	P
Tanaidacea sp.#2		+	U
Phylum SIPUNCULIDA (1 species)			
Sipunculida sp.#2		+	SDF
Phylum ECHINODERMATA			
Class HOLOTHUROIDEA (1 species)			
Paracaudina chilensis		+	SSDF

[a] Not recorded in previous surveys

[1] Incorrectly identified as Sipunculida sp.#1 in the 2004 and 2005 subtidal surveys.

[2] Listed by Grange (1977) as a deposit feeder. The species is possibly ditrophic.

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