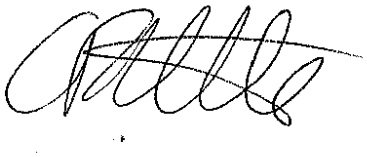
Shellfish Contaminant Monitoring Programme: Status and Trends Analysis 1987 - 2011

December 2013 Technical Report TR2013/054

Auckland Council
Technical Report TR2013/054
ISSN 2230-4525 (Print)
ISSN 2230-4533 (Online)

ISBN 978-1-927266-66-3 (Print)
ISBN 978-1-927266-67-0 (Pdf)

This report has been peer reviewed by the Peer Review Panel using the Panel's terms of reference
Submitted for review on 1 August 2013 Review completed on 19 December 2013 Reviewed by 2 reviewers
Approved for Auckland Council publication by:    Name: Greg Holland Position: Manager, Research, Investigations and Monitoring Unit
Date: 19 December 2013

Recommended citation:

Stewart, M., Gadd, J., Ballantine, D and Olsen, G (2013). Shellfish contaminant monitoring programme: status and trends analysis 1987-2011. Prepared by NIWA for Auckland Council. Auckland Council technical report, TR2013/054

Shellfish Contaminant Monitoring Programme: Status and Trends Analysis 1987 - 2011

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NIWA Report: HAM2012-115
NIWA Project: ARC13210

Executive Summary

Background

The Shellfish Contaminant Monitoring Programme (SCMP) has been run by Auckland Council (AC) (and formerly the Auckland Regional Council (ARC)) since 1987. AC has monitored bioaccumulative contaminant levels in Pacific oysters (*Crassostrea gigas*) at four core sites in the Manukau Harbour (Cornwallis, Grannys Bay, Hingaia and Pahurehure) yearly since 1987. Annual mussel (*Perna canaliculus*) monitoring was introduced in the Waitemata Harbour (three sites - Upper Harbour, Chelsea and Illiomama) and Tamaki Estuary (one site) in 1999, and in the Manukau Harbour in 2000 (three sites - Mangere Bridge, Papakura Channel and Weymouth).

Oysters are collected from in-situ wild populations while mussels are sourced from a Coromandel mussel farm, seeded on to strings and then deployed for three months prior to harvesting. Pre-deployment mussels are also analysed in order to calculate subsequent contaminant load from each site. Both species are harvested in early summer and five replicate samples from each site are analysed for metal and organic contaminants and one combined sample from each site is analysed for condition.

Shellfish are sedentary “biomonitors” used to assess the bioavailable contaminant load at a designated site. These bioavailable contaminant data are amalgamated with other environmental monitoring programmes - the Saline Water Quality Programme, the Sediment Contaminant Monitoring Programme and the Benthic Ecology Programme - to provide a holistic assessment of environmental contamination in the Auckland region.

Contaminants measured have varied throughout the lifetime of the programme (see Appendix A for descriptions of contaminants; Appendix B for history of mussel contaminant analyses and Appendix C for history of oyster contaminant analyses) and currently include six key heavy metals: arsenic; cadmium; chromium; copper; lead and zinc and a suite of legacy organic contaminants including: dichlorodiphenyltrichloroethane (DDT) and breakdown products; polycyclic aromatic hydrocarbons (PAHs); polychlorinated biphenyls (PCBs); and minor organochlorine pesticides (OCPs). As indicators of shellfish health, condition and lipid content are also measured.

Report aims

To provide an assessment of all aspects of the SCMP, AC conducts regular audits. The previous audit in 2007 (Mills 2007), recommended a follow-up in 5 years. AC has requested a status and trends analysis (this report) and a separate review of the SCMP (a second following report Stewart*, et al.* (2013)).

This report is broken down into distinct areas:

- An assessment of current QA procedures used by analytical laboratories;
- Analysis of current contaminant and condition status for each site;
- Statistical analyses of contaminant and condition trends over the lifetime of the SCMP;
- Comparisons of SCMP data with other shellfish monitoring programmes; food safety guidelines; and other regional environmental monitoring programmes.

Key findings

QA procedures and data were assessed, to determine whether changing analytical laboratories in 2005 (metals) and 2009 (organics) had any significant effect on the data. Metals have been analysed by Watercare Laboratory Services Ltd since 2005 (previously AgResearch), while organics have been analysed by AsureQuality Limited since 2009 (previously NIWA). For both current laboratories, QA procedures are comprehensive and provide sufficient information to measure analytical performance for the SCMP. An assessment of organics QA data has revealed that there were no significant changes as a consequence of changing analytical laboratories. This assessment was not possible for metals as no QA data is available prior to 2005. However, a change to the digestion procedure was implemented in 2011. This change does not appear to significantly affect the results for samples from the SCMP.

Recommendations arising from the QA assessment are:

- Re-assess why a shelf temperature of 25-30°C is used for freeze drying, with possible implications in the loss of volatile contaminants;
- Consider using a certified reference material (CRM) that contains levels of organic contaminants which more closely resemble the range observed in shellfish from the Auckland region;
- Decrease the spike concentration for PAHs by at least ten-fold (10 ng) to produce a spiked PAH data set which is in a similar range to real samples;
- AC to request blank data for PAH analyses;
- Confirm that the procedure used to measure %lipid is robust and reliable for future organic contaminant analyses;
- Consider conducting a small pilot study to measure if there are any significant differences between levels of contaminants (for both metals and organics) when extracting either wet tissue or freeze-dried tissue.
- We strongly recommend long-term storage of tissue samples (dried or frozen) for future investigations and retrospective analysis of e.g., emerging contaminants.

Results for current status are:

- Based on a combined average contaminant score, mussel sites decrease in quality in the order: Pre-deployment; Papakura Channel; Illiomama; Weymouth; Chelsea; Upper Harbour; Mangere Bridge; Tamaki. The site ranking for mussels is very similar to the ranking provided in 2007 (Kelly 2007), suggesting only minimal relative change has occurred since that time.
- Based on the combined average contaminant score, oyster sites decrease in quality in the order: Cornwallis; Hingaia; Pahurehure; Grannys Bay. The ranking of oyster sites is unchanged from that provided in 2007 (Kelly 2007).
- For condition:
    - Oyster condition was highest at Cornwallis and lowest at Grannys Bay.
    - Mussel condition was substantially higher at Illiomama compared to the other sites and was lowest at Mangere Bridge. The condition index for the pre-deployment mussels was generally lower than the monitoring sites.

    - Pre-deployment mussel condition appears to have some effect on contaminant tissue concentrations, probably increasing variability and therefore decreasing the ability to detect trends.
- For heavy metals:
    - Arsenic concentrations were similar among both species with highest levels in Cornwallis oysters and lowest levels in Mangere Bridge mussels.
    - Cadmium concentrations were approximately twice as high in oysters compared to mussels and were highest in oysters at Hingaia. Lowest cadmium concentrations were measured in mussels at Tamaki and Illiomama.
    - Chromium concentrations were similar in oysters and mussels, were lowest at the Hingaia and Pahurehure oyster sites and the Illiomama mussel site and highest at Mangere Bridge mussel site.
    - Lead concentrations were around 3 times higher in mussels than in oysters and were substantially lower at Cornwallis than at all other sites. Highest concentrations of lead were measured at Upper Harbour, Chelsea and Tamaki mussel sites.
    - Copper concentrations were a factor of 50 times higher in oysters than in mussels and for oysters were highest at Grannys Bay and lowest at Cornwallis. Lowest copper concentrations were for pre-deployment mussels and at Weymouth and Papakura Channel mussel sites.
    - Zinc concentrations were a factor of 30 times higher in oysters than in mussels. For oysters, zinc concentrations were highest at Grannys Bay and lowest at Cornwallis.
    - Pre-deployment mussels generally had lower arsenic, chromium, copper and lead, similar zinc, and higher cadmium concentrations than monitoring sites.
- For organics:
    - Species-specific differences between organic contaminant concentrations in mussels and oysters were much smaller than was observed for metals.
    - Of the oyster sites, Grannys Bay generally had the highest concentrations of organic contaminants, Hingaia and Pahurehure had intermediate concentrations, and Cornwallis consistently had the lowest concentrations.
    - Of the mussel sites, Mangere Bridge, Tamaki and Upper Harbour had the highest concentrations of most organochlorine contaminants. Total PAHs were highest at Tamaki.
- The only strong correlations between contaminants exhibited across the two species were zinc with cadmium, copper and DDT; copper with DDT; lead with PAHs; and chlordane with PCBs.
- Multivariate analysis was used to summarise the status of the sites. Differences between shellfish type (oyster vs. mussels) generally occurred along the second most important axis, with the most important axis summarising differences in contaminant status which were unassociated with differential uptake rates of the two species. Variables most strongly related to these differences were DDT, chlordane, copper, and PCBs.
- Multivariate analysis linking contamination and condition to land-use suggest sites of the same category (reference (primarily indigenous forest), urban, semi-urban) generally group together, with the most significant difference being between urban sites and reference sites.

Current contaminant status for mussels and oysters was compared for sites in the Manukau Harbour. Overall, median concentrations of contaminants are higher in oysters than mussels, with the exception of lead and lindane, which are lower in oysters than mussels.

Results for current trends are:

Trend comparisons between raw mussel contaminant data and pre-deployment subtracted contaminant data revealed pre-deployment subtraction is not a useful approach for trend analysis and, as such, all trends were undertaken on raw mussel data.

Contaminant temporal trend analysis was undertaken on dry weight data for oysters at two time periods - 1987 to 2011 (lifetime of SCMP) and from 1999 to 2011 (to compare with mussels), using the NIWA developed statistical tool “Time Trends”. Generally, there were a greater number of significant and meaningful trends for the full time series than in the shorter time series. There was also a lack of concordance between meaningful trends observed for oyster metal concentrations for the two time periods, but much closer concordance for organic suites.

A summary of the heavy metal trends were:

- For mussels, increasing trends were observed for arsenic (4 out of 7 sites), cadmium (6/7) and zinc (5/7), while decreasing trends were observed for chromium (6/7), copper (6/7) and lead (7/7).
- For oysters (1987-2011 only), increasing trends were observed for arsenic (3 out of 4 sites), while decreasing trends were observed for cadmium (4/4), chromium (4/4), copper (4/4) and lead (4/4). Zinc was increasing at two sites and decreasing at two sites.

A summary of organics trends were:

- For both species, generally organic contaminant levels have decreased over all time periods analysed, although PAHs did show some minor increases over the shorter time periods.
- Lipid content has declined at all sites except Illiomama, suggesting that it may not be a suitably stable variable to use in standardising the data.

An alternative trend analysis method, known as the Akritas-Theil-Sen (ATS) nonparametric regression method, was also used for highly censored (less than detection level) data. Comparisons with the Time Trends analysis suggested that the ATS method was more sensitive with good agreement between the two methods for oysters, but less agreement for mussels.

Condition trend analysis was only possible on data from 2006-2011, which suggested no significant change in condition has occurred over this time period.

Distance-based linear modelling (DistLM) was used to quantitatively model the relationship between the multivariate contaminant data, and the predictor variables of year of sampling. Year was a significant predictor of the combined contaminant concentrations for all sites except Illiomama, explaining a high proportion of variance. There were no obvious trends over time based on the combined influence of contaminants when all sites were examined together. When sites were examined individually, there were considerable between-site differences for oysters but not for mussels.

Differences in contaminant trends and the combination of contaminant and condition trends between sites were examined by principal component analysis (PCA), which indicated differences in the contaminant trends in oysters and mussels, and that trends in contaminants - and not condition - dominate this analysis. However, similar to the summary of status based on current values, the axis explaining most of the variability is not affected by the differences between oysters and mussels and is driven by trends in organic suites.

Analysis using the correlation coefficient Kendall's tau suggested:

- There is no statistically significant correlation between the trends in contaminant concentrations and the trends in condition.
- There is no statistically significant correlation between the trends in oysters and the trends in mussels.
- There is a significant correlation between the condition trends in oysters and the condition trends in mussels. However, as the condition trends were not statistically significant, this has little relevance for trend analysis.

Trend comparisons were undertaken between oyster and mussel sites in the Manukau Harbour as this is the only harbour where there are both oyster and mussels sites, albeit no sites containing both species. There were few meaningful comparable trends in either metals or organics and no condition trends were meaningful. However, some similarities in trends suggest that it would be worthwhile to sample some sites with both oysters and mussels (for metals at least) to determine to what degree variations in trends are dependent on differential uptake of contaminants by each species.

There were no strong correlations between climate variables and contaminants or PCA scores but there were some correlations between shellfish condition and climate variables, although condition data were only available from 2006.

The SCMP contaminant data were compared to the United States (US) National Status & Trends (NS&T) mussel watch programme and the French Réseau National d'Observation (RNO) de la Qualité du Milieu Marin:

- Generally, the current status of mussel and oyster contamination from the Auckland region is comparable to the RNO data and considered low by US NS&T criteria, with a few exceptions for oyster concentrations of copper, arsenic, lead and zinc which were occasionally in medium or high categories.
- Generally SCMP trends reflect those seen within the RNO mussel watch programme and the NS&T mussel watch programme (for organics), but differ for metals.

Selected organics and metal oyster concentrations were compared with data from oyster sites around Mangere wastewater treatment plant (WWTP) to assess the environmental significance of the upgrade of Mangere WWTP in 2001. Generally, where a spike in concentrations was observed in Mangere WWTP sites after 2001, these were mirrored at Grannys Bay and occasionally (and to a lesser extent) at Cornwallis. Concentrations have since returned to at or below those prior to the upgrade.

Shellfish wet weight contaminant concentrations were compared with relevant national and international guidelines for human consumption. All three relevant metal concentrations were well below these guidelines. Organics data were extremely low compared with guideline values, usually less than 1% of the guideline value. The exception was benzo[a]pyrene which had mussel concentrations around 9-10% of the guideline at Chelsea, Tamaki and Upper Harbour. No consideration was given to bacterial or viral factors when assessing human health implications of consuming these shellfish, as this is outside the scope of the SCMP.

Shellfish contaminant status and trend results were compared (where possible) with nearby sediment contaminant, benthic health and saline water quality sites. Strong correlations were observed between shellfish concentrations and sediment concentrations for copper, lead and zinc. Generally, decreasing lead, increasing zinc and variable copper trends in sediment were consistent with shellfish data. Only very weak relationships were observed between shellfish PCA scores and saline water quality. There were very few nearby benthic health programme sites, although a general relationship was observed between benthic health and shellfish site rankings where sites were available.

Conclusions

The SCMP is providing contaminant information that cannot (at present) be directly obtained by other marine monitoring programmes, specifically an assessment of the bioavailable concentrations of selected contaminants in the Auckland region. That said, there is the *potential* to replace the SCMP in the future with a combination of sediment and benthic health monitoring, but further assessment should be carried out before this is considered.

The data provided by the SCMP continues a long-standing assessment of in-situ shellfish contaminant concentrations and is now of a sufficiently high standard that (as long as this is maintained) future status and trend assessments can be carried out with confidence. Contaminant concentrations can be assessed by benchmarking against international shellfish monitoring programmes and national and international food safety guidelines. Temporal contaminant trends can be used to assess the environmental consequence of banning specific contaminants and assessing broad scale land-use changes in upstream catchments.

The SCMP has seen many changes throughout its lifetime. Any changes to the programme have been based on sound scientific knowledge to ensure that it has a maximum chance of improving the relevance of the outputs. Changes would not be possible without periodical assessments of the current contaminant status and trends over time and thorough reviews of the programme.

Many of the programme changes put in place to date have resulted in improvements to the quality of the data outputs, through introduction of new sites and species (mussels), changes to the analytical suites of contaminants, and improvements in data quality as analytical laboratory capabilities mature.

Of course, like all monitoring programmes, the SCMP has to evolve further in the future to remain relevant. A review of the SCMP for the future would need to assess the relevance of:

- The suitability of maintaining two different species - with the associated variance and logistical issues that arise from this.

- Are the current monitoring sites sufficient to provide contaminant information for the whole Auckland region? For example, are new areas that are subjected to intensive land-use changes sufficiently covered to assess the environmental impacts of those changes?
- Many legacy contaminant concentrations have now reduced in the environment to the extent where many are now only detected due to improved analytical technology. Their continued inclusion in analytical suites - especially in light of new “emerging” contaminants now becoming more relevant - needs to be assessed.

Added to this are increasing budgetary constraints and an ever-pressing need to ensure the SCMP is providing quality information. As such, the review should also concentrate on other alternatives to assess what aspects could be reduced or removed and still maintain the required information. This could include assessing how the frequency of monitoring affects the ability to perform future trend analysis; assessing how a reduction of replicates affects the variability of the data; and whether there are any viable alternatives that could replace the SCMP in the future.

Potential implications of these discussed changes are covered in much more detail in the associated programme review report (Stewart*, et al.* 2013).

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1.0 Introduction

1.1 Background

The Shellfish Contaminant Monitoring Programme (SCMP) has been run by Auckland Council (AC) (and formerly The Auckland Regional Council (ARC)) since 1987. AC has monitored contaminant levels in Manukau Harbour Pacific oysters (*Crassostrea gigas*) every year since 1987 (excluding 1991 and 2004; see Appendix C). Annual mussel (*Perna canaliculus*) monitoring (with the exception of 2004; see Appendix B) was introduced in the Waitemata Harbour and Tamaki Estuary in 1999, and in the Manukau Harbour in 2000. Oysters are collected from in-situ wild populations within the Manukau Harbour. Mussels are sourced from a Coromandel mussel farm, seeded on to strings and then deployed for three months prior to harvesting. Pre-deployment mussels are also analysed in order to calculate subsequent contaminant load from each site. Both species are harvested for analysis in early summer with five replicate samples of approximately 15 shellfish for metals analysis, 30 shellfish for organics analysis and one combined sample of 50 shellfish for condition analysis collected at each site.

There are a total of five oyster sites and seven mussel sites monitored (Figure 1-1 and Table 1-1). No sites contain both mussels and oysters; however, some mussel and oyster sites in the Manukau harbour are within a few kilometres of each other.

Table 1-1 Site names and coordinates in the SCMP

Site Number	Site Name	Sentinel Shellfish	Easting	Northing
43914	Pahurehure	Oysters	1770911	5896630
44161	Cornwallis	Oysters	1742800	5903176
44164	Mill Bay	Oysters	1743159	5904578
1043823	Hingaia	Oysters	1769516	5893827
43911	Grannys Bay	Oysters	1756183	5911301
43900	Papakura Channel	Mussels	1753405	5900096
43912	Mangere Bridge	Mussels	1757583	5911004
43913	Weymouth	Mussels	1764909	5897819
7718	Illiomama	Mussels	1768255	5924625
7898	Upper Harbour	Mussels	1748951	5927685
8237	Upper Tamaki	Mussels	1765577	5913819
7717	Chelsea	Mussels	1754059	5923396
16	Pre-deployment Mussels	Mussels	n/a	n/a

Figure 1-1 Map of oyster and mussel sites in the SCMP

As shellfish are filter feeders, they process large volume of water and can bioaccumulate certain contaminants, such as heavy metals, organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) in their tissues. These contaminants can be difficult to measure directly in the water column due to low concentrations and high temporal variability. Water column measurements also don't provide an indication of the bioavailability of contaminants. As such, the SCMP uses contaminant levels in oyster and mussel tissue to provide a time integrated indirect measure of ambient seawater quality.

Data from the SCMP is used to provide information for State of Environment (SoE) monitoring, as required under section 35 of the Resource Management Act (RMA). Uses of the monitoring data also include; stormwater quality management; resource consenting; policy development, and public education. The SCMP is one of the 4 marine monitoring programmes used to assess the SoE, the others being the Saline Water Quality Programme, the Regional Sediment Chemistry Monitoring Programme and the Benthic Ecology Programme.

A previous review and audit of the SCMP was undertaken in 2007 (Mills 2007). This review strongly recommended continuing with the SCMP for at least another 5 years. Auckland Council has since revisited these recommendations and called for a subsequent review. AC has requested a status and trends analysis (this report) and a separate review of the SCMP (a second following report) (Stewart*, et al.* 2013).

The National Institute of Water & Atmospheric Research Ltd (NIWA) has been contracted by Auckland Council to provide status and trends analyses on data provided by AC for both mussels and oysters. These analyses and the section in this report that addresses each are:

1. Presentation and interpretation of status and trends analysis and results, including suitable statistical analyses (both univariate and multivariate) and conclusions about trends through time, including but not limited to:
    a) Contaminant data trends over time at regional, harbour and individual site level for both metals and organics and for dry weight and lipid normalised ‘Total’ and ‘limited’ suites for organics (**section 5.3**).
    b) Condition data trends over time – at regional, harbour and individual site level (**section 5.6**).
    c) Comparison of contaminant data trends with condition data trends (**section 5.7**).
    d) Comparison of post deployment contaminant and condition levels with pre-deployment contaminant and condition levels for mussels (**section 5.1**).
    e) Comparisons among sites within each of the mussel and oyster programmes (**section 4.1**) and correlations between contaminants for individual metals and organic contaminant group totals (**section 4.2**).
    f) Comparisons between mussel and oyster results in the Manukau e.g., Mangere Bridge mussels vs. Grannys Bay oysters, Weymouth mussels

vs. Pahurehure and Hingaia oysters and Papakura Channel mussels vs. Cornwallis / Mill bay oysters (**section 6.1 and 6.0**).

g) Exploration of spatial variation in contaminant and condition levels and links to current land use and changes in land use activity over time. This section to include plots comparing sites as per Appendix 2 of WR131 or similar (**section 4.5**).

h) Assessment of any relationship between climate cycles and shellfish contaminant and condition levels (**section 6.2**).

i) Comparison of results against other key regional and international shellfish contaminant monitoring programmes and databases (including Watercare results for Mangere WWTP, if available) (**section 6.3**).

j) Comparison of results against national and international standards or guidelines (environmental as well as human health). The report should detail any national and international standards and guidelines that can be used for comparison. Wet weight comparisons with NZFSA standards (wet weight data is available from 2005) to also be included in this section (**section 6.4**).

2. Comparison of shellfish contaminant status and trend results with sediment contaminant status and trend results from nearby sites. Comparison of shellfish contaminant status and trend results with nearby benthic health model and saline water quality site status and trends results (**section 6.5**).

3. Review and report the QA data and its implications for data variability, reliability and trend detection. Assess the on-going adequacy of the QA information to determine data variability and reliability and make any suggestions for improvement. Include reporting of QA results for blanks, within and between batch replicates, certified reference materials and spiked / surrogate data recovery (**section 3.0**).

4. Assess any consequences for data analysis from the changeover in labs between NIWA and AsureQuality in 2009 e.g., changes in data variability, QA data, Detection Limits, compounds analysed (and subsequent 'Totals') (**section 3.0**).

5. Descriptions of the various contaminants and their sources and impacts as per Appendix A of TP332 (**Appendix A**).

6. List of contaminants measured over time and any changes in lab providers as per Appendix B and D of TP332 (**Appendix B** and **Appendix C**).

2.0 Methodology

2.1 Data sources

2.1.1 Contaminant data

Mussel and oyster contaminant data were received in Excel format from AC. Data was used ‘as is’ with the exception of 1999 oyster metals data where several data points below detection for chromium and for lead were provided as 0. When data was 0, we substituted it with a less than value which was lowest of the replicates for that site. If all data for that site was 0, we used the detection limit for other sites.

2.1.2 Totals / suites

Limited suites and extended suites were created from the data by summing each appropriate congener. Most limited and extended suites are defined in Appendix B and Appendix C, with the exception of minor organic contaminant suites used for current status analyses only: chlorobenzenes (sum of hexachlorobenzene and pentachlorobenzene); endosulfans (sum of endosulfans A&B and endosulfan sulfate) and other PAHs (sum of fluorine; acenaphthylene; acenaphthene; 2-methylphenanthrene). Where a congener was below detection limit, this value was substituted with zero. It is recognised that this method has limitations and may result in some under-estimation of the true value. Alternative methods were explored such as substitution with the detection limit and with one-half the detection limit; and using the Kaplan-Meier (KM) statistical procedure to generate a sum.

For most contaminant suites, the sums are dominated by a few congeners at higher concentration and the method used made little difference to the overall sum. For some samples and suites, the detection limits were the same for all congeners in which case the KM procedure could not be used (Helsel 2012).

2.1.3 Other data

All data were received from AC in Excel format. Condition data and QA data were received on 3rd July 2012. Saline water quality data were received on 12th July 2012 and sediment chemistry data were received on 13th July 2012. All data were used ‘as is’.

2.2 Concordance correlation coefficient

Throughout the history of the SCMP, different analytical laboratory providers have been used, which are summarised in Appendix B (for mussels) and Appendix C (for oysters).

There is considerable literature on establishing equivalence between methods on the basis of their ability to enumerate samples. Various measures have been used therein, all with some shortcomings. The "concordance correlation coefficient" was first proposed by Lin (1989) for assessment of concordance in continuous data. It represents a breakthrough in assessing agreement between alternative methods for continuous data in that it appears to avoid all the

shortcomings associated with the panoply of usual procedures (Pearson correlation coefficient *r*, paired t-tests, least squares analysis for slope and intercept, coefficient of variation, intraclass correlation coefficient). The concordance correlation coefficient measures departures from the 1:1 line that would occur were the two methods to be in perfect agreement. In more technical language it is defined as 1 – [Expected squared perpendicular deviation from the 1:1 line]/[Expected squared perpendicular deviation from the 1:1 line when the two variables are uncorrelated]. It is robust on as few as 10 pairs of data (Lin 1989). It is important to note that there are typographical errors in Lin's original paper. Corrections have since been published (Lin 2000). Further details are given in McBride (2005).

A calculator for measuring Lin's sample concordance correlation coefficients (ρ_c) has been developed by NIWA for the assessment of continuous data (NIWA 2012a). Within this report, Lin's sample concordance correlation coefficients were calculated for the six key metals to establish agreement between two different digestion methods used by Watercare Laboratory Services (section 3.1.3) and for selected organic contaminant QA data to compare data generated by NIWA and AsureQuality laboratories (section 3.2.3).

2.3 Current status and between site differences

2.3.1 Data used

For the analysis of current status and between site differences, contaminant concentrations in the shellfish, and shellfish condition were investigated based on data from 2009 to 2011. Whilst the most recent year's data (2011) could have been used on its own, it was considered that using three years of data would allow for any outliers to be smoothed and provide a better estimate of the overall status. Data from the Mill Bay oyster site were not included in the status comparisons as there were data only from 2009 for this site. There were no changes in the analytical laboratory providers during this time period (2009-2011) and no major changes in the detection limits for contaminants.

The contaminants included in the status analysis include the six individual metals: arsenic, cadmium, chromium, copper, lead and zinc, on a dry weight basis. At all sites, all metals were measured at concentrations above the detection limits from 2009 to 2011, simplifying the graphical and statistical comparisons.

Lipid normalised concentrations of dieldrin, lindane and the 'full' or 'extended' suites (Appendix B and Appendix C) for dichlorodiphenyltrichloroethane (DDT) and breakdown products, chlordanes, endosulfans, Polycyclic Aromatic Hydrocarbons (PAHs) and Polychlorinated Biphenyls (PCBs) were also used for the current status analysis. Dry weight concentrations of all organic contaminants (including those above plus endosulfans, mirex, aldrin, endrins, chlorobenzenes and other PAHs) were also included for comparison. Extended suites were used for the status analysis (cf. limited suites used for trends analysis) as the same set of contaminants were analysed in samples and years from 2009 to 2011. Lipid normalised data was calculated as (dry weight concentration / % lipid) x 100.

For oysters, metals and all organics except lindane and endosulfans were consistently above the detection limit. For mussels there were several samples where concentrations of individual DDT, PAH, and PCB congeners were below detection. The suites were produced by summing all compounds above detection, as undertaken for the trends analysis.

For mussels, the pre-deployment contaminant concentrations were not subtracted as this resulted in many negative values for cadmium, lead and zinc, and for copper at some sites. The concentrations of contaminants in the mussels pre-deployment were considered in the status analysis as an additional 'site'.

2.3.2 Site quality ranking

Sites were ranked relative to both contaminants and condition. Mussel and oyster sites were ranked separately.

For contaminant ranking, the following contaminants were given equal rating: As; Cd; Cr; Cu; Pb; Zn; DDT; chlordanes; dieldrin; lindane; PAHs; PCBs. Each was given a ranking from 1 (lowest concentration) up to 8 (seven mussel deployment sites plus one pre-deployment site) or 4 (oyster sites). The average ranking across all contaminants was calculated and used to rank the quality of each site.

Sites were also ranked by condition index; calculated as dry tissue weight (g) / dry shell weight (g).

2.3.3 Box plots

Box plots were used to graphically illustrate the differences in concentrations of each contaminant by site. Box plots were produced in the statistical program R (Version 2.15.0). Shaded bars for the approximate confidence interval about the median were used to indicate significant differences. Following standard practice these confidence intervals were calculated as $\pm 1.58 \times IQR/\sqrt{n}$, where IQR is the Inter Quartile Range and n is the number of data (sometimes called the "sample size").

2.3.4 Multivariate summary of current status

Multivariate techniques were also used to summarise differences between sites, based on the combined influence of contaminants and contaminants together with condition. The data used for this multivariate analysis was as described above (section 2.3.1) with the exception that lindane and endosulfans were not included due to the large number of samples below detection. Condition index (as calculated by Coastal Research and Consulting Ltd.) was also included as a variable. Median concentrations for each site for the period 2009-2011 were generated.

Multivariate analysis was undertaken in PRIMER (Version 6.1.5) after normalising all variables, and a resemblance matrix was constructed based on Euclidean distances. Nonmetric multi-dimensional scaling (NMDS) ordination was used to most effectively display site clusters, followed by Principal Component Analysis (PCA) to demonstrate which variables were most important in differentiating the sites.

2.3.5 Land use data

Land use data was obtained from the Land Cover Database version 3 (LCDB3), which is a thematic classification of 33 land cover and land use classes. The polygon features contain a code and boundary representing the land cover type for the period summer 1996/97, summer 2001/02 and summer 2008/09 (Landcare Research 2012). Data for summer 2008/09 has been used in this report.

2.4 Trend analysis

2.4.1 Data used

The contaminants used for trend analysis were those that had been analysed consistently over the period of monitoring (see Appendix B and Appendix C). This included the six individual metals: arsenic, cadmium, chromium, copper, lead and zinc, on a dry weight basis. For the metals, where samples measured below the detection limit, this value was substituted with half the limit of detection (except for the analyses described in section 2.4.4). The organics included the individual compounds of dieldrin and lindane and the suites for DDT, chlordanes, PAHs and PCBs. For the suites of organic contaminants, these were based on sums of each parameter / congener in the suite, substituting zero where data was below the detection limit. For dieldrin, all data was above the detection limit. For lindane, there were many samples below the detection limits, and these detection limits changed substantially over the period of monitoring. Therefore only the method explained in section 2.4.4 was used for lindane.

2.4.2 Trend analysis

Trend analysis was applied to the dataset using Time Trends, a NIWA developed statistical tool, available on the NIWA website (NIWA 2012b). More specifically, trend analysis was applied to assess changes in condition of mussels and oysters, metal concentrations in oysters and mussels and organic contaminants in oysters and mussels. Results are presented for both dry weight and lipid normalised trends for oysters and mussels. For oysters, data collection commenced in 1987 so trends are presented for three time periods: 1987-2011 (full time period), 1999-2011 (for comparison with mussels data) and 2006-2011 (for comparison with condition data). For mussels, annual data collection commenced in 1999, so trends have been calculated for two time periods: 1999-2011 (full time period) and 2006-2011 (for comparison with condition data). Trends in oyster and mussel condition have been calculated for the period 2006-2011. Some condition data were available from 2000-2003 however as there were differences in the methodology used for the shell dry weight this was not used. No condition data were available for 2005.

For mussels, trend analyses were undertaken on pre-deployment subtracted data and raw data. A comparison of both is presented in section 5.2, with raw data presented in the trends section (section 5.3).There was no pre-deployment data for 1999 so pre-deployment data for 2000 was used in this case.

As in previous trend analysis work, and following Smith et al. (1996), the non-parametric Seasonal Kendall Slope Estimator (SKSE) was used to represent the magnitude and direction of trends in

data. Values of the SKSE were normalised by dividing through by the raw data median to give the relative SKSE (RSKSE), allowing for direct comparison between sites measured as % change per year. The RSKSE may be thought of as an index of relative rate of change. A positive RSKSE value indicates an overall increasing trend, while a negative RSKSE value indicates an overall decreasing trend. The SKSE calculations were accompanied by a Seasonal Kendall test (performed within TimeTrends) of the null hypothesis that there is no monotonic trend. If the associated P-value is small (i.e., $P < 0.05$), the null hypothesis can be rejected (i.e., the observed trend, either upwards or downwards, is most unlikely to have arisen by chance).

2.4.3 Categorisation of trends

Scarsbrook (2006) recognised that statistical significance of a trend (particularly with a large dataset of up to 228 (19 x 12) data points for each combination of site and variable in the National River Water Quality Network (NRWQN) over the 1989-2007 period) does not necessarily imply a 'meaningful' trend, i.e., one that is likely to be relevant in a management sense. We have followed Scarsbrook (2006) in denoting a 'meaningful' trend as one for which the RSKSE is statistically significant and has an absolute magnitude > 1% $year^{-1}$. Scarsbrook (2006) recognised that the choice of 1% per year as the "meaningful" threshold is arbitrary. However, at this stage we do not see any basis for an alternative approach and a 1% change per annum corresponds to 10% change per decade – a degree of change that is likely to become noticeable or detectable within a human lifespan. Trends were accordingly categorised as follows:

- **No significant change** – the null hypothesis for the Seasonal Kendall test **was not** rejected (i.e., $P > 0.05$). In the results section, non-significant trends are shown with an arrow indicating the direction of change (→ ↑ ↓).
- **Significant increase/decrease** – the null hypothesis for the Seasonal Kendall test **was** rejected (i.e., $P < 0.05$) and the RSKSE value was less than 1% per year (between zero and 1%). None of the trends calculated for this dataset fell into this category.
- **'Meaningful' increase/decrease** – the null hypothesis for the Seasonal Kendall test was rejected (i.e., $P < 0.05$) **and** the magnitude of the trend (SKSE) was greater than one percent per annum of the raw data median (i.e., the RSKSE value was greater than 1% per year). All of the significant trends for this dataset fell into this category. These significant and meaningful trends are indicated in the results section by arrows (↑ ↓), and are highlighted either in red (increasing) or blue (decreasing).

Trends can be detected in short-term data which are in conflict to longer-term data. Generally, the longer the time for the trend to be established the more reliable the trend will be as there are more data points to establish this relationship. Shorter term trends can provide information on more recent changes in contaminant concentrations and/or condition that are potentially lost in the longer term trend period; for example, recent land-use changes that may release previously unavailable contaminants into the environment. Therefore, it is important to examine the results of all trend time periods both statistically (as above) and graphically, by examining plots of data.

2.4.4 Trends using methods for censored data

An alternative method to the trend analysis described above was investigated for individual metals and organic compounds where there were a large number of censored data points (i.e. data below the detection limit). This included arsenic, cadmium, chromium, lead and lindane in both oysters and mussels. For these contaminants, many samples contained concentrations below the detection limits, particularly in the early years of monitoring. Furthermore, the detection limits varied for each sample, and have changed considerably over time, generally downwards as laboratory processes have changed and improved. For these reasons, trends based on substitution with half the limit of detection may not be suitable and an alternative approach was investigated.

The method used for the censored data is known as the Akritas-Theil-Sen (ATS) nonparametric regression method. The ATS slope is halfway between the maximum and minimum slopes that produce a zero value for Kendall's tau (the correlation coefficient), using both the uncensored and censored data (Helsel 2012). As this is a nonparametric test, there are no assumptions about the distribution of the data. This statistical test was undertaken in R version 2.15.0 using the NADA package (Helsel 2012). A linear slope (ATS slope) is calculated, which can be interpreted as the change in concentration per year. A P-value is also calculated to indicate whether this slope is statistically significant.

2.4.5 Multivariate analysis of trends

Median concentrations for each site/year were used for the multivariate analysis. As there were many censored data points for some metals, an alternative to substitution with half the detection limit was investigated for calculating the median concentration for each year. The median concentration was calculated using Kaplan-Meier estimates, which account for censored data by using rank data to produce a survival function plot from which the median is calculated. This was undertaken using the NADA package in R version 2.15.0 (see Helsel 2012 for more details). For most years, this resulted in no change to the median concentration; however there were still many years when a median could not be calculated using this method as more than 50% of the data were censored and the smaller observation was censored (see Helsel 2012). As this approach could not be used, censored data were substituted with a value of half the detection limit and median concentrations then calculated in the usual fashion.

The contaminants included were those that had been analysed consistently over the period of monitoring and had been consistently measured above detection limits. This included the six individual metals (arsenic, cadmium, chromium, copper, lead and zinc), dieldrin and the 'limited' suites for DDT, chlordanes, PAHs and PCBs. Limited suites were used to ensure that any trends in the data were not due to changes in the number of individual compounds / congeners measured. As with the data used for trend analysis described in section 2.4.1, the suites were produced by summing all compounds above detection. Lindane was not included in this analysis as the laboratory change resulted in a major decrease in the detection limits and there were a large number of samples below detection in the early years of the programme. Dry weight data was used

for metals and lipid normalised dry weight data used for organics. For mussels, raw data was used rather than pre-deployment subtracted data, as explained in section 5.2.

Median concentrations for each site and year of monitoring were then generated. Arsenic concentrations in the first year of sampling (1987) were exceptionally low compared to following years. The reason for this could not be assessed from the data, but as errors could not be ruled out, all data for 1987 were deleted from the analysis these data were deleted. Data from 1999 were also deleted as the concentrations of cadmium in this year were exceptionally high and errors in the dataset could not be ruled out as the cause of this.

Multivariate distance-based linear models were used to analyse the trends over time, i.e., the relationship between the multivariate contaminant data and the predictor variables of year of sampling and year grouped into approximately 5-yearly groups. DistLM (PERMANOVA+ (Version 1.0.3) for PRIMER) was used with a backwards elimination procedure for the predictor variables and AIC (Akaike's Information Criterion) as the selection criteria.

2.4.6 Comparison of condition and contaminant trends

The RSKSE values generated in the trend analysis described in Section 2.4.2 were used to assess whether trends in contaminants and condition were related. The organic contaminant data were analysed as lipid normalised and dry weight and the limited suites were used as these suites were less affected by changes over time due to changes in analytical methods. For the mussels, the contaminant trend data used was without subtraction of the pre-deployment contaminant concentrations as there were missing values in the trends with this subtraction. As condition data was only available from 2006 to 2011, trends in contaminant concentrations for the same time period were used in this comparison.

Principal component analysis (PCA) was used to summarise similarities and differences between site status based on (a) trends in contaminants and (b) trends in both contaminants and condition. Congruency between condition and contaminant trends were then assessed using the correlation coefficient Kendall's tau, based on the separate resemblance matrices for condition and contaminant trends.

2.5 Comparison of mussels and oyster data in the Manukau Harbour

As for the differences in status between sites, box plots were used to graphically illustrate the differences in concentrations of each contaminant by site. Statistical differences in each contaminant between oyster and mussel sites in the Manukau Harbour were assessed using a two-tailed Wilcoxon rank sum test, which is a non-parametric test similar to a t-test. As a non-parametric test, this makes no assumptions about the distribution of the data and so makes inferences about differences in medians, rather than differences in means (as a t-test does). These tests were undertaken in the statistical program R (Version 2.15.0). A P-value of less than 0.05 was considered statistically significant.

Comparisons were also made between nearby sites in the number and direction of trends.

2.6 Comparison with climate and weather

2.6.1 Data used

Data for the Southern Oscillation Index (SOI) and Z1 (the pressure difference between Auckland and Christchurch) were obtained on a monthly basis from 1987 to 2011. SOI data was taken from monthly mean pressures at Tahiti and Darwin, as available currently from the Australian Bureau of Meteorology (Australian Bureau of Meteorology 2012). Z1 was calculated from monthly mean sea level pressure data at Auckland and Christchurch taken from NIWA's CliFlo database. Mullan (1995) describes these climate variables in greater detail.

Rainfall, wind and temperature data was sourced from NIWA's CliFlo database. For the oyster sites and the mussel sites in the Manukau Harbour, Tamaki Estuary and for Illiomama, rainfall, wind speed and direction and air temperature data from the Auckland Airport site were used. For Chelsea and the Upper Harbour sites, wind and temperature data from the North Shore (at Takapuna) and rainfall data from the Henderson site (at River Park) was used.

The SOI, Z1 and temperature values were averaged for the approximately three-month period of mussel deployment and for a three-month period prior to oyster collection each year (typically September to November). Rainfall was summed for the same period. To calculate the wind exposure, the fetch distance in each of 8 compass sectors around each monitoring site was measured. The time the wind spent in each sector (based on wind direction data from either Auckland Airport or North Shore) was multiplied by the fetch and wind speed for each site. This was summed for the three-month period of deployment / prior to collection.

The contaminants included in this analysis were the same contaminants as used in the multivariate trend analysis. This included the six individual metals: arsenic, cadmium, chromium, copper, lead and zinc, on a dry weight basis. For the metals, where samples measured below the detection limit, this value was substituted with half the limit of detection. The organics included the individual compound dieldrin and the limited suites for DDT, chlordanes, PAHs and PCBs. For the suites of organic contaminants, these were based on sums of each parameter / congener in the suite, substituting zero where data was below the detection limit. For dieldrin, all data was above the detection limit. Lindane was not included as there were many samples below the detection limits, and these detection limits changed substantially over the period of monitoring. Dry weight data was used for metals and lipid normalised dry weight data used for organics. For mussels, raw data was used rather than pre-deployment subtracted data as explained in section 5.2. Median concentrations for each site for each year of monitoring were then generated.

2.6.2 Statistical analysis

Correlations between the climate variables and contaminants (individual contaminants or contaminant suites) were investigated using scatter plot matrices and calculation of correlation coefficients using the statistical program R (Version 2.15.0). Correlation coefficients indicate the strength of the relationship, with a value close to 1 being strong and a value close to zero being weak. The sign of the correlation coefficient (positive or negative) indicates the direction of the relationship.

2.7 Comparison of status data with relevant guidelines

Average concentrations were calculated from 2009-2011. As a conservative approach, all data below detection limit were substituted with detection limit for that sample. Dry weight concentrations were converted to wet weight by multiplying by dry weight/wet weight correction factor for each sample. Wet weight concentrations were averaged at each site over the 3-year period.

Metal concentrations were compared with the current FSANZ Standard 1.4.1 (FSANZ 2011), where available. Standard 1.4.1 only includes arsenic, cadmium and lead. Total arsenic (As_{tot}) concentrations were converted to inorganic arsenic (As_i) for direct comparison with Standard 1.4.1. Without arsenic speciation information, it is necessary to estimate the inorganic arsenic proportion. Schoof and Yager (2007) suggested that for marine and estuarine fish, the toxic As_i proportion is only 2-3% of the total arsenic concentration. Schoof and Yager (2007) stated that there was "little correlation between As_{tot} concentrations and As_i concentrations, however, when only As_{tot} data are available to assess health risks from arsenic in seafood, these data could support conservative, upper end estimates of the percent of As_{tot} likely to be As_i". However, without arsenic speciation studies to determine accurate As_i concentrations, a conservative approach is usually more prudent and has been used in this case.

Separate sets of organic suites were created to those used for trends analysis to enable comparisons with FSANZ Standards 1.4.1 (FSANZ 2012) and 1.4.2 (FSANZ 2012):

- Aldrin and dieldrin;
- BHC (alpha, beta & delta-HCH);
- Chlordane (cis and trans-chlordane);
- DDT (p,p'-DDT, o,p'-DDT,p,p'-DDD, p,p'-DDE);
- HCB (hexachlorobenzene);
- Heptachlor (heptachlor and heptachlor epoxide);
- Lindane (gamma-HCH);
- PCBs (Sum of all PCBs measured).

Furthermore, the European Commission has set maximum concentrations for certain contaminants in foodstuffs, which includes the metals cadmium and lead and the carcinogenic PAH, benzo[a]pyrene (European Commission 2006).

2.8 Comparison of contaminant data with other SCM programmes

2.8.1 SCMP data

For comparisons with NS&T Mussel Watch and French RNO programme data, median concentrations were calculated for mussels and oysters at each site in the SCMP, using dry weight data from 2009-2011. Any concentration below detection limit was set at the DL. Median,

maximum and minimum concentrations for both species across the whole catchment were also calculated.

For Mangere Waste Water Treatment Plant (WWTP) comparisons, mean data (plus 1 standard deviation) was calculated based on five replicates from 1995 to 2007. All data was dry weight µg/kg (organics) and mg/kg (metals). All contaminant data less than detection were set to the limit of detection. One replicate from Cornwallis (1998) was not included in mean data due to large data outliers.

2.8.2 NS&T Mussel Watch

The US National Status & Trends (NS&T) 2008 Mussel Watch report (Kimbrough*, et al.* 2008) includes the six heavy metals, As, Cd, Cr, Cu, Pb and Zn.

The report also includes the following organic suites:

- PCBs (Sum of 18 PCBs) PCB8/5, PCB18, PCB28, PCB44, PCB52, PCB66, PCB101/90, PCB105, PCB118, PCB128, PCB138, PCB153/132/168, PCB170/190, PCB180, PCB187, PCB195/208, PCB206, PCB209.
- DDT (Sum of 6 compounds) 2,4'-DDD; 2,4'-DDE; 2,4'-DDT; 4,4'-DDD; 4,4'-DDE; 4,4'-DDT.
- Chlordane (Sum of 4 compounds) Alpha-Chlordane, Heptachlor, Heptachlor-Epoxide, Trans-Nonachlor.
- Dieldrin (Sum of 2 compounds) Aldrin, Dieldrin.
- PAHs (Sum of 19 parent PAH compounds plus 19 groups of alkylated PAHs)

The NS&T suites of organic contaminants are consistent with those provided by Auckland Council from the SCMP, with the exception of PAHs. The Auckland SCMP suite of PAHs includes only 12 (cf. 38 for NS&T). However, these differences are possibly irrelevant as Auckland PAH totals are extremely low compared with those in the NS&T Mussel Watch report (see section 6.3).

NS&T status data was derived from the most recent published data (2004-2005) and were assigned to a concentration range: high, medium or low.

NS&T trends analyses were undertaken on the full time-scale of data (1986-2005). Spearman's rank correlation was used to evaluate whether concentrations co-varied predictably as a function of time. The Spearman's rank correlation procedure is a nonparametric technique that is free of assumptions about concentrations being normally distributed with a common variance about sites. The variables used for the Spearman's test were year and site concentration rank median (n = 10). Concentration was standardized by ranking to allow for inter-species comparison. The Spearman's rank correlation statistical test was used to evaluate individual contaminants at the site, regional and national scales.

Results are presented as decreasing (↓), increasing (↑) or exhibiting no trend (→).

2.8.3 Réseau National d'Observation (RNO)

The French Réseau National d'Observation (RNO) de la Qualité du Milieu Marin programme has provided monitoring data from 1979. Reports are in French so Google Translate was used to translate to English where appropriate.

A 2006 report provided status data for the heavy metals Cd, Cr, Cu, Pb and Zn, plus the organics DDT, lindane, PCB153 and fluoranthene (RNO 2006). RNO provided median dry weight data from 2000 to 2004 - except for Cr (2001-2004) -for mussels in the Manche-Atlantique region (west and north of France) and Mediterranean (Mediterranean sea) and oysters in the Manche-Atlantique region.

Trends data was contained in a 2000 report (RNO 2000). The period covered by this study is from 1979 to 1999 for the metals, from 1979 to 1997 for DDT, from 1992 to 1997 for PCB153, from 1982 to 1997 for lindane, and from 1994 to 1998 for PAHs.

2.8.4 Mangere Waste Water Treatment Plant (WWTP)

Watercare's Harbour Environmental Monitoring Programme (HEMP) (and its precursor) has collected data on the environmental quality of Manukau Harbour since 1995. It provides a near continuous monitoring dataset, which spans the period when the Mangere WWTP underwent a major upgrade during the late 1990s - early 2000s. This upgrade culminated in the decommissioning of four large oxidation ponds and their reconnection with Manukau Harbour (Kelly 2010).

Most recent contaminant data from five oyster sites around Manukau Harbour - Airport, Blockhouse Bay, Cape Horn, Mangere and Puketutu Light - between 1995 and 2007, were compared with data from two oyster sites in the SCMP - Cornwallis and Grannys Bay. Contaminants compared were cadmium, copper, lead, zinc, total DDT, dieldrin and chlordane (technical equivalent). Equivalent contaminants from the SCMP were compiled for the same time frame, with extended suites of DDT and chlordane used for comparisons with Mangere WWTP data.

3.0 QA Assessment

3.1 Metal contaminants

3.1.1 Background

Metals have been analysed by Watercare Laboratory Services Ltd since 2005. No QA data for metals is available prior to 2005, so the consequences of a change in analytical provider throughout the lifetime of the programme cannot be assessed for metals by assessing QA data (see Appendix B and Appendix C for chronological list of analytical providers for mussels and oysters, respectively).

Robyn Abernathy, Senior Technician at Watercare Laboratory Services Ltd - with shared responsibility for the AC shellfish programme metals analysis - was contacted on Monday 23rd July 2012 to discuss laboratory procedures and aspects of QA/QC. Steve Money, Department Head of Inorganic Chemistry at Watercare Services Ltd - with chief responsibility for the AC shellfish programme metals analysis - was contacted on Monday 14th August 2012 to discuss laboratory procedures and aspects of QA/QC. Additional data on QA/QC samples was provided by Steve Money on 24th August 2012 to assist with this review.

Watercare Services Ltd are an IANZ accredited Laboratory and received accreditation for the acid digestion procedure and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) metals analyses methodology in 2011. However, there was a change to the digestion procedure used in 2011 in order to provide better recoveries for selected metals (e.g., mercury and tin) in shellfish tissue. Prior to 2011 a sub-sample of wet homogenised shellfish tissue was digested with boiling nitric acid prior to analysis by ICP-MS. The digestion procedure currently utilizes a mixture of nitric and hydrochloric acid followed by the addition of hydrogen peroxide. The method change was adopted to provide a more robust and efficient method for routine analyses of metals in shellfish tissue with improved recoveries for a larger range of metals. This latter method has IANZ accreditation. In 2010 a cross-comparison of selected samples was undertaken in order to assess any differences which might result from a change in digestion methodology. Both oyster (eight samples) and mussel (fourteen samples) tissue from the AC shellfish monitoring programme and two QA samples (NIST SRM 1566b oyster tissue and in-house wet composite of mussel/oyster tissue) were assessed.

3.1.2 QA procedures

A range of QA performance measures are employed to ensure accuracy for the analysis of metals.

a) The ICP-MS is calibrated using certified elemental standards prior to each analysis run. Immediately following calibration, the calibration is verified at two different concentrations for each element using second-source certified elemental standards. These standards are re-analysed at intervals throughout and at the end of the run to ensure the ICP-MS instrument calibration is still within specified limits for quantitation. This is a critical step in the QA procedure as instrument drift can result

in higher analytical variability. Acceptance criteria for recovery of these standards are currently ±15% of the certified value.

b) Blanks are regularly analysed (1 per batch) to check for the presence of any metal contamination. All blanks must be low enough (because they are often used to set detection limits) to ensure all measured data for the batch is well above the detection limits before releasing data. Blank data for metals must be below 2.5X the MDL or 10% of the lowest sample result, whichever is greater, in accordance with USEPA Method 200.8.

c) In-house control samples of archived frozen oyster or frozen mussel tissue homogenate are analysed with every batch of shellfish to check between-batch precision.

d) Certified reference materials (CRM) are analysed with each batch of shellfish. They include the National Institute of Standards and Technology (NIST) SRM 1566b (freeze-dried oyster tissue), SRM 2976 (freeze-dried mussel tissue) and NIST SRM DORM-3 (Fish Protein). The latter CRM is used principally to check on levels of chromium which is not certified in either SRM 1566b or SRM 2976. These certified reference standards contain levels of metal contaminants which are comparable with levels observed in the AC shellfish monitoring programme. Data is only released if levels of metal contaminants lie within 85-115% of the certified concentrations (i.e., accuracy of ±15%).

The QA procedures are comprehensive and provide sufficient information to measure analytical performance for the AC shellfish monitoring programme. The QA data for assessing accuracy and precision for within-batch and between-batch should be provided with the dataset for independent review.

All data is checked and created electronically and is held within the laboratory management system (LIMS). All data is checked using established procedures and must pass acceptance criteria before being released.

Minimum detection limits (MDLs) are determined by Watercare Services Ltd according to USEPA 40 CFR Part 136 B in which either real samples or CRMs containing the analytes of interest, were digested and analysed at two-fold and successive five-fold dilutions. In this approach a valid detection limit was determined for each element from the results. The calculated detection limits were compared to historical method blanks where available. If the blank value exceeded the MDL, the detection limit was adjusted upwards to a level where the method blank would rarely exceed it. The final “MDL” determined is effectively a reporting limit rather than a true MDL (Table 3-1).

A review of AC shellfish metals data for 2011 for both oysters and mussels has shown that minimum concentrations reported are typically more than ten times greater than the MDLs for most metals except copper. Mussels typically have lower levels of copper in their tissue than oysters. The MDL for copper was 2 mg/kg and this is relatively close to levels observed in mussels from most sites except Tamaki (12 mg/kg). The minimum result for chromium in the pre-deployment sample (0.11 mg/kg) was also only 2-3 times above the detection limit (0.04 mg/kg) for this metal, hence the result is likely to be more variable. It should be noted that chromium is a difficult element

to measure precisely in shellfish, and Watercare Services Ltd have indicated that results are highly variable. This is also the reason why chromium is not certified or why a guideline value is not available for NIST 1566b and 2976 CRMs.

Table 3-1 Analytical method detection limits (MDLs) for metals in mussels and oysters from 2011 monitoring data.

Element	MDL (mg/kg)
Arsenic	0.04
Cadmium	0.006
Chromium	0.04
Copper	2
Lead	0.02
Zinc	5

3.1.3 Variability between digestion methods

The concordance correlation coefficient was used to assess the effect of different digestion methods for metals. It measures departures from the 1:1 line that would occur were the two methods to be in perfect agreement (see section 2.2 for further explanation).

There is as yet no literature giving a descriptive scale for the degree of agreement. Accordingly it is *tentatively* suggested that the scales in Table 3-2 be used for values of the coefficient in given ranges.

Table 3-2 Lin's sample concordance correlation coefficient scale used for the descriptive degree of agreement between methods(NIWA 2012a).

Strength-of-agreement	Concordance coefficient
Almost perfect	>0.99
Substantial	>0.95–0.99
Moderate	0.90–0.95
Poor	<0.90

The Lin's sample concordance correlation coefficients were calculated for all metals and selected metals for two replicate AC oyster samples from four sites, NIST SRM 1566b oyster tissue and in-house wet QA composite of mussel/oyster tissue (Table 4-3), and two replicate AC mussel samples from seven sites (2010 sampling) (Table 3-4). Concordance correlation coefficients were calculated for all metals and selected metals to ensure there was no bias from incorporating higher level concentration data (> 12 mg/kg).

The majority of data were > 0.99 indicating excellent agreement between samples using the different digestion methods. The in-house wet QA composite of mussel/oyster tissue and two of the AC mussel samples from 2010 resulted in concordance correlation coefficients >0.98 indicating substantial agreement for the different digestion methods. One replicate of mussel tissue from

Chelsea had a concordance correlation coefficient of 0.97, which is still showing substantially good agreement (Table 3-4).

Table 3-3 Lin's concordance correlation coefficients calculated for heavy metal data for selected oyster replicates and QA samples from 2010 for comparison of different digestion procedures

Sample Information	Concordance coefficient (As, Cd, Cr, Pb, Cu, Zn)	Concordance coefficient (As, Cd, Cr, Pb)
Grannys Bay Rep 1	>0.99	>0.99
Grannys Bay Rep 2	>0.99	>0.99
Cornwallis Rep 1	>0.99	>0.99
Cornwallis Rep 2	>0.99	0.99
Pahurehure Rep 1	>0.99	>0.99
Pahurehure Rep 2	>0.99	>0.99
Hingaia Rep 1	>0.99	>0.99
Hingaia Rep 2	>0.99	>0.99
NIST SRM 1556a freeze-dried oyster	>0.99	>0.99
In-House wet composite oyster/mussel	0.98	0.99

Concordance correlation coefficients were calculated for all metals and selected metals to ensure there was no bias from incorporating higher level concentration data (> 12 mg/kg).

Table 3-4 Lin's concordance correlation coefficients calculated for heavy metal data for selected mussel replicates from 2010 for comparison of different digestion procedures.

Sample Information	Concordance coefficient (As, Cd, Cr, Pb, Cu, Zn)	Concordance coefficient (As, Cd, Cr, Pb)
Tamaki Rep 1	>0.99	0.99
Tamaki Rep 2	0.99	0.98
Chelsea Rep 1	>0.99	>0.99
Chelsea Rep 2	>0.99	0.97
Upper Harbour Rep 1	>0.99	>0.99
Upper Harbour Rep 2	0.99	0.99
Illiomama Rep 1	>0.99	>0.99
Illiomama Rep 2	>0.99	>0.99
Weymouth Rep 1	>0.99	0.99
Weymouth Rep 2	>0.99	>0.99
Papakura Channel Rep 1	>0.99	>0.99
Papakura Channel Rep 2	>0.99	>0.99
Mangere Bridge Rep 1	>0.99	>0.99
Mangere Bridge Rep 2	>0.99	>0.99

Concordance correlation coefficients were calculated for all metals and selected metals to ensure there was no bias from incorporating higher level concentration data (> 12 mg/kg).

The change in digestion procedure does not appear to significantly affect the results for samples from the SCMP, hence it is not expected to have any significant influence on the quantitative determination of metals in the shellfish tissue. Therefore, the 2011 data set can be used with confidence for comparison with earlier data for trends analysis.

However, it is evident that the new digestion procedure delivers more variable data evidenced from higher coefficients of variation for the data sets generated for the QA samples analysed repeatedly (Figure 3-1). In addition, the variability in metals data was generally more pronounced for

cadmium, copper and zinc for the in-house wet composite of mussel/oyster tissue when compared with freeze-dried ground NIST SRM 1566b oyster tissue.

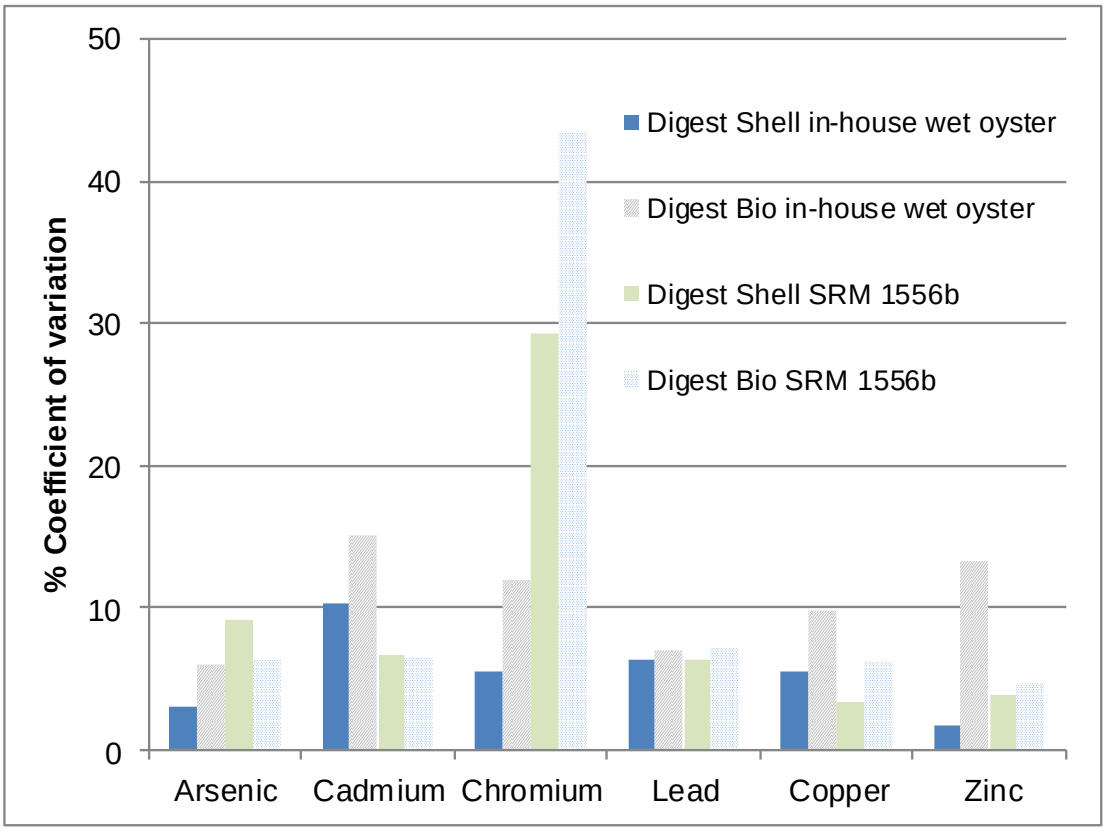


Figure 3-1 Variability (% coefficients of variation) in shellfish metal concentrations for replicate analyses of QA samples analysed by Watercare Services Ltd in 2010. Data generated to compare different digestion procedures. Digest Shell is the older procedure used up to 2010 and Digest Bio is IANZ accredited procedure used since 2011. Data kindly provided by Dr Steve Money of Watercare Services Ltd.

3.1.4 Variability

An assessment of Watercare Services Ltd QA data for the AC shellfish monitoring programme between 2006 until 2011 was undertaken to measure the level of variability inherent in the analyses of selected heavy metals over this time period. The QA samples routinely analysed with batches of AC shellfish include (NIST) SRM 1566b (freeze-dried oyster tissue), SRM 2976 (freeze-dried mussel tissue), NIST SRM DORM-3 (Fish Protein) and in-house control samples of archived frozen oyster / mussel tissue homogenate and in-house dried pacific oyster homogenate. The NIST SRM DORM-3 (Fish Protein) has only been analysed since 2011 in order to get a measure of method performance specifically for the analysis of chromium which is not certified in the other CRMs.

The % coefficient of variation (%CV) is commonly used as a measure of data variability and is calculated by dividing the standard deviation of the data set by the mean and converting to a percentage. The data is presented in Figure 3-2 and assists in identifying where variability is greatest and if any other factors may be affecting variability of the data.

As outlined previously, chromium is a notably difficult element to measure precisely in shellfish and is highly variable as evidenced from high %CVs observed for all QA samples. The NIST SRM DORM-3 (Fish Protein) was purchased in 2011 to assist in validating data for chromium. A %CV for chromium of 9.8% was measured following triplicate analyses of NIST SRM DORM-3 in 2011, which is excellent.

It is clear that the %CVs are highest for the in-house wet shellfish composite (Figure 3-2) and this may be because the samples were not truly homogeneous or it may be an effect of digesting wet tissue. In general the variation in the data for dried tissue is lower with %CVs < 12.1%, with the exception of chromium. The question still remains whether the variability observed for the QA in-house wet shellfish composite is also inherent in the wet shellfish homogenates of AC shellfish monitoring programme. Details of analytical variability for heavy metals analysed prior to 2007 was described previously in the Shellfish Contaminant Monitoring Programme Review and Audit report produced by Diffuse Sources Ltd in 2007 (Mills 2007). %CVs were plotted for AC samples and showed high data variability for copper, lead and chromium (>20%), but this only occasionally interfered with the detection of differences in metals concentrations between sites. Outliers do have a significant influence on variability for some sites and such outliers should be removed for purposes of assessing trends. The comparison of this data indicates that the variability is definitely more pronounced for the QA in-house wet shellfish composite and may be due to heterogeneity of the wet QA samples rather than a direct result of analytical variability from the digestion procedure and/or ICP-MS analyses.

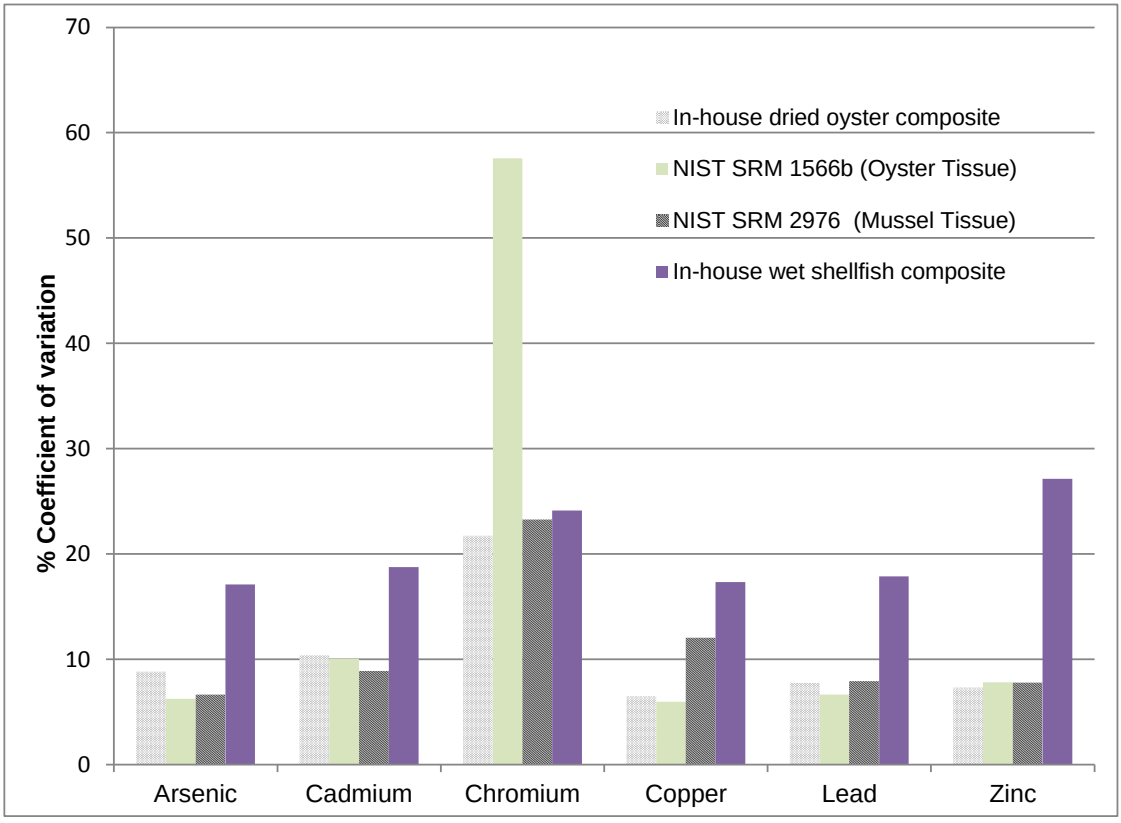


Figure 3-2 Variability (% coefficients of variation) in shellfish metal concentrations for all QA samples analysed by Watercare Services Ltd between 2006 and 2011. Data kindly provided by Dr Steve Money of Watercare Services Ltd.

While data variability for QA samples is still pronounced for chromium (for reasons described earlier) the remaining metals show relatively lower %CVs, suggesting trend assessment should not be compromised significantly by year-to-year analytical variability.

3.1.5 Recommendations

In light of the QA data review we would recommend considering a change to the methodology in order to reduce analytical variability by incorporating a freeze-drying and grinding step pre-digestion of heavy metals and ICP-MS analyses for all future AC shellfish monitoring samples.

3.2 Organic contaminants

3.2.1 Background

Organic contaminants were analysed at NIWA in the Organic Chemistry Laboratory until 2008. Greg Olsen was the principal analyst with responsibility for the AC shellfish monitoring programme from 2000. Details of analytical procedures and QA procedures were covered in the Shellfish Contaminant Monitoring Programme Review and Audit report produced by Diffuse Sources Ltd in 2007 (Mills 2007). The review recommended that alternative analytical methods be considered to improve sensitivity, particularly for polychlorinated biphenyls (PCBs) and organochlorine pesticides such as DDTs. Greater sensitivities (lower minimum detection limits) were considered advantageous, especially for the less contaminated sites, for on-going trend analysis, where levels of legacy contaminants such as DDTs and PCBs are likely to continue to reduce over time. The Environmental Section of AsureQuality Limited in Wellington was engaged by Auckland Council to provide more sensitive organic contaminant data for on-going trend assessments for the Shellfish Contaminant Monitoring Programme from 2009.

Phil Bridgen, Scientist at AsureQuality Limited, with responsibility for the AC shellfish programme organic contaminant analyses, was contacted on Monday 23rd April 2012 to discuss laboratory procedures and aspects of QA/QC.

3.2.2 QA procedures

The Environmental Section of AsureQuality Limited is an analytical laboratory with IANZ accreditation. Methods employed for trace level organic contaminant analyses of shellfish tissue are the same or directly comparable to those used internationally in similar shellfish monitoring programmes by NOAA for the NS&T Mussel Watch Program in USA. These include the US EPA GC-HRMS Isotope dilution methods 1699 and 1668A for organochlorine pesticides and PCBs respectively. Polycyclic aromatic hydrocarbons (PAHs) were measured using a modified procedure based upon Isotope dilution method CARB 429.

Samples were homogenised and freeze-dried over a 24 or 48 hour cycle depending on the mass of material. Samples were slowly heated to between 25-30°C over a 24 hour period using a vacuum pressure typically between 0.1 and 0.01 mbar. Although samples are heated to a higher temperature when compared with previous methods (sample temperatures < -10 C) the freeze-dried homogenised shellfish produced for extraction should be comparable, particularly for the

organic contaminant analytes of interest. Analysis of wet tissue or additional control of the freeze drying (maintaining sample temperatures < -10 C) would be required if measuring the more volatile PAH components such as naphthalene.

3.2.2.1 PAH subtraction

All PAH data are blank subtracted. An average of three blanks for each batch analysed was used to correct the PAH data. In some analytical laboratories (including NIWA) the blanks are commonly used to set minimum detection limits (MDLs) for selected PAHs for the method. The blank-subtraction approach is not uncommon and given that the levels of PAHs in the blanks are generally low, this has little bearing on the majority of data. Levels of PAHs in the blanks are generally lower than 0.2 ng/g based on 2 g freeze-dry weight tissue extraction. However, for those sites with low total PAHs (e.g., pre-deployment, Illiomama and Weymouth) the amount subtracted may represent as much as 15% of total PAH.

3.2.2.2 CRM selection

AsureQuality includes the analyses of either NIST SRM 1974b or SRM 2974a (freeze-dried mussel tissue) as one of the measures of method performance over time. These certified reference materials (CRMs) do have high levels of organic contaminants which are not directly comparable with levels observed in the AC shellfish monitoring programme. We recommend using either NIST SRM 2977 (freeze-dried mussel tissue) or an equivalent CRM that contains levels of organic contaminants which more closely resembles the range observed in shellfish from the Auckland region. The CRM results were not evaluated in terms of batch acceptance criteria by AsureQuality. The batch acceptance criteria were primarily determined from the spiked QA samples (OPR), as per the EPA/CARB methods. The analysis of CRMs does provide additional information on how AsureQuality results compare with those expected for the reference material and allows comparisons to be made from year-to-year.

3.2.2.3 Spiked samples

Method performance is principally assessed by measuring spiked recoveries. PCBs at 1-2 ng are spiked into five grams of freeze-dried mussel tissue or OCs at 1 ng and PAHs at 100 ng are spiked into two grams of freeze-dried mussel tissue. Samples are extracted and analysed using the same methodology as for AC shellfish samples. The levels of PCBs and OCs which are spiked are comparable to those observed in shellfish tissue from the shellfish monitoring programme, however the levels of PAHs are approximately five times those typically observed. We recommend decreasing the spike concentration for PAHs by at least ten-fold (10 ng) to produce a spiked PAH data set which is in a similar range to real samples. The AsureQuality acceptance criteria for spiked samples are 50-150% for PCBs and PAHs and 50-120% for OCs. These limits have been derived from their respective EPA/CARB methods.

3.2.2.4 Minimum detection limits (MDLs)

MDLs for these tests are specifically determined for each analyte, for each sample, based on the level of noise measured for that particular extract. As a number of factors can influence the noise level (such as matrix effects, interferences, instrument variation, etc.) the calculated detection limits are likely to vary between samples/analytes/injections. However, AsureQuality do strive to ensure that the obtained detection limits are within the targeted range agreed with by the customer.

The QA procedures are comprehensive and provide sufficient information to measure analytical performance for the AC shellfish monitoring programme. The QA data for assessing accuracy and precision for within-batch and between-batch should be provided with the data set for independent review. Blank data for PAH analyses should also be requested to check that levels are low relative to levels reported for mussels and oysters.

All data are created electronically and held within the laboratory management system (LIMS). All data are checked using established procedures and must pass acceptance criteria before being released.

3.2.3 Variability

The variability associated with the change of analytical laboratories between NIWA and AsureQuality was assessed by two comparisons:

- Three archived samples (Chelsea, Illiomama and Tamaki) of freeze-dried mussel tissue from 2008 sampling was analysed in 2009 by AsureQuality and compared with the 2008 NIWA data set.
- Bulk Weymouth mussel tissue, collected in 2007, was analysed by AsureQuality in 2009, 2010 and 2011 and compared with NIWA 2008 data.

In addition, to assess intra-batch variability for AsureQuality data, two blind replicates of mussel tissue from Illiomama and Mangere Bridge were analysed in conjunction with 2010 AC shellfish monitoring samples.

The "concordance correlation coefficient", first proposed by Lin (1989) for assessment of concordance in continuous data (and reviewed in section 2.2), was calculated for sets of paired organic contaminant data to measure agreement between alternative methods. Differences in detection limits between the two analytical providers (NIWA and AsureQuality) would not significantly affect the analysis when there are few data below detection limits. However, concordance correlation coefficients were not used for contaminants with very low contaminant concentrations and with a significant number of values less than detection limit (for example lindane). Graphical comparisons of variability for bulk Weymouth 2007 mussels are displayed in Appendix I.

The proposed descriptive scale in Table 3-5 may be used to define the degree of agreement for values of the coefficient in given ranges.

Table 3-5 Lin's sample concordance correlation coefficient scale used for the descriptive degree of agreement between methods.

Strength-of-agreement	Concordance coefficient
Almost perfect	>0.99
Substantial	>0.95–0.99
Moderate	0.90–0.95
Poor	<0.90

3.2.3.1 Archived replicates of 2008 mussel tissue from Chelsea, Illiomama, and Tamaki

Lin's concordance correlation coefficients were calculated for organic contaminant data for three selected archived AC mussel samples from 2008 sampling. One replicate sample of mussel tissue from Chelsea, Illiomama, and Tamaki was re-analysed by AsureQuality in 2009 for direct comparison with earlier data generated by NIWA. Dry weight (Table 3-6) and lipid normalised (Table 3-7) correlation coefficients were calculated for limited and extended suites. These correlations were performed with (left column) and without (right column) the PAH data set.

In general, lipid-normalised data (Table 3-7) shows better agreement (substantial or higher) than the dry weight data (Table 3-6), with the exception of Tamaki. This anomaly may be explained by the low % lipid result of 4.8% when re-analysed by AsureQuality in 2009. A value of 7.4% was originally determined in 2008 and this disparity would result in larger differences between lipid normalised data for organic contaminants. By correcting the lipid normalised Tamaki data, using the % lipid result from 2008, correlation coefficients >0.99 were obtained for both the limited and extended suites.

These data show that there is substantially good agreement or better between organic contaminant data sets generated by NIWA and AsureQuality for the selected samples analysed. This agreement is less pronounced for the dry weight data and there is little difference between extended and limited suites. The removal of PAH data from the suites of organic contaminants resulted in minor changes to the calculated correlation coefficient, resulting in better agreement for dry weight data (Table 3-6), but less agreement for lipid normalised data (Table 3-7).

The lipid normalised data does show better agreement, but this is very much dependent upon a reliable result for %lipid which is used in the calculation. We would recommend confirming that the procedure used to measure %lipid is robust and reliable for future organic contaminant analyses.

Table 3-6 Lin's concordance correlation coefficients calculated from organic contaminant data (dry weight) for archived AC mussels from Chelsea, Illiomama, and Tamaki sampled in 2008 and re-analysed in 2009.

Sample Information	Concordance coefficient (dry weight DDTs, Chlordanes, PCBs, PAHs, dieldrin and HCB)	Concordance coefficient (dry weight DDTs, Chlordanes, PCBs, dieldrin and HCB)
Limited suites		
Chelsea Rep 4	0.95	>0.99
Illiomama Rep 4	0.91	>0.99
Tamaki Rep 2	>0.99	>0.99
Extended suites		
Chelsea Rep 4	0.96	0.99
Illiomama Rep 4	0.95	>0.99
Tamaki Rep 2	>0.99	>0.99

Table 3-7 Lin's concordance correlation coefficients calculated from organic contaminant data (lipid normalised) for archived AC mussels from Chelsea, Illiomama, and Tamaki sampled in 2008 and re-analysed in 2009.

Sample Information	Concordance coefficient (Lipid-normalised DDTs, Chlordanes, PCBs, PAHs, dieldrin and HCB)	Concordance coefficient (Lipid-normalised DDTs, Chlordanes, PCBs, dieldrin and HCB)
Limited suites		
Chelsea Rep 4	0.99	0.97
Illiomama Rep 4	0.97	0.94
Tamaki Rep 2	0.89	0.84
Extended suites		
Chelsea Rep 4	0.99	0.99
Illiomama Rep 4	0.99	0.98
Tamaki Rep 2	0.91	0.89

3.2.3.2 Comparison of organic contaminant data for Weymouth 2007 bulk replicates

Bulk Weymouth mussel tissue, collected in 2007, was analysed by AsureQuality in 2009, 2010 and 2011. Lin's concordance correlation coefficients were calculated for mean organic contaminant data measured by NIWA in 2007 and again by AsureQuality in 2009. Correlation coefficients were calculated for dry weight and lipid normalised limited and extended suites.

These data show that there is substantially good agreement or better between organic contaminant data sets generated by NIWA and AsureQuality for bulk Weymouth mussel tissue (Table 4-8).

Table 3-8 Lin's concordance correlation coefficients calculated for organic contaminant data for AC bulk Weymouth mussel tissue sampled in 2007. Replicates of Weymouth mussel tissue were re-analysed by AsureQuality in 2009 for direct comparison with average data produced in 2007.

Sample Information	Concordance coefficient (dry weight DDTs, Chlordanes, PCBs, PAHs, dieldrin and HCB)	Concordance coefficient (Lipid-normalised DDTs, Chlordanes, PCBs, PAHs, dieldrin and HCB)
Limited suites	0.99	0.99
Extended suites	>0.99	0.99

3.2.3.3 Blind replicates of 2010 mussel samples

To assess intra-batch variability for AsureQuality data, Lin's concordance correlation coefficients were calculated for organic contaminant data for two blind replicates of AC mussel tissue from 2010 sampling. Replicate samples of mussel tissue from Illiomama, and Mangere Bridge were re-analysed by AsureQuality in 2010 for direct comparison with earlier data generated for each site. Correlation coefficients were calculated for dry weight and lipid normalised limited and extended suites.

Substantial or better agreement was observed for both blind replicates for all organic contaminant data (Table 3-9 and Table 3-10) and indicates that there is excellent within-batch reproducibility for the analysis of AC shellfish samples at AsureQuality.

Table 3-9 Lin's concordance correlation coefficients calculated for organic contaminant data (dry weight) for two blind replicates of AC mussel tissue from Illiomama and Mangere Bridge in 2010.

Sample Information	Concordance coefficient (dry weight DDTs, Chlordanes, PCBs, PAHs, dieldrin and HCB)	Concordance coefficient (dry weight DDTs, Chlordanes, PCBs, dieldrin and HCB)
Limited suites		
Illiomama	0.98	>0.99
Mangere Bridge	>0.99	0.99
Extended suites		
Illiomama	0.99	>0.99
Mangere Bridge	>0.99	>0.99

Table 3-10 Lin's concordance correlation coefficients calculated for organic contaminant data (lipid normalised) for two blind replicates of AC mussel tissue from Illiomama and Mangere Bridge in 2010.

Sample Information	Concordance coefficient (lipid normalised DDTs, Chlordanes, PCBs, PAHs, dieldrin and HCB)	Concordance coefficient (lipid normalised DDTs, Chlordanes, PCBs, dieldrin and HCB)
Limited suites		
Illiomama	0.99	>0.99
Mangere Bridge	>0.99	>0.99
Extended suites		
Illiomama	0.99	>0.99
Mangere Bridge	>0.99	>0.99

3.2.4 Recommendations

Recommendations from assessing the organic QA data are:

- Re-assess why a shelf temperature of 25-30°C is used for freeze drying, with possible implications in the loss of volatile contaminants.
- Consider using a CRM that contains levels of organic contaminants which more closely resemble the range observed in shellfish from the Auckland region.
- Decrease the spike concentration for PAHs by at least ten-fold (10 ng) to produce a spiked PAH data set which is in a similar range to real samples.
- AC to request blank data for PAH analyses.
- Confirm that the procedure used to measure %lipid is robust and reliable for future organic contaminant analyses.

Further recommendations include considering a small pilot study to measure if there are any significant differences between levels of contaminants when extracting either wet tissue or freeze-dried tissue. The results would be useful in determining how samples may be archived long-term for the organic contaminants of interest.

We strongly recommend long-term storage of tissue samples (dried or frozen) for future investigations and retrospective analysis of e.g., emerging contaminants (Becker and Wise 2010). Environmental specimen banks (ESBs) have a role in quality assurance, as specimens banked from on-going contaminant monitoring programmes are readily available for re-analysis and verification of previous analytical results. Formal environmental specimen banking is the systematic long-term preservation of well-documented, representative environmental specimens that are available for deferred (i.e., retrospective) analysis and evaluation.

3.3 Consequences of changing analytical laboratories

An assessment of QA data has revealed that there are no significant changes as a consequence of changing analytical laboratories (organics) or digestion procedure (metals).

Concordance coefficient analyses have shown that for metals:

- The change in digestion procedure does not appear to significantly affect the results for samples from the AC SCMP; hence it is not expected to have any significant influence on the quantitative determination of metals in the shellfish tissue. Therefore, the 2011 data set can be used with confidence for comparison with earlier data for trends analysis.

Concordance coefficient analyses have shown that for organics:

- These data show that there is substantially good agreement or better between organic contaminant data sets generated by NIWA and AsureQuality for the selected samples analysed. This agreement is less pronounced for the dry weight data and there is little difference between extended and limited suites. The removal of PAH data from the suites of organic contaminants resulted in only minor changes to the calculated correlation coefficient.

4.0 Current Status

4.1 Comparisons among sites

The current status of contaminant concentrations in the shellfish, and shellfish condition was investigated based on data from 2009 to 2011. Whilst the most recent year's data (2011) could have been used on its own, it was considered that using three years of data would reduce the effect of outliers and provide a better estimate of the overall status. Data from the Mill Bay oyster site were not included in the graphical comparisons as there were data only from 2009 for this site, however this site was included in the tables for comparison with Cornwallis oyster site.

For mussels, the pre-deployment contaminant concentrations were not subtracted as this resulted in many negative values for cadmium and lead and some negative values for zinc and copper. The concentrations of contaminants in the mussels pre-deployment are shown as an additional 'site' on the box plots below and in the summary tables.

4.1.1 Shellfish condition

The condition index (dry tissue weight / dry shell weight) for all oysters and mussels is shown for each site in Figure 4-1. The condition index is calculated on approximately 50 individual shellfish from each site for each year. Condition index was not compared between the different shellfish types due to different shellfish morphometry. The condition index for oysters was similar across sites, although it was highest (and most variable) at Cornwallis. The lowest median was at Grannys Bay. For mussels, the condition index was substantially higher at Illiomama compared to the other sites and was lowest at Mangere Bridge. Condition index for the pre-deployment mussels was lower than for four of the monitoring sites (Illiomama, Upper Harbour, Chelsea and Papakura Channel) and higher than Mangere Bridge.

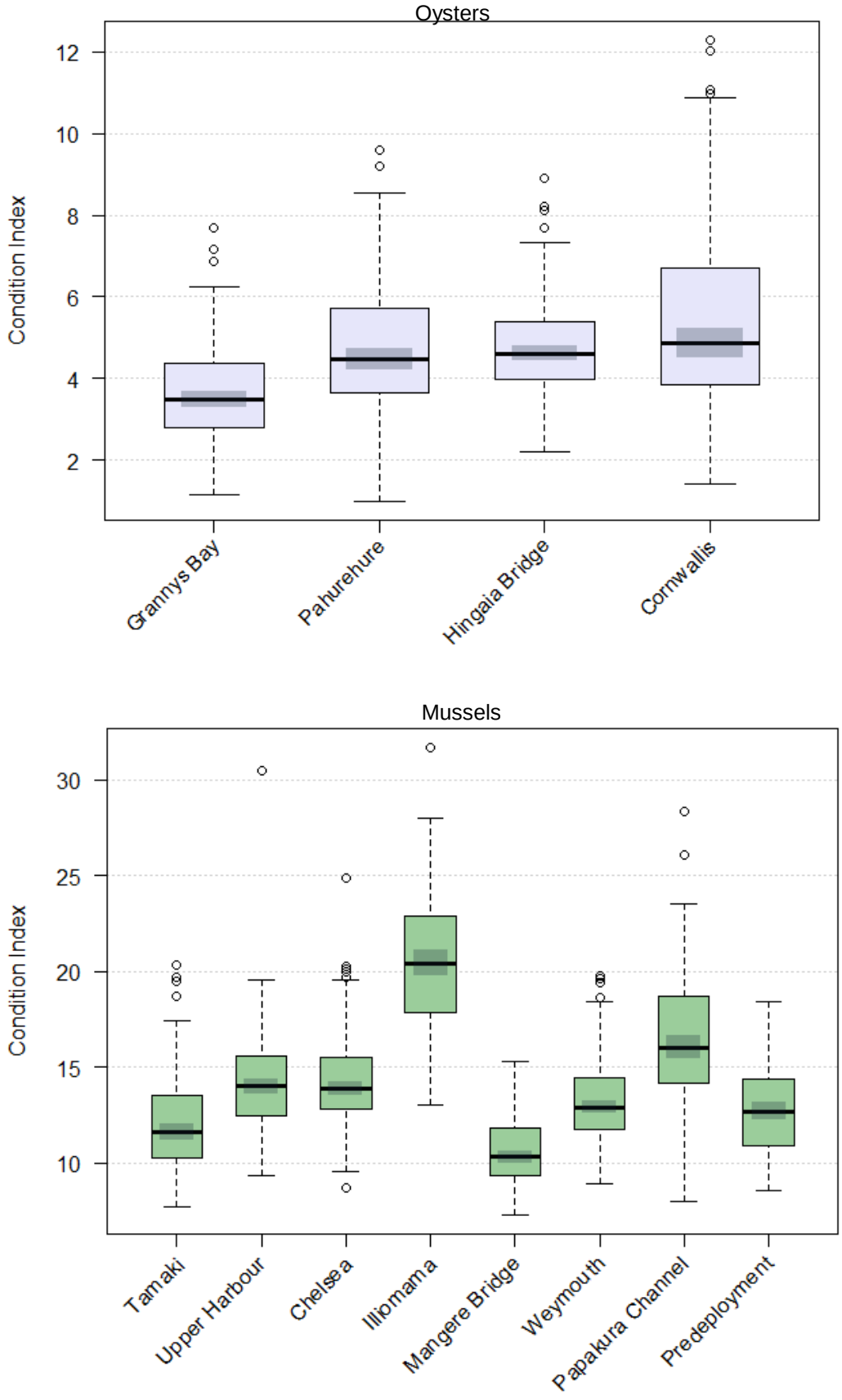


Figure 4-1 Condition index for oysters and mussels at each site in the SCM programme.
Shaded boxes overlaid on box plots indicate the confidence interval about the median. Whiskers represent 1.5 x interquartile range with circles representing data outliers outside this range.

4.1.2 Metals

The median concentrations of metals at each site for the period 2009 – 2011 are summarised in Table 4-1. At all sites, all metals were measured at concentrations above the detection limits. As presented in Table 4-1, and in Figure 4-2, the concentration of arsenic was highest at Cornwallis oyster site and lowest at Mangere Bridge mussel site and in the pre-deployment mussels. Cadmium concentrations were approximately twice as high in oysters than in mussels (note log-scale in Figure 4-2) with highest concentrations at Hingaia oyster site. The pre-deployment mussels had higher concentrations of cadmium than all the mussel deployment sites, which may be a result of leaching of cadmium from historic mining sites (Tracey and van den Broek 1987) and/or extensive use of superphosphate fertiliser in the Coromandel (Butler and Timperley 1996). Lowest cadmium concentrations were measured at Tamaki and Illiomama mussel sites. Chromium concentrations (Figure 4-3) were similar in oysters and mussels and were lowest at Hingaia and Pahurehure oyster sites and Illiomama mussel site. Chromium concentrations in the pre-deployment mussels were substantially lower than at all the deployed mussel sites.

Unlike other metals, lead concentrations (Figure 4-3) were around 3 times higher in mussels than in oysters and were substantially lower at Cornwallis oyster site than at all other oyster or mussel sites. Highest concentrations were measured at Upper Harbour, Chelsea and Tamaki mussel sites.

Table 4-1 Summary of median metal concentrations in oysters and mussels, from 2009 to 2011 (mg/kg dry weight) by site.

Site	Arsenic	Cadmium	Chromium	Copper	Lead	Zinc
Oysters						
Grannys Bay	9.7	1.2	0.9	870	0.7	4000
Pahurehure	8.6	1.4	0.6	310	0.5	2400
Hingaia	9.2	1.6	0.7	420	0.4	2300
Cornwallis	13.0	1.0	0.8	110	0.2	1500
Mill Bay	12.0	0.6	0.7	83	0.2	890
All oysters (median)	9.7	1.2	0.7	310	0.4	2300
Mussels						
Tamaki	7.7	0.4	1.1	12.0	1.7	93
Upper Harbour	7.8	0.5	0.9	7.6	1.6	82
Chelsea	8.8	0.5	1.0	7.6	1.6	81
Illiomama	8.6	0.4	0.6	5.0	0.9	60
Mangere Bridge	6.8	0.6	1.5	5.9	1.2	71
Weymouth	8.3	0.6	1.0	4.3	0.7	68
Papakura Channel	8.7	0.4	0.8	4.5	0.4	66
All mussels (median)	8.3	0.5	1.0	5.9	1.2	71
Pre-deployment	6.9	0.9	0.2	3.6	0.5	72

Mill Bay 2009 data only; all mussels (median) values do not include pre-deployment mussels.

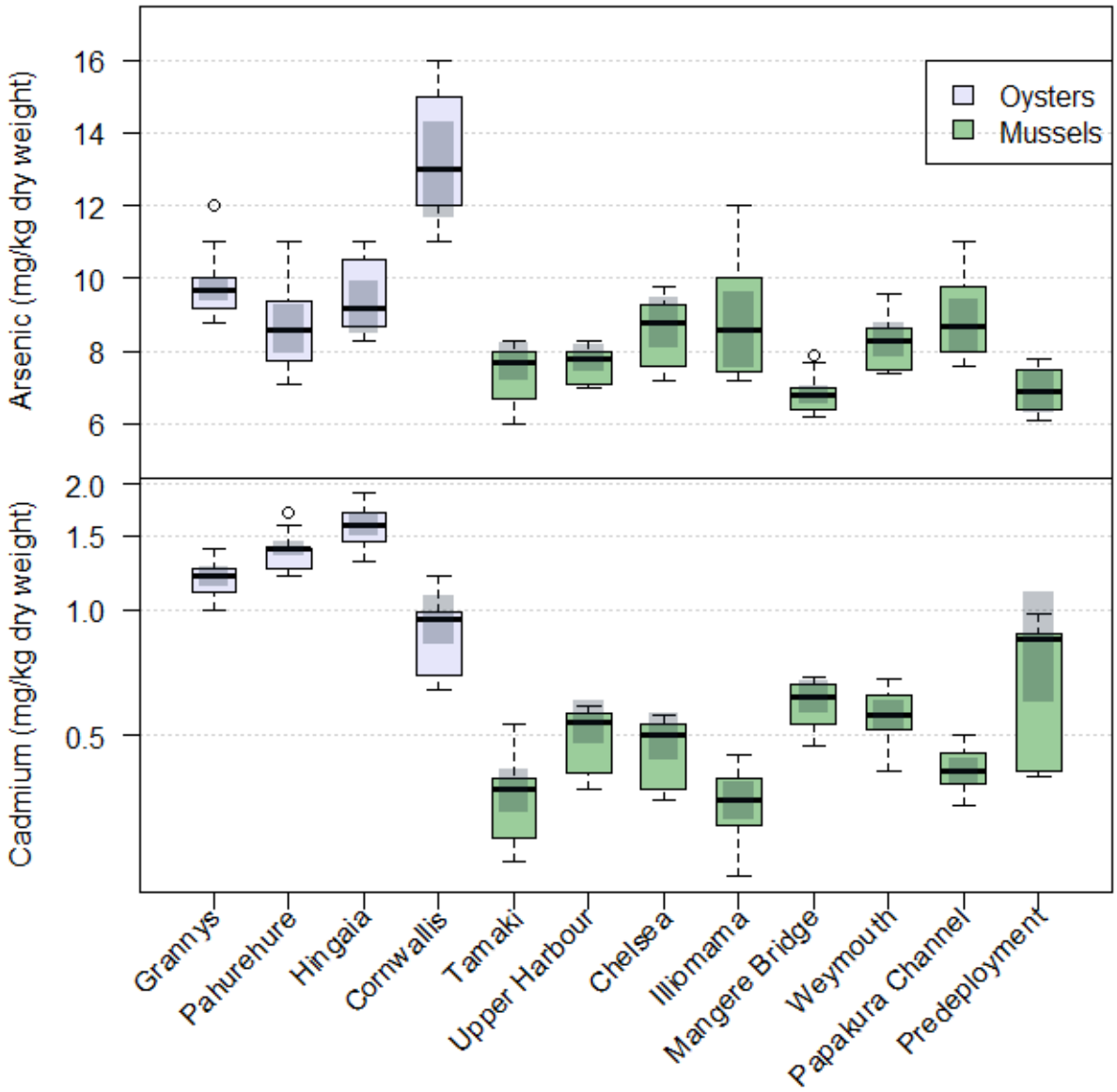


Figure 4-2 Arsenic and cadmium concentrations in oysters and mussels at each site in the SCM programme. Note log-scale on y-axis for cadmium. Shaded boxes overlaid on box plots indicate the confidence interval about the median. Whiskers represent 1.5 x interquartile range with circles representing data outliers outside this range.

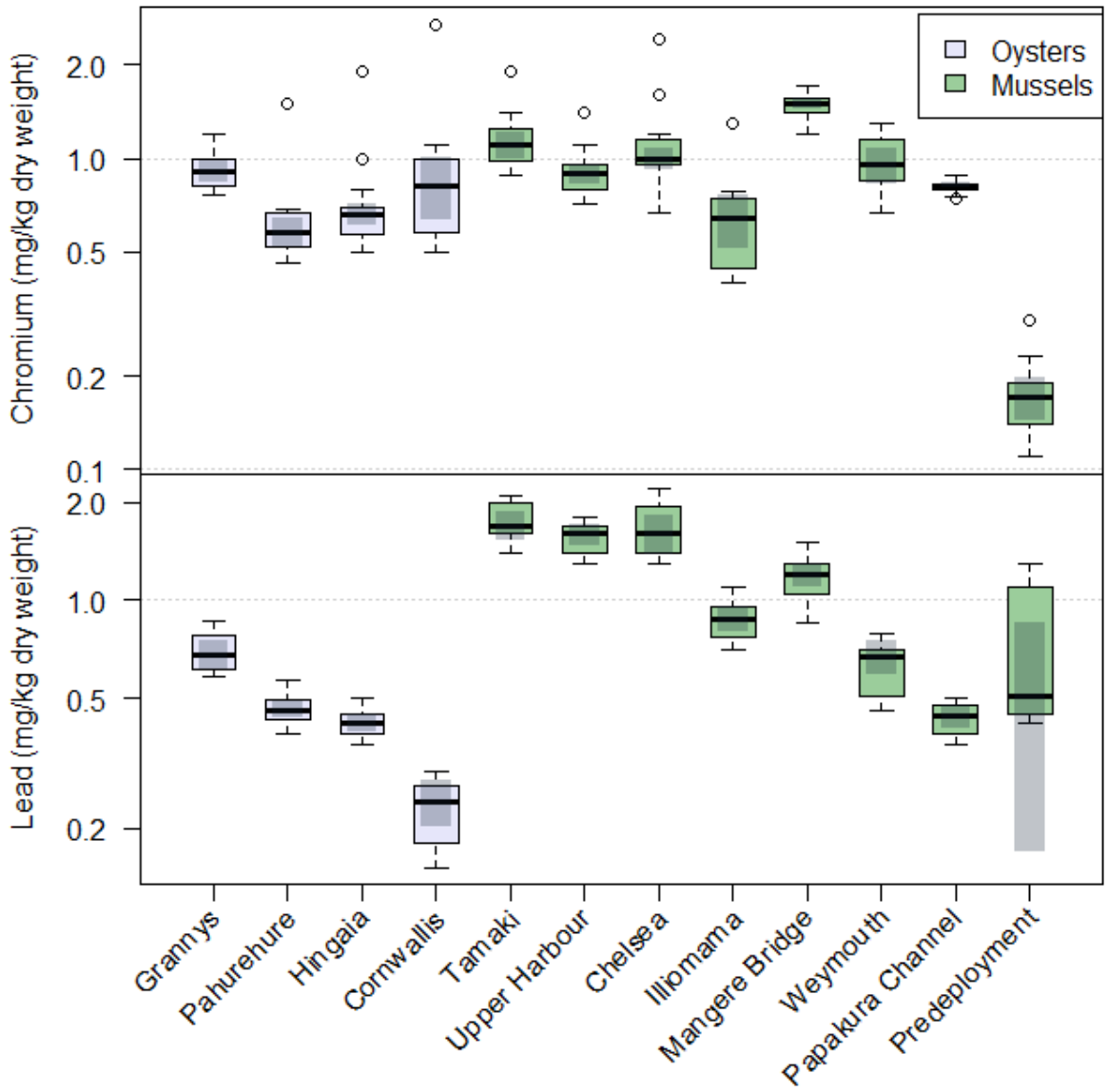


Figure 4-3 Chromium and lead concentrations in oysters and mussels at each site in the SCM programme. Note log-scale on y-axis. Shaded boxes overlaid on box plots indicate the confidence interval about the median. Whiskers represent 1.5 x interquartile range with circles representing data outliers outside this range.

Copper and zinc concentrations in the oysters were a factor of 10 or more higher than in the mussels and therefore separate plots are shown for these metals for each shellfish type (Figure 4-4 and Figure 4-5). For the oysters, copper and zinc concentrations were highest at Grannys Bay and lowest at Cornwallis (Figure 4-4). For the mussels, copper concentrations were lower in the pre-deployment mussels than at all sites; however zinc concentrations were higher in the pre-deployment mussels than at sites at Papakura Channel, Mangere Bridge, Weymouth and Illiomama (Figure 4-5). Copper and zinc concentrations were both highest at Tamaki. Lowest concentrations of copper were measured at Papakura Channel and Weymouth. Lowest concentrations of zinc were measured at Illiomama.

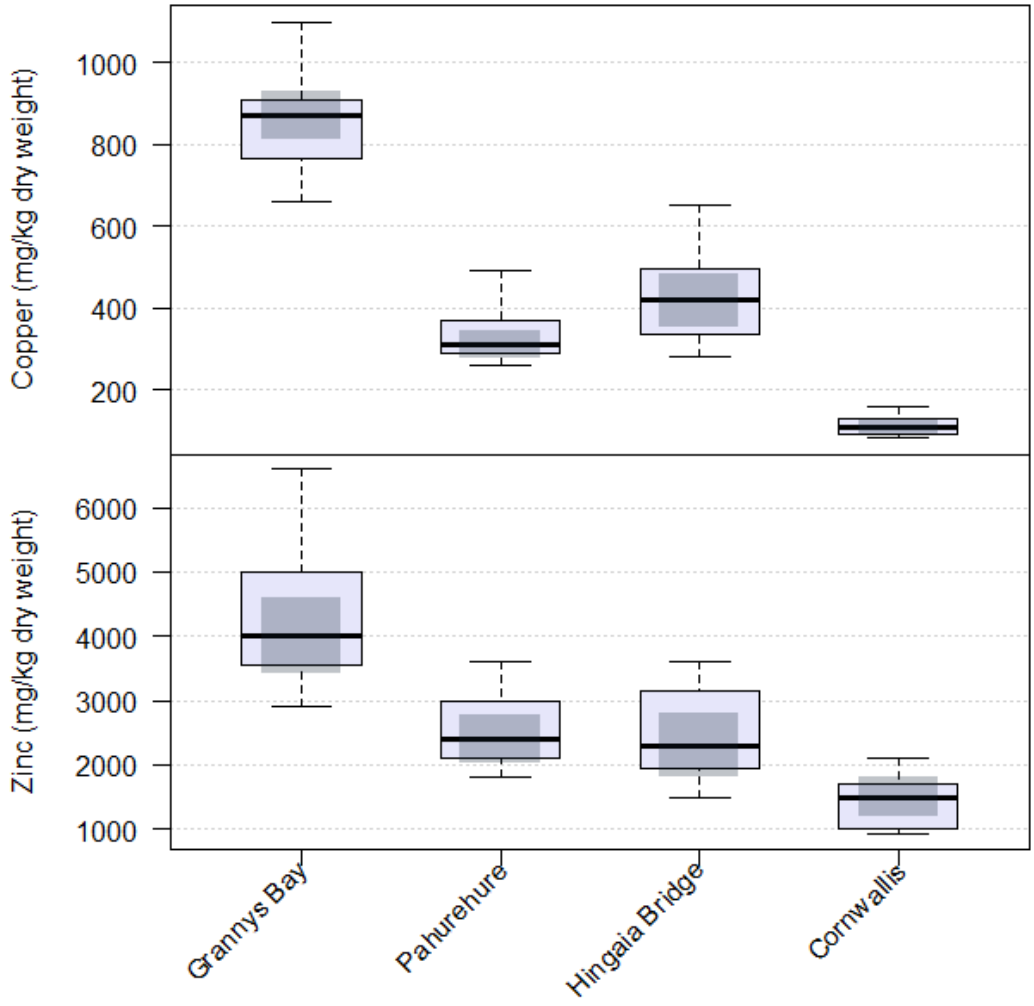


Figure 4-4 Copper and zinc in oysters at each site in the SCM programme.
Shaded boxes overlaid on box plots indicate the confidence interval about the median.

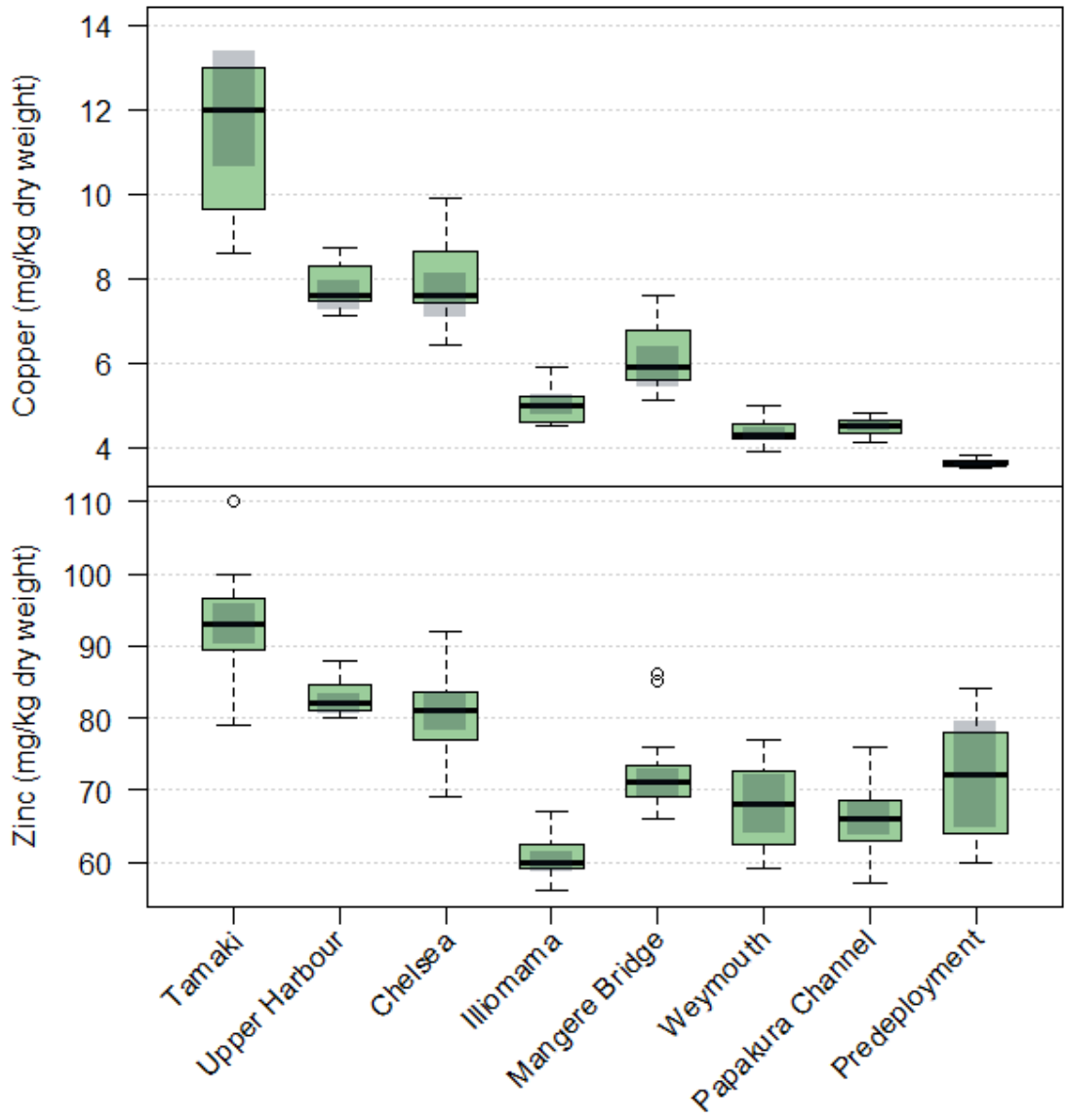


Figure 4-5 Copper and zinc in mussels at each site in the SCM programme.
Shaded boxes overlaid on box plots indicate the confidence interval about the median. Whiskers represent 1.5 x interquartile range with circles representing data outliers outside this range.

Differential uptake of metals between different shellfish biomonitoring species is known to occur (Rainbow 1995). In terms of differential uptake of metals between mussel and oyster species in the SCMP, zinc and copper concentrations were substantially higher (30 and 50 times, respectively, based on median values), and cadmium was around 2 times higher, in oysters than in mussels, while lead was around 3 times higher in mussels than in oysters. These differences in uptake are similar to that observed in the NS&T mussel watch programme, which stated that zinc and copper are usually 10 times higher in oysters than mussels and lead often 3 times higher in mussels than oysters (Kimbrough*, et al.* 2008), although the magnitudes of difference for zinc and copper are much greater in the SCMP data.

4.1.3 Organics

The median concentrations of lipid normalized organic contaminants at each site for the period 2009-2011 are summarised in Table 4-2. Additional dry weight data for all organic suites are provided in Table 4-3. Of note: the minor organic contaminant suites presented in Table 4-3 that were not used for trend analyses (endosulfans, mirex, aldrin, endrins, chlorobenzenes and other PAHs) are potentially over-estimated as any data below detection limit for these contaminants was set at detection limit.

Compared to the metals, the differences between contaminant concentrations in mussels versus oysters are much smaller. There are however substantial differences between sites. As with the metals, the pre-deployment concentrations of organic contaminants were not subtracted for the statistics generated below or for the plots that follow; however as can be seen from the median concentrations in Table 4-2, for all organic contaminants (with the exception of lindane for which concentrations are affected by a large proportion of censored data) the pre-deployment concentrations are much lower than the concentrations in mussels at the monitored sites.

Of the oyster sites, Grannys Bay generally had the highest concentrations of organic contaminants, Hingaia and Pahurehure had intermediate concentrations, and Cornwallis and Mill Bay (measured in 2009 only) consistently had the lowest concentrations.

Of the mussel sites, Mangere Bridge and Tamaki had the highest concentrations of most organochlorine pesticides. Total PAHs were also high at Tamaki, but higher in mussels from the Upper Harbour and Chelsea sites than the Mangere Bridge site, suggesting different sources for these contaminants.

Table 4-2 Summary of median lipid-normalised concentrations of organic contaminants (µg/kg) in oysters and mussels, from 2009 to 2011.

Site	DDTs	PCBs	PAHs	Chlordanes	Dieldrin	Lindane	Endosulfans
Oysters							
Grannys Bay	550	570	976	33.5	27.2	0.8	0.02
Pahurehure	253	161	769	8.8	24	0.2	0.09
Hingaia	344	133	542	7.9	24.8	0.2	0.14
Cornwallis	101	90	154	5.5	6.3	0.2	0.02
Mill Bay	122	97	159	6.1	6.7	0.2	0.02
Site	DDTs	PCBs	PAHs	Chlordanes	Dieldrin	Lindane	Endosulfans
Mussels							
Tamaki	103	505	1777	23.6	32.5	0.0	0.04
Upper Harbour	167	359	1498	12.3	10.9	0.0	0.03
Chelsea	138	291	1137	10.7	8.3	0.0	0.01
Illiomama	73	136	354	6.5	6.3	0.0	0.00
Mangere Bridge	211	400	931	23.9	22.1	1.8	0.03
Weymouth	54	87	304	1.7	9.2	0.4	0.03
Papakura Channel	40	64	171	1.9	5.1	0.6	0.00
Pre-deployment	1	1	9	0.0	0.3	0.6	0.02

Mill Bay 2009 data only; All suites were extended suites (see Appendix B and Appendix C).

Table 4-3 Summary of median dry weight concentrations of organic contaminants (µg/kg) in oysters and mussels, from 2009 to 2011.

Site	DDTs	PCBs	PAHs	Chlordanes	Dieldrin	Lindane	Endosulfans	Mirex	Aldrin	Endrins	Chlorobenzenes	Other PAHs
Oysters												
Grannys Bay	32	25	42	0.9	1.5	0.09	0.51	0.17	0.06	0.32	0.05	2.88
Pahurehure	18	10	51	0.5	1.8	0.04	0.97	0.47	0.04	0.43	0.05	2.59
Hingaia	27	7	34	0.4	1.9	0.03	1.07	0.57	0.04	0.28	0.05	2.14
Cornwallis	10	8	17	0.4	0.7	0.05	0.40	0.11	0.02	0.33	0.05	1.76
Mill Bay	14	8	17	0.4	0.8	0.03	0.30	0.11	0.02	0.26	0.02	2.54
	DDTs	PCBs	PAHs	Chlordanes	Dieldrin	Lindane	Endosulfans	Mirex	Aldrin	Endrins	Chlorobenzenes	Other PAHs
Mussels												
Tamaki	5	23	73	0.8	1.6	0.07	0.64	0.10	0.04	0.47	0.57	3.15
Chelsea	8	18	65	0.4	0.5	0.04	0.33	0.05	0.03	0.39	0.42	3.37
Upper Harbour	10	19	68	0.5	0.6	0.05	0.69	0.07	0.04	0.43	0.49	3.40
Illiomama	6	11	25	0.4	0.5	0.03	0.44	0.04	0.03	0.41	0.27	2.46
Mangere Bridge	11	20	38	0.7	1.2	0.10	0.53	0.10	0.04	0.29	0.30	1.67
Weymouth	2	4	11	0.1	0.4	0.05	0.41	0.16	0.03	0.21	0.32	0.71
Papakura Channel	2	3	9	0.2	0.3	0.05	0.26	0.07	0.03	0.39	0.31	0.44
Pre-deployment	1	1	7	0.1	0.3	0.04	0.20	0.02	0.03	0.19	0.21	1.19

Mill Bay 2009 data only; All suites were extended suites (see Appendix B and Appendix C) except chlorobenzenes (sum of hexachlorobenzene and pentachlorobenzene); endosulfans (sum of endosulfans A&B and endosulfan sulfate); endrins (sum of endrin, endrin aldehyde and endrin ketone); and other PAHs (sum of fluorine; acenaphthylene; acenaphthene; 2-methylphenanthrene. Any data below detection limit was set to detection limit for summation of contaminant suite concentrations.

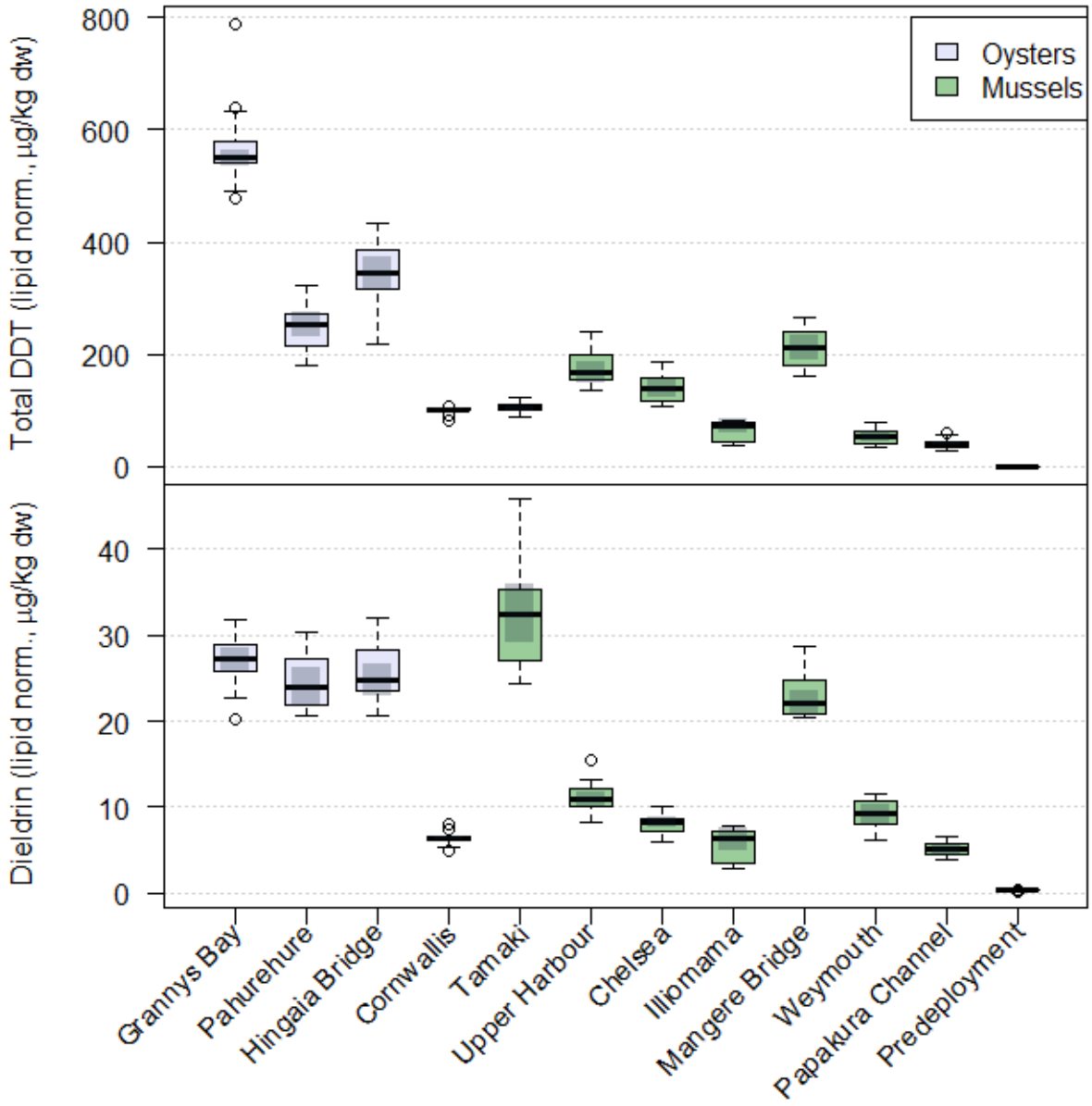


Figure 4-6 Total DDT and dieldrin in oysters and mussels at each site in the SCM programme. Shaded boxes overlaid on box plots indicate the confidence interval about the median. Whiskers represent 1.5 x interquartile range with circles representing data outliers outside this range.

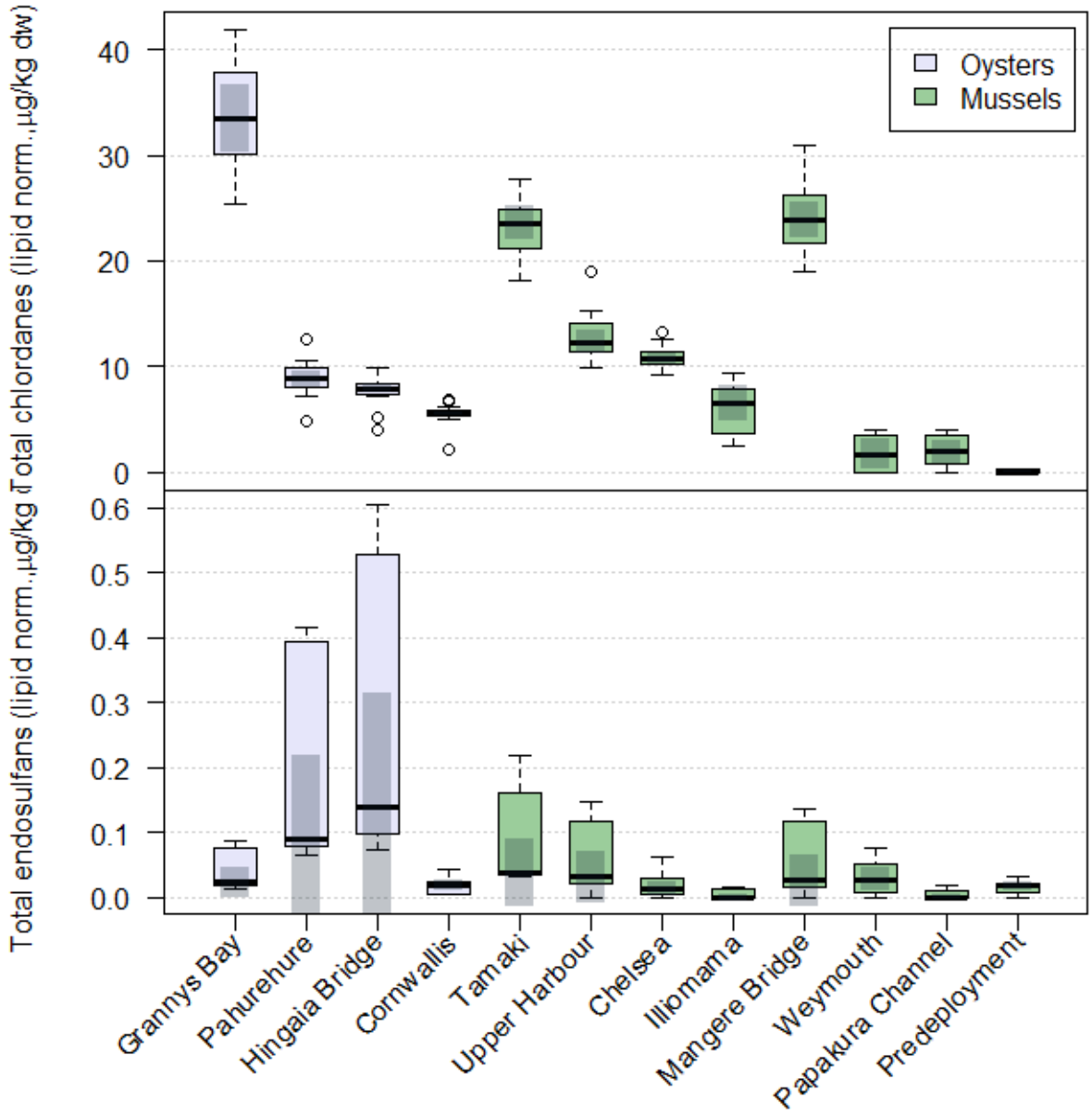


Figure 4-7 Total chlordanes and total endosulfans in oysters and mussels at each site in the SCM programme. Shaded boxes overlaid on box plots indicate the confidence interval about the median. Whiskers represent 1.5 x interquartile range with circles representing data outliers outside this range.

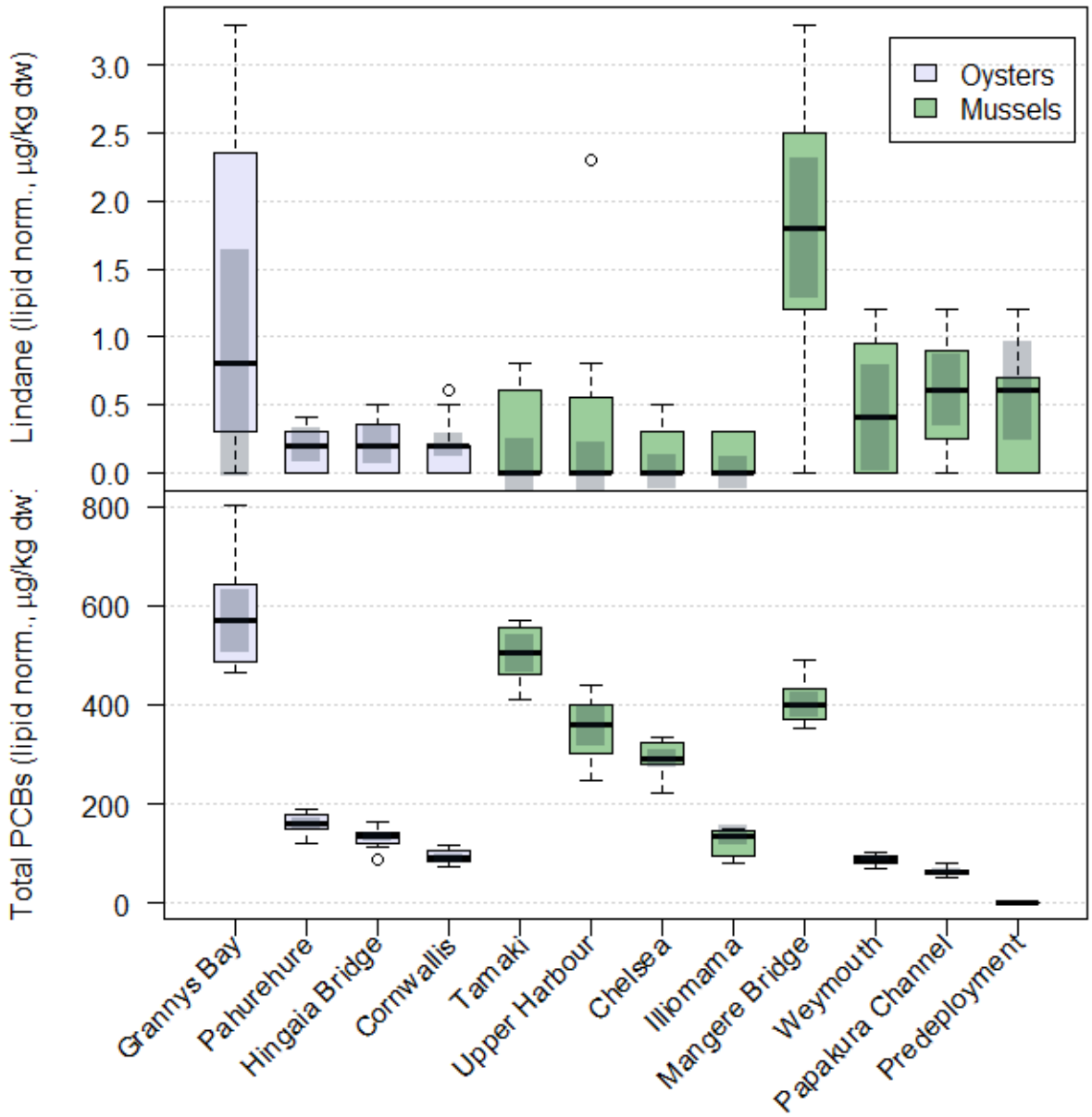


Figure 4-8 Lindane and total PCBs in oysters and mussels at each site in the SCM programme. Shaded boxes overlaid on box plots indicate the confidence interval about the median. Whiskers represent 1.5 x interquartile range with circles representing data outliers outside this range.

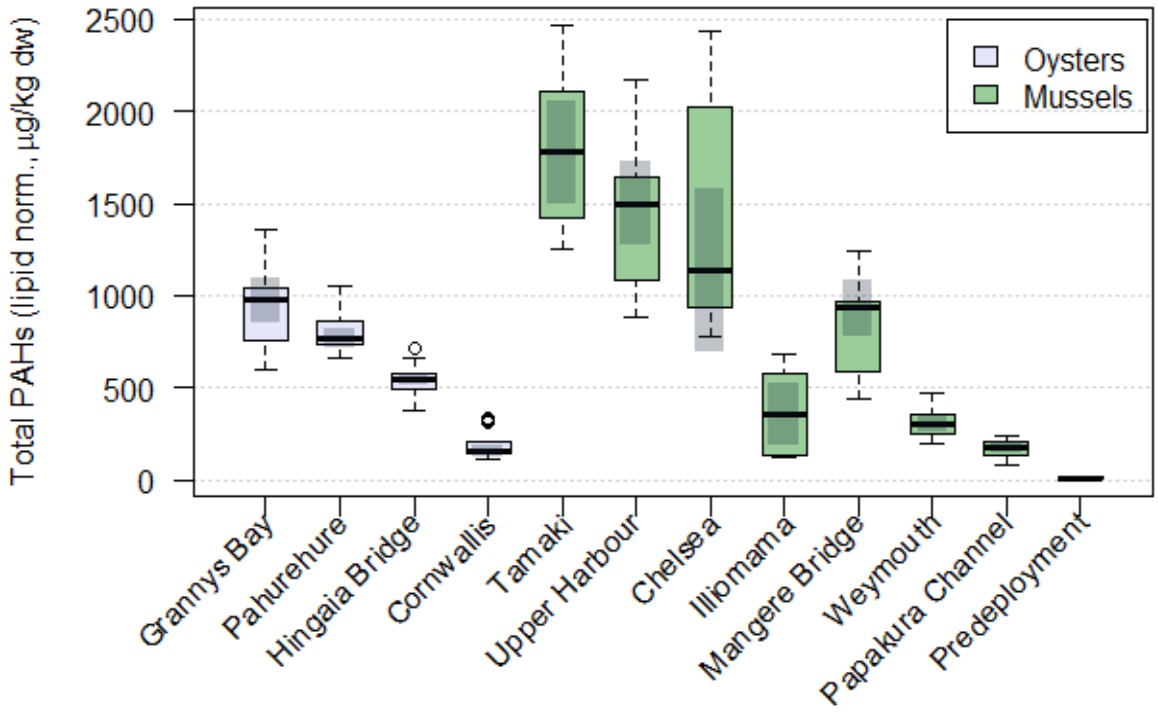


Figure 4-9 Total PAHs in oysters and mussels at each site in the SCM programme. Shaded boxes overlaid on box plots indicate the confidence interval about the median. Whiskers represent 1.5 x interquartile range with circles representing data outliers outside this range.

4.2 Correlations between contaminants

Pearson correlations between individual metals and organic contaminant group totals (extended suites) were examined for the 2009-2011 data (see Appendix D). For metals, mussels and oysters were assessed separately as the concentrations were very different in each. There were clear correlations between copper and lead, copper and zinc; and lead and zinc ($R > 0.7$) for both oysters (Figure Appendix 1) and mussels (Figure Appendix 2). The correlations suggest a common source for these three contaminants which is likely to be road runoff, as these are the most common contaminants in urban stormwater. Arsenic, cadmium and chromium were not highly correlated to any other metals ($R < 0.7$) for either species, suggesting the sources of these metals are quite different to copper, lead and zinc. Stormwater may still be the vector for these metals to enter the marine environment, however the sources may be more specific, e.g., related to specific industrial land uses.

For organic data mussels and oysters were assessed together. There were clear correlations between DDT and total chlordanes; total chlordanes and total PCBs; total chlordanes and dieldrin; and total PAHs and total PCBs (Figure Appendix 3). These correlations suggest similar sources, potentially agricultural land for the pesticides and industrial land for the PAHs and PCBs.

The only strong correlations ($R > 0.7$) exhibited across the two species between metals and organics were zinc with DDT; copper with DDT; and lead with PAHs (data not shown). The urban

stormwater source of the metals explains a high correlation with PAHs however the two correlations with predominantly agriculturally derived DDT are harder to define.

4.3 Effect of pre-deployment condition of mussels

Canonical analysis of principal coordinates (CAP) of the relationships between pre-deployment condition of mussels and concentrations of contaminants in their tissues, from 2009-2011, revealed a moderate correlation of 0.78. This correlation was unaffected by time. This suggests that pre-deployment condition (PDC) does have some effect, probably increasing variability and decreasing the ability to detect trends. Once more than 7 years have been sampled, analysis of trends can be undertaken using PDC as a covariate, hopefully reducing variability and clarifying trends. The results from this analysis would need to be put into the context of any trends (or lack of trends) observed within the longer time series.

4.4 Status summary

4.4.1 Site quality ranking

The relative quality of each mussel and oyster site was ranked, relative to contaminants and condition. Sites were ranked primarily based on average contaminant score, with condition score included for reference. Mussel site rankings are presented in Figure 4-10 with oyster site rankings presented in Figure 4-11. Note: a lower average contaminant score denotes better quality while a higher condition score denotes healthier shellfish.

Based on average contaminant score, mussel sites decreased in quality in the order: Pre-deployment; Papakura Channel; Illiomama; Weymouth; Chelsea; Upper Harbour; Mangere Bridge; Tamaki. The condition score for mussels appears to loosely follow an inverse relationship with average contaminant score for mussels (Figure 4-10). The site ranking for mussels is very similar to the qualitative ranking assessment provided in 2007 (Kelly 2007), suggesting only minimal relative change has occurred since that time.

Based on the average contaminant score, oyster sites decreased in quality in the order: Cornwallis; Hingaia; Pahurehure; Grannys Bay. The condition score for oysters appears to have a tighter inverse relationship with average contaminant score for oysters (Figure 4-11) than was observed for mussels. The ranking of oyster sites in unchanged from that provided in 2007 (Kelly 2007).

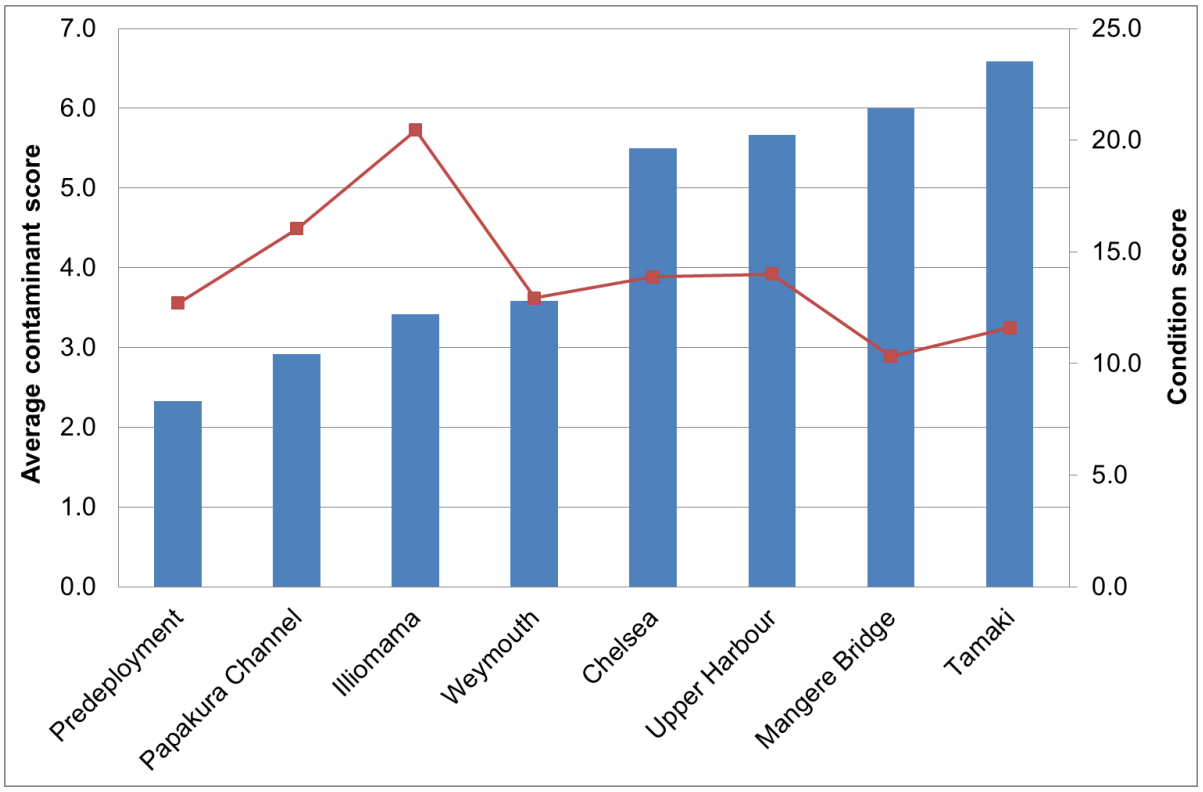


Figure 4-10 Ranking of mussel site quality by average contaminant score and median condition score. Blue columns denote contaminant score. Red line denotes condition score.

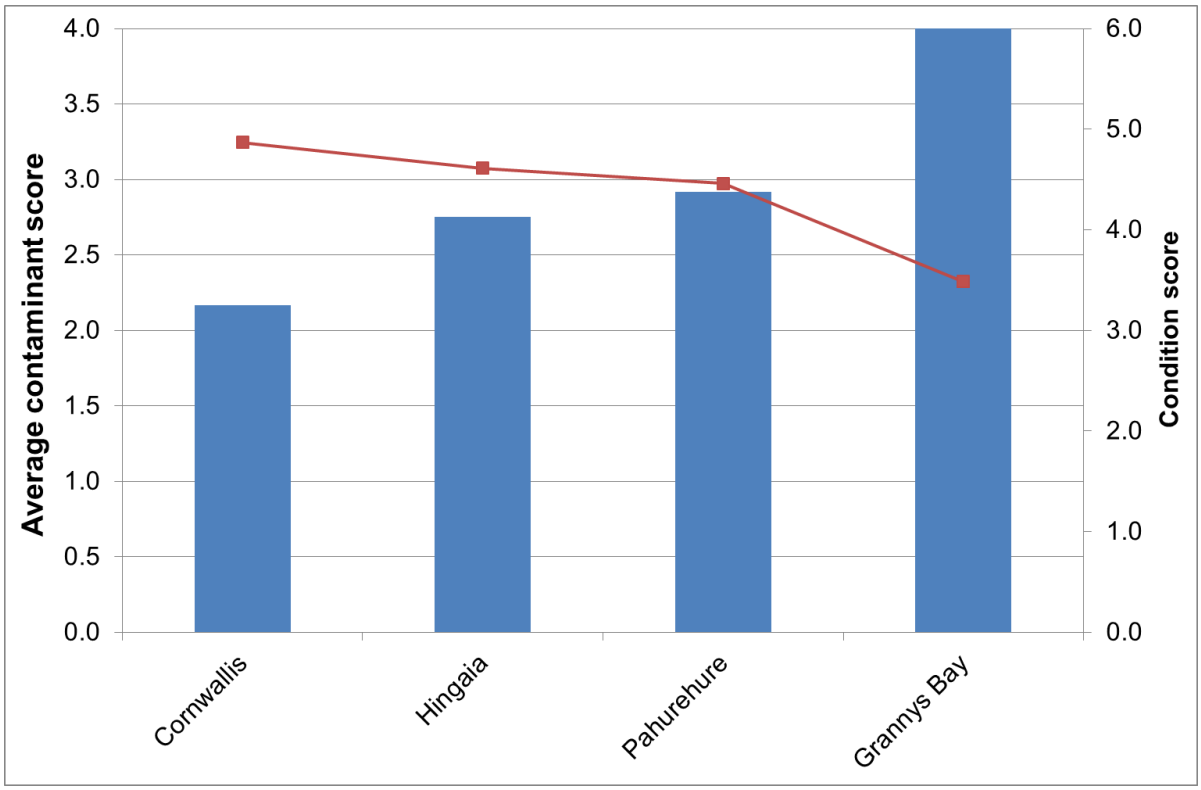


Figure 4-11 Ranking of oyster site quality by average contaminant score and median condition score. Blue columns denote contaminant score. Red line denotes condition score.

4.4.2 Multivariate analysis

Similarities in current site status based on the combined influence of contaminants and condition were examined using multivariate analysis (Figure 4-12 and Figure 4-13). Oyster sites occupied the bottom part of the Nonmetric multi-dimensional scaling (NMDS) ordination plot. The mussel sites of Chelsea, Mangere Bridge, Tamaki and Upper Harbour grouped together (Figure 4-12), as did the two oyster sites of Pahurehure and Hingaia (which are located very near to each other). The oyster site of Grannys Bay appears to be different from all other sites. Three mussel sites (Illiomama; Weymouth; Papakura Channel) and the pre-deployment mussels, group together with the two oyster sites of Mill Bay and Cornwallis. These sites (with the exception of Weymouth) are generally located in the outer harbour and further from contaminant sources than the others.

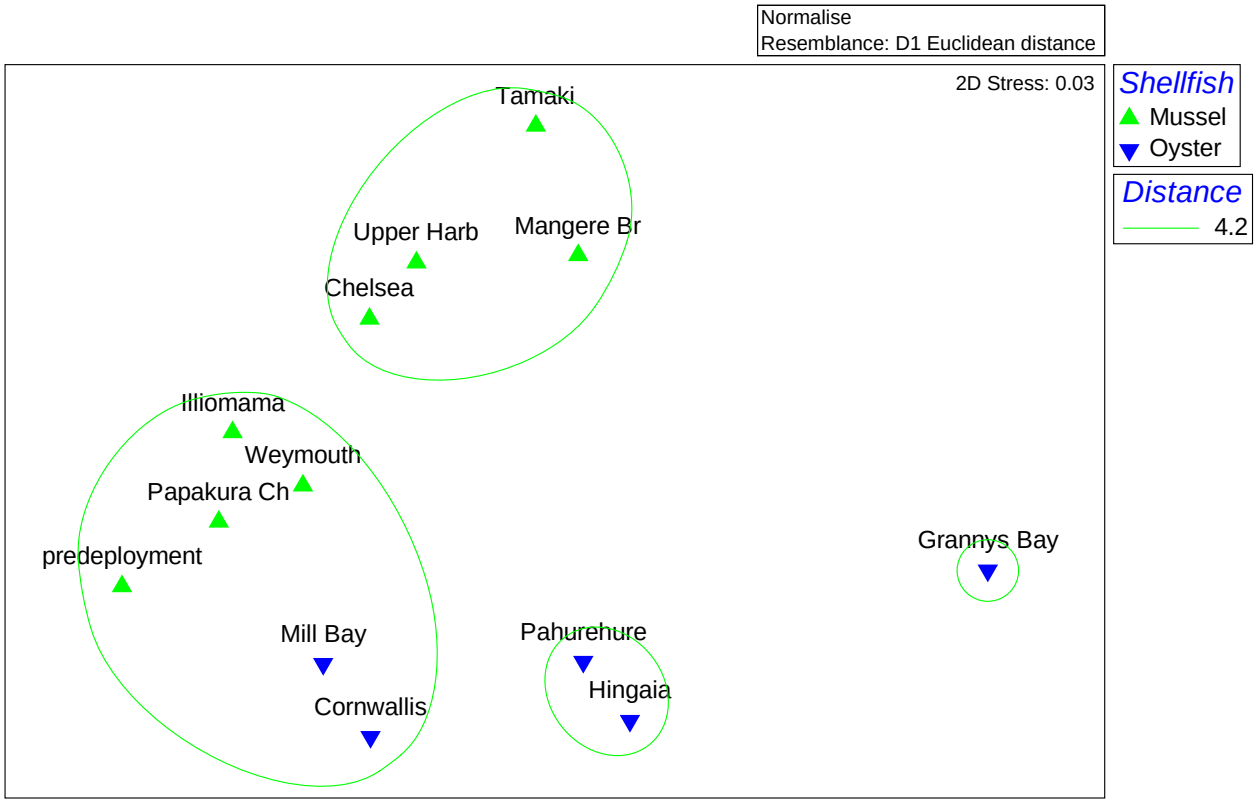
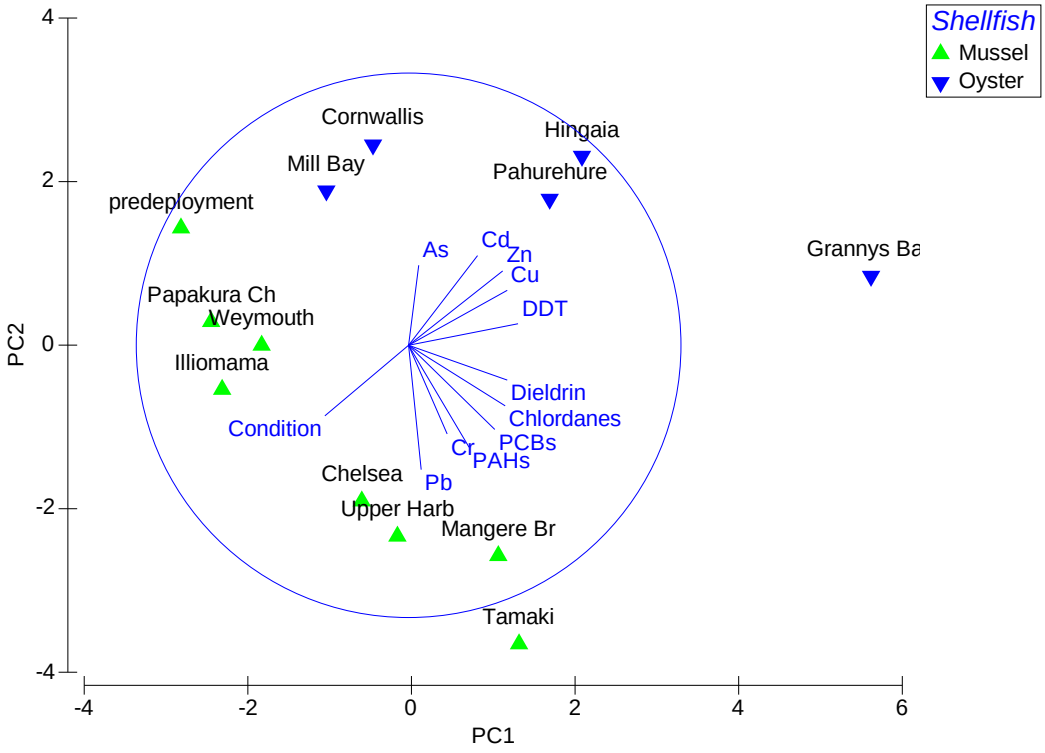


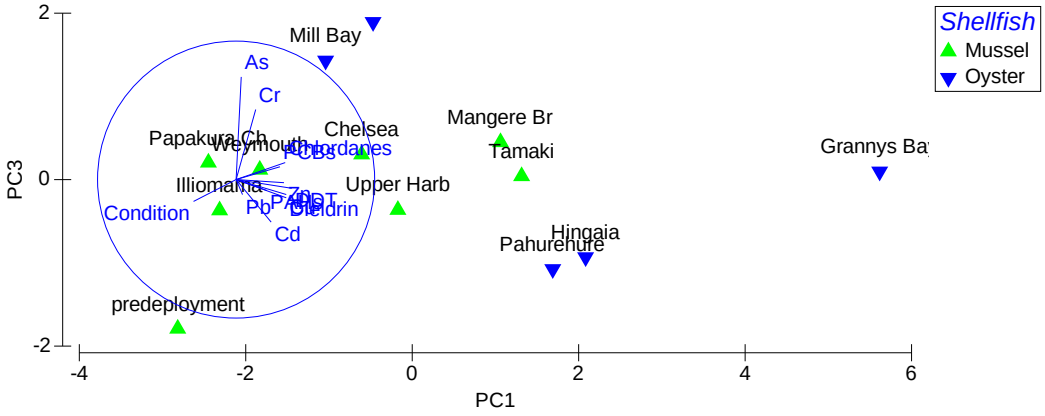
Figure 4-12 NMDS plot of the groupings between mussel and oyster sites based on condition and concentrations of key metals (dry weight) and organic suites (lipid normalised dry weight).

The PCA analysis also shows differences between mussel and oyster sites, predominantly due to higher concentrations of arsenic, cadmium, copper, zinc and DDT in oysters (Figure 4-13). Although there are also strong differences in condition, with the measure of condition in mussels being higher than oysters, this did not affect the PCA (no difference in the results of the analysis when condition was removed from the analysis (plot not shown)). The strongest drivers of differences between sites are arsenic, chromium, lead, condition and DDT (based on eigenvectors for PC1 to PC4 where PC1 explains 51.5% of the variation, PC2 explains 31.6% and PC3 and PC4 explain 6.6% and 4%, respectively). Differences between oyster and mussel sites generally

occurred along PC2, suggesting that PC1 is the best axis for summarising differences in contaminant status unassociated with differential uptake rates of the two species. Variables most strongly related to these differences were DDT, chlordane, copper, and PCBs.

When condition is included in the PCA there was little difference in the results compared to the analysis without condition. This, along with the results of site quality ranking discussed in the previous section, indicates that condition and contaminant concentrations are correlated. This suggests that condition is either strongly affected by the contaminants in the water column that the oysters and mussels are taking up, or by another factor that is strongly correlated with the contaminants but has not been measured.





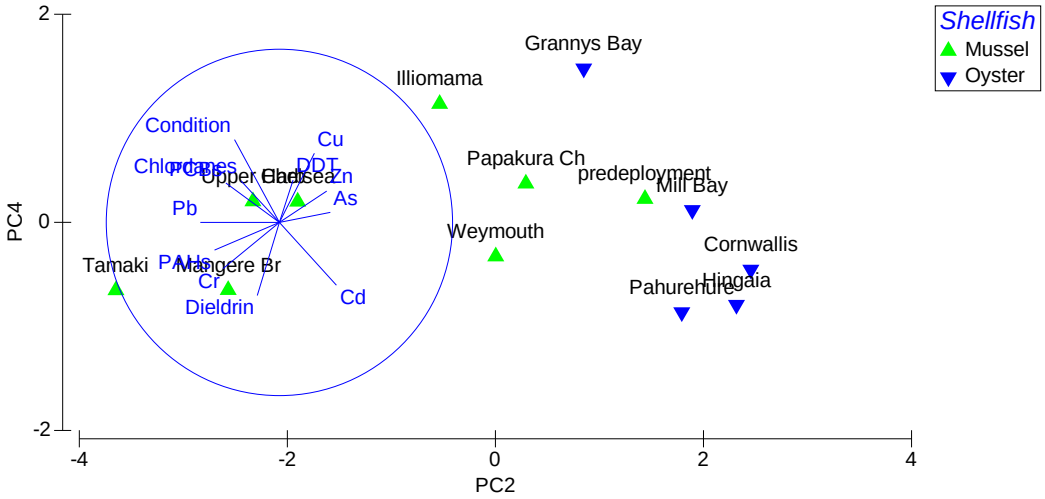


Figure 4-13 PCA plots of the differences between mussel and oyster sites based on condition and concentrations of key metals (dry weight) and organic suites (lipid normalised dry weight).

4.5 Links to land use

The overall contaminant concentrations and condition as quantified by PC1 score (51.5%) is shown for each site in relation to land use in Figure 4-14. For comparison, condition index in relation to land use is provided in Figure 4-15. The lowest PC1 scores - relating to lower contaminant concentrations - appear to be at the sites located in the outer parts of each harbour and the highest scores are in the upper reaches, or adjacent to urban land use.

Each site was assigned to a land use category based on the major land use in the upstream catchment, or to reference for the reference sites of Illiomama (mussels) and Mill Bay and Cornwallis (oysters). Figure 4-16 shows the between site groupings based on contaminant concentrations and condition with land use category as a factor. These results suggest a general increase in PC1 score (increasing contaminant concentrations) moving from reference sites (primarily indigenous forest), through semi-urban sites (e.g., Papakura Channel and Weymouth mussel sites; Hingaia oyster site), to urban sites (e.g., Mangere Bridge mussel site; Pahurehure and Grannys Bay oyster sites).

Differences of note are: Grannys Bay oyster site which is not grouped with any other sites; the oyster sites of Pahurehure and Hingaia group together despite different land uses. However, these are very closely located so although Hingaia has a rural upstream catchment it may be influenced by the neighbouring more urban catchments.

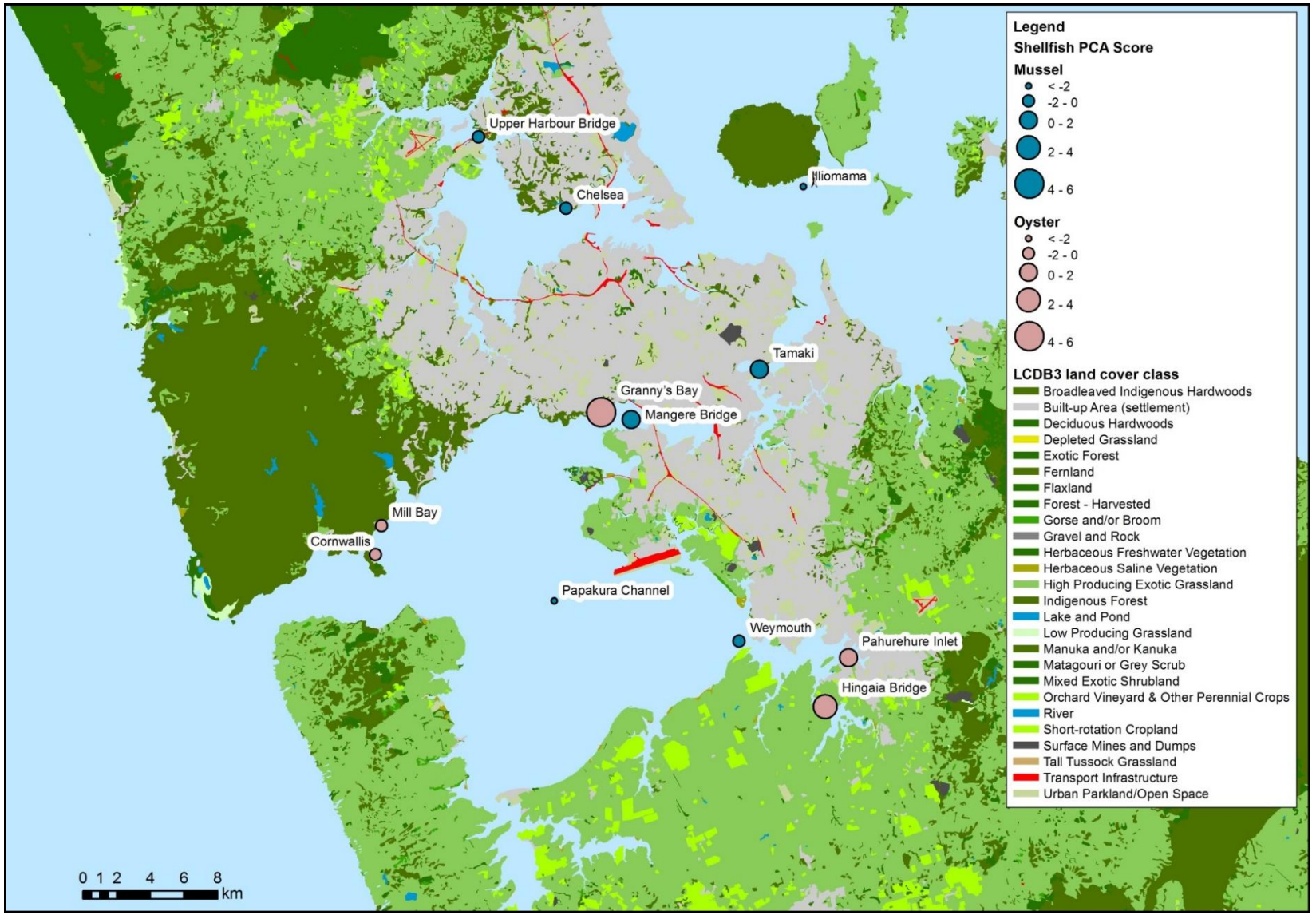


Figure 4-14 PC1 score for oysters and mussels compared to land use in the Auckland Region. Note that increasing circle size relates to increasing PCA score, and increasing contaminant concentrations

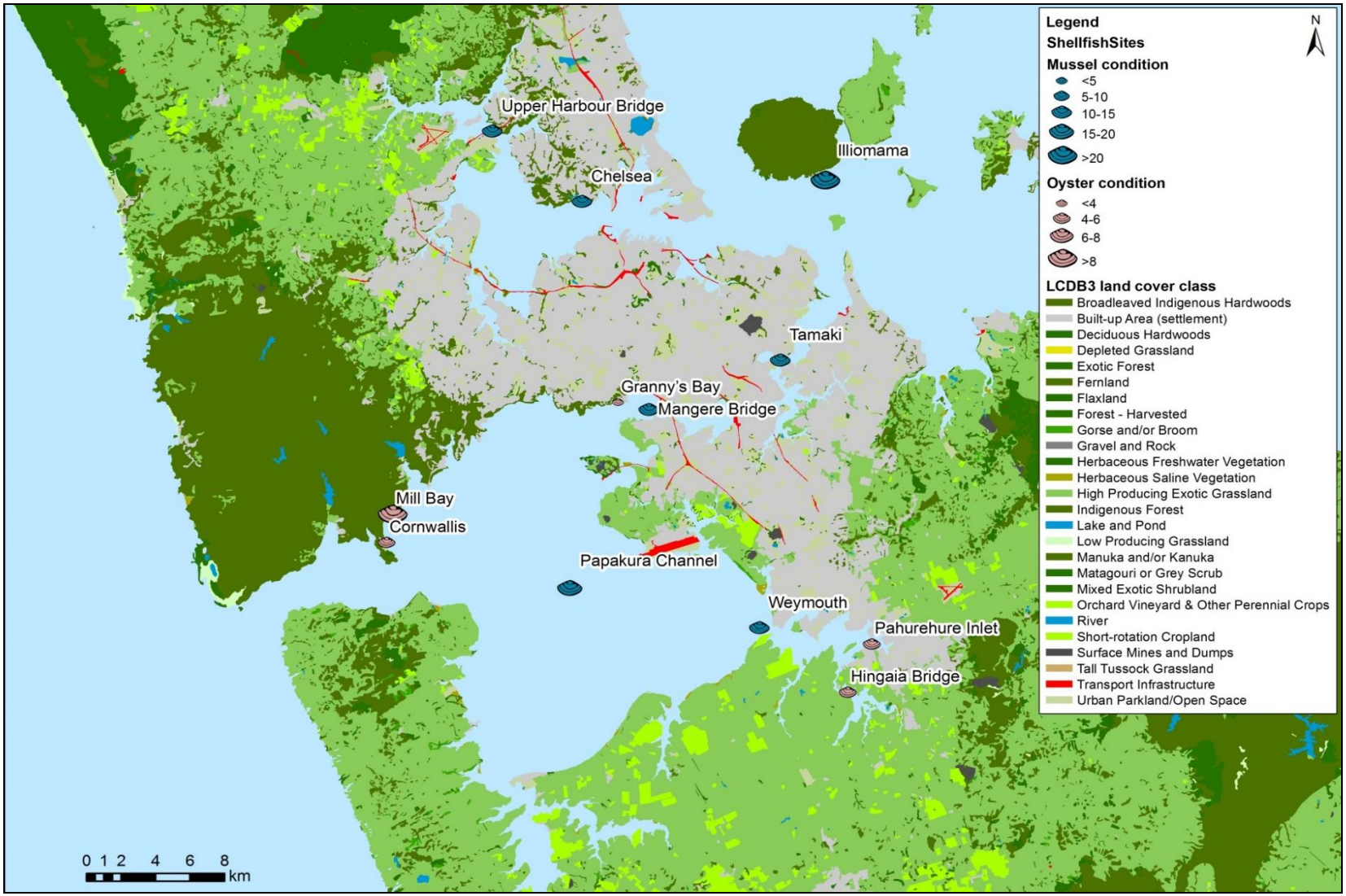


Figure 4-15 Condition index for oysters and mussels compared to land use in the Auckland Region.

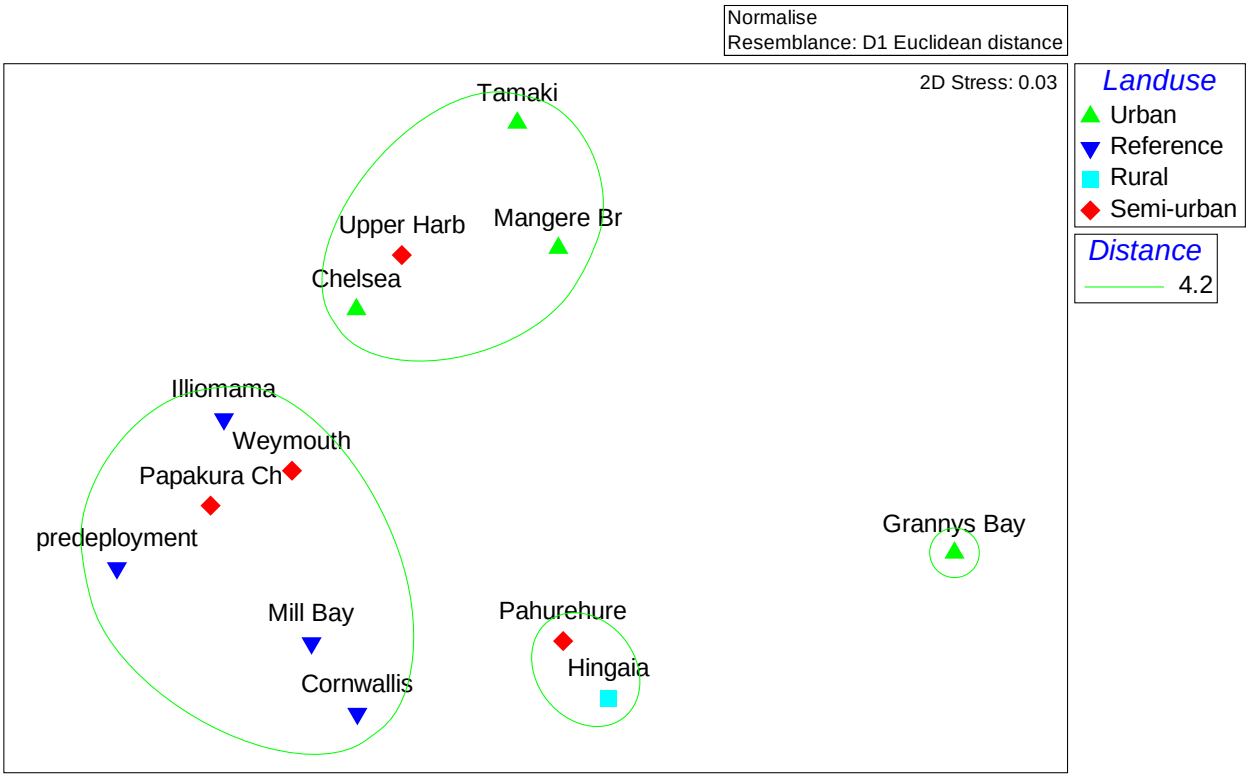


Figure 4-16 NMDS plot of groupings between mussel and oyster sites also showing land use, based on condition and concentrations of key metals (dry weight) and organic suites (lipid normalised dry weight).

Analysis of similarities (ANOSIM, Primer) based on these land use categories indicated an overall significant difference with a P-value of 0.04. Pairwise tests (Table 4-4) indicated that this difference is due to a significant difference between urban sites and reference sites (P-value 0.029). Differences between other groups were not statistically significant (Table 4-4), although this may be due to the lack of replication and the need to include both oysters and mussels in the same analysis.

Table 4-4 Summary of P-values from pairwise tests of different land use types using ANOSIM.

	Reference	Rural	Semi-urban	Urban
Reference	-	0.20	0.57	0.029
Rural	0.20	-	0.20	0.40
Semi-urban	0.57	0.20	-	0.14
Urban	0.029	0.40	0.14	-

A comparison of Land Cover Database version1 (LCDB1) and version2 (LCDB2) indicated that the Upper Harbour mussel site is the only site where there has been any change in land-use which is more than minor. Even at this site, the overall change in land use is small compared to the total size of the catchment. Therefore, no assessment of the influence of land use trends on contaminant concentrations or condition was undertaken.

5.0 Trends

5.1 Statement on significance

As covered in section 2.4.3, trends have been categorised into:

- Non-significant (P > 0.05).
- Significant but not meaningful (P < 0.05 *but* RSKSE value < 1% per year).
- Significant and meaningful (P < 0.05 *and* RSKSE value >1% per year).

Non-significant trends are still included in the results section, as they give a holistic view of trends across the area and indicate the general direction of change. As the threshold between significant and non-significant trends is arbitrary (P value of 0.05), it is useful to view non-significant trends in context of significant trends. The direction of non-significant trends can be useful, as they might be indicative of an emerging future issue. There were no significant trend results that were not meaningful when analysed by the Time Trends method (section 5.3) and only one by the Akritas-Theil-Sen (ATS) nonparametric regression method (an alternate method for censored data, see section 5.4). All significant and meaningful trends have been highlighted red (when increasing) and blue (when decreasing).

As stated in section 2.4.3, trends can be detected in short term data which are in conflict to longer term data. Even though longer time trends are more reliable, shorter trends can provide information on more recent changes in contaminant concentrations or condition that are potentially lost in the longer term trend period. Therefore, it is important to examine the results of all trend time periods both statistically (as above) and graphically, by examining plots of data.

5.2 Comparison of post deployment and pre-deployment data for mussels

Trend comparisons between raw mussel contaminant data and pre-deployment subtracted contaminant data were made for the 6 key metals (Table 5-1) and organics suites (Table 5-2), using Time Trends.

The metals data trends were clearly affected by pre-deployment subtraction (Table 5-1). This was due to the concentrations of metals in the pre-deployment mussels being higher than at many sites, resulting in many negative values for cadmium, lead and zinc and for copper at some sites.

Conversely, organic suite trends were not affected by pre-deployment subtraction (Table 5-2), as concentrations of organics at the pre-deployment sites were very low in comparison to the SCMP sites.

These data suggest that pre-deployment subtraction is not a useful approach for trends analysis (especially for metals data) and that future trends should be undertaken on raw mussel data. All subsequent contaminant trends in this report are based on dry weight data which have not been pre-deployment subtracted.

Table 5-1 Comparison of trends for raw mussel data and pre-deployment subtracted mussels data for 6 key metals from 1999-2011.

	Tamaki	Upper Harbour	Chelsea	Illiomama	Mangere Bridge	Weymouth	Papakura Channel	Median RSKSE
Arsenic	↑	↑	↑	↓	↑	↓	↓	↓
Arsenic (-PD)	↓	↑	↑	↑	↓	↑	↑	↓
Cadmium	↓	↑	↑	↑	↑	↑	↑	↓
Cadmium (-PD)	↑	↑	↑	↑	↑	↑	↑	↑
Chromium	→	↓	↓	↓	↓	↓	↓	↓
Chromium (-PD)	↑	↓	↑	↑	↓	↓	↓	↓
Copper	↓	↑	↓	↓	↓	↓	↓	↓
Copper (-PD)	↓	↓	↓	↓	↓	↓	↓	↓
Lead	↓	↓	↓	↓	↓	↓	↓	↓
Lead (-PD)	↑	↑	↑	↑	↑	→	↓	↓
Zinc	↑	↑	↑	↓	↓	↑	↑	↓
Zinc (-PD)	↑	↓	↓	↑	↓	↓	↓	↓

Significant and meaningful trends have been highlighted in red (increasing) and blue (decreasing); non-significant trends are not highlighted; → = median value of 0; (-PD) = pre-deployment subtracted.

Table 5-2 Comparison of trends for raw mussel data and pre-deployment subtracted mussels data for organic contaminant suites from 1999-2011.

	Tamaki	Upper Harbour	Chelsea	Illiomama	Mangere Bridge	Weymouth	Papakura Channel	Median RSKSE
Limited suite DDTs	↓	↑	↓	↑	→	↓	↓	↓
Limited suite DDTs (-PD)	↓	↓	↓	↓	↓	↓	↓	↓
Extended suite DDTs	↓	↓	↓	↓	↓	↓	↓	↓
Extended suite DDTs (-PD)	↓	↓	↑	↑	↓	↓	↓	↓
Limited suite Chlordanes	↓	↓	↓	↓	↓	↓	↓	↓
Limited suite Chlordanes (-PD)	↓	↓	↓	↓	↓	↓	↓	↓
Extended suite Chlordanes	↓	↓	↓	↓	↓	↓	↓	↓
Extended suite Chlordanes (-PD)	↓	↓	↓	↓	↓	↓	↓	↓
Limited suite PAHs	↓	↑	↓	↓	↓	↓	↓	↓
Limited suite PAHs (-PD)	↓	↑	↑	↓	↓	↓	↓	↓
Extended suite PAHs	↓	↑	↓	↓	↑	↓	↓	↓
Extended suite PAHs (-PD)	↓	↑	↑	↓	↑	↓	↓	↓
Limited suite PCBs	↓	↓	↓	↓	↓	↓	↓	↓
Limited suite PCBs (-PD)	↓	↓	↓	↓	↓	↓	↓	↓
Extended suite PCBs	↓	↓	↓	↓	↓	↓	↓	↓
Extended suite PCBs (-PD)	↓	↓	↓	↓	↓	↓	↓	↓
Dieldrin	↓	↓	↓	↓	↓	↓	↓	↓
Dieldrin (-PD)	↓	↓	↓	↓	↓	↓	↓	↓

Significant and meaningful trends have been highlighted in blue (decreasing); non-significant trends are not highlighted; (-PD) = pre-deployment subtracted; → = median value of 0

5.3 Contaminant temporal trend analysis using time trends

5.3.1 Metals

5.3.1.1 Oyster metals 1987-2011

For the 1987-2011 time period, there were significant and meaningful declining trends in cadmium at Grannys Bay, copper at Cornwallis and Hingaia, and in lead at Cornwallis (Table 5-3 & Figure 5-1). Other trends were not significant but have been included in Appendix E (Figure Appendix 4) for reference. Generalising over all sites, arsenic was increasing (3 out of 4 sites) and cadmium (4/4), chromium (4/4), copper (4/4) and lead (4/4) were decreasing. Zinc was increasing at two sites and decreasing at two sites (Table 5-3).

Table 5-3 Summary of metal trends in oysters from 1987 to 2011.

	Grannys Bay	Pahurehure	Hingaia	Cornwallis
Arsenic	↑	↓	↑	↑
Cadmium	↓	↓	↓	↓
Chromium	↓	↓	↓	↓
Copper	↓	↓	↓	↓
Lead	↓	↓	↓	↓
Zinc	↑	↓	↓	↑

Significant and meaningful trends have been highlighted blue (decreasing); non-significant trends are not highlighted; no trends for Mill Bay (2008/2009 data only).

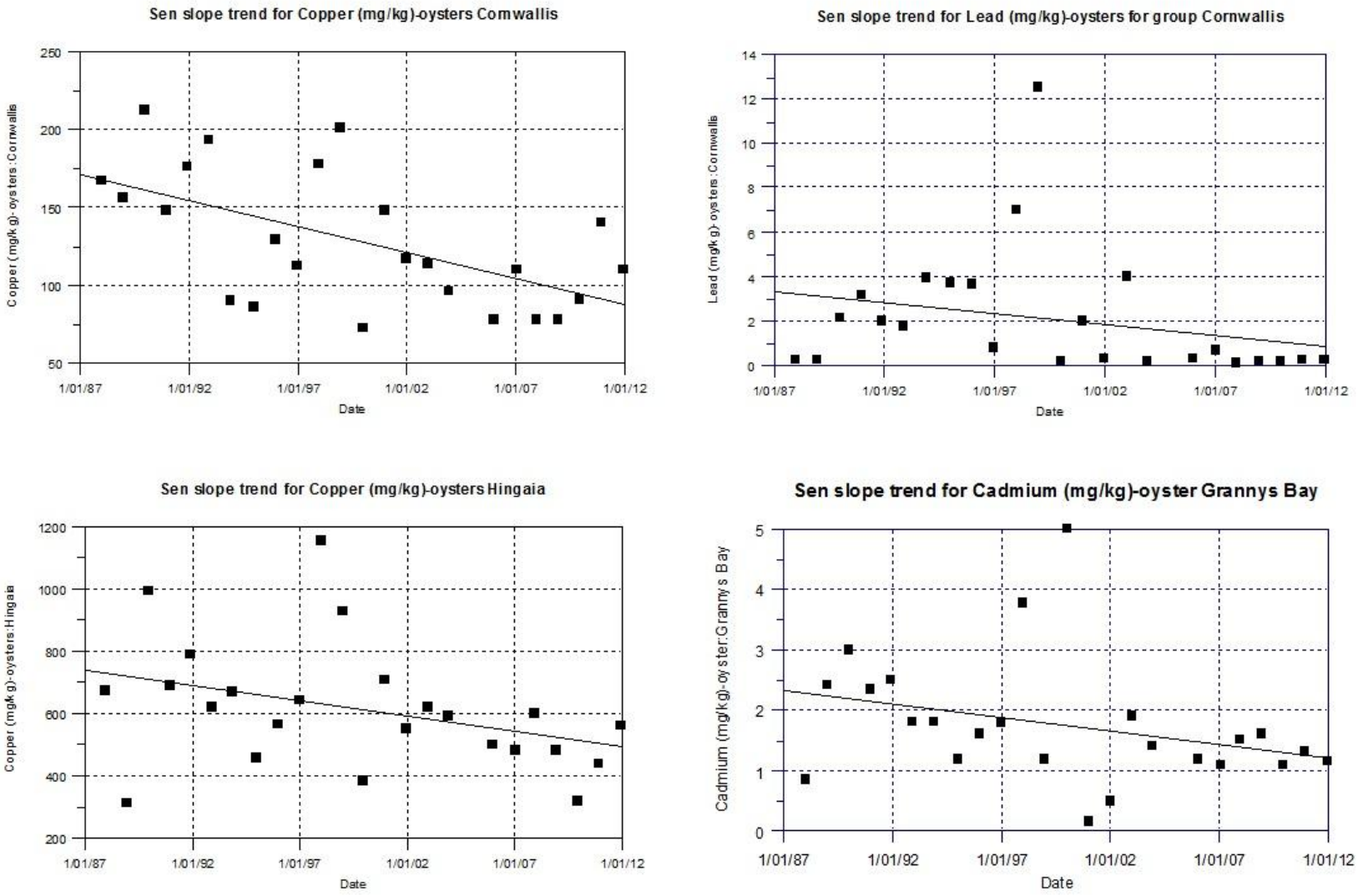


Figure 5-1 Significant and meaningful trends in heavy metals at oyster sites (1987-2011). Data points are median values from five replicates.

5.3.1.2 Oyster metals 1999-2011

For the 1999–2011 time period, there were significant and meaningful increasing trends in copper at Grannys Bay, and in zinc at Grannys Bay and Hingaia. Overall zinc (4 out of 4 sites), arsenic (3/4) and cadmium (2/4) were increasing while lead (4/4) and chromium (4/4) were decreasing (Table 5-4).

Table 5-4 Summary of metal trends in oysters from 1999 to 2011.

	Grannys Bay	Pahurehure	Hingaia	Cornwallis
Arsenic	↑	↑	↓	↑
Cadmium	↓	→	↑	↑
Chromium	↓	↓	↓	↓
Copper	↑	↑	↓	↓
Lead	↓	↓	↓	↓
Zinc	↑	↑	↑	↑

Significant and meaningful trends have been highlighted in red (increasing); non-significant trends are not highlighted; no trends for Mill Bay (2008/2009 data only); → designates median value of 0

Interestingly - as illustrated in Figure 5-2 - the three significant and meaningful increases observed for metals in the 1999-2011 time period were not consistent with the longer time period (1987-2011) specifically:

- The significant and meaningful increasing copper trend at Grannys Bay observed over the shorter time period was a decreasing trend (although not significant) over the full time series (1987-2011).
- The significant and meaningful increasing zinc trend at Grannys Bay over the shorter time period was an increasing trend (although not significant) over the full time series.
- The significant and meaningful increasing zinc trend at Hingaia observed over the shorter time period was a decreasing trend (although not significant) over the full time series (1987-2011).

This lack of concordance between significant and meaningful trends observed for some oyster metal concentrations for the two time periods is not surprising as changes in contaminant loads entering the environment are not necessarily linear over time. For example, short term spikes in concentration of some contaminants may be attributable to mobilisation of sediment due to urban development, which will exhibit a short term increase in environmental concentrations (and hence an increasing short term trend) but in the context of a longer time frame may still be reduced (and hence show a decreasing long term trend).

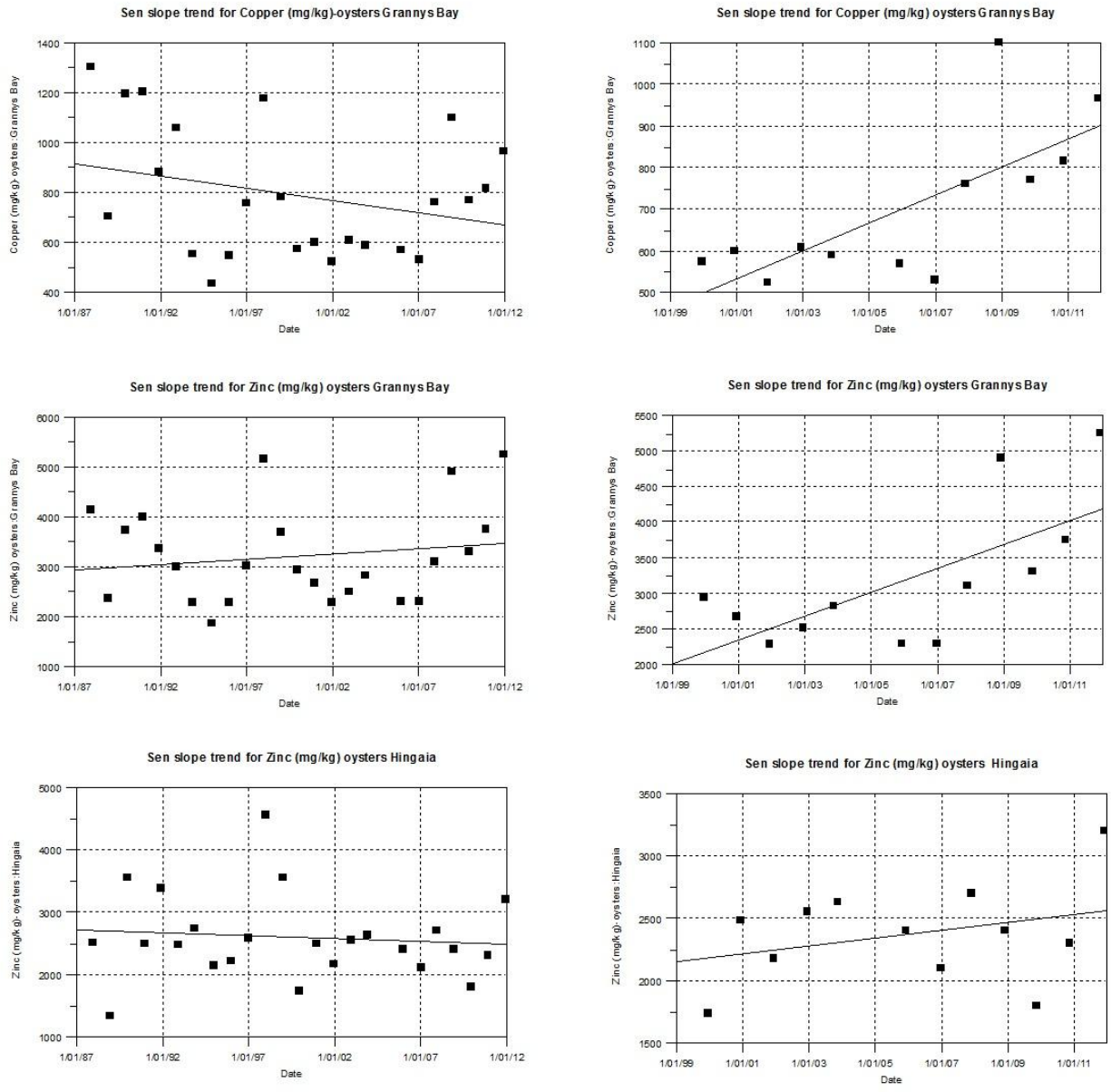


Figure 5-2 Comparisons of oyster heavy metal trends over 1987-2011 (left column) and 1999-2011 (right column)

5.3.1.3 Mussel metals 1999-2011

For the 1999-2011 time period there were significant and meaningful declining trends in chromium at Papakura Channel, Mangere Bridge and Weymouth, and in zinc at Illiomama (Table 5-5 & Figure 5-3). Other trends were not significant but have been included in Appendix A (Figure Appendix 6). Generalising across all sites, increasing trends (most not significant) were observed for arsenic (4 out of 7 sites), cadmium (6/7) and zinc (5/7), while decreasing trends were observed for chromium (6/7), copper (6/7) and lead (7/7).

Table 5-5 Summary of metal trends in mussels from 1999 to 2011

	Tamaki	Upper Harbour	Chelsea	Illiomama	Mangere Bridge	Weymouth	Papakura Channel	PD
Arsenic	↑	↑	↑	↓	↑	↓	↓	↓
Cadmium	↓	↑	↑	↑	↑	↑	↑	↑
Chromium	→	↓	↓	↓	↓	↓	↓	↓
Copper	↓	↑	↓	↓	↓	↓	↓	↓
Lead	↓	↓	↓	↓	↓	↓	↓	↓
Zinc	↑	↑	↑	↓	↓	↑	↑	↑

Significant and meaningful trends have been highlighted in blue (decreasing); non-significant trends are not highlighted; all data are dry weight; → designates median value of 0; PD = pre-deployment mussels.

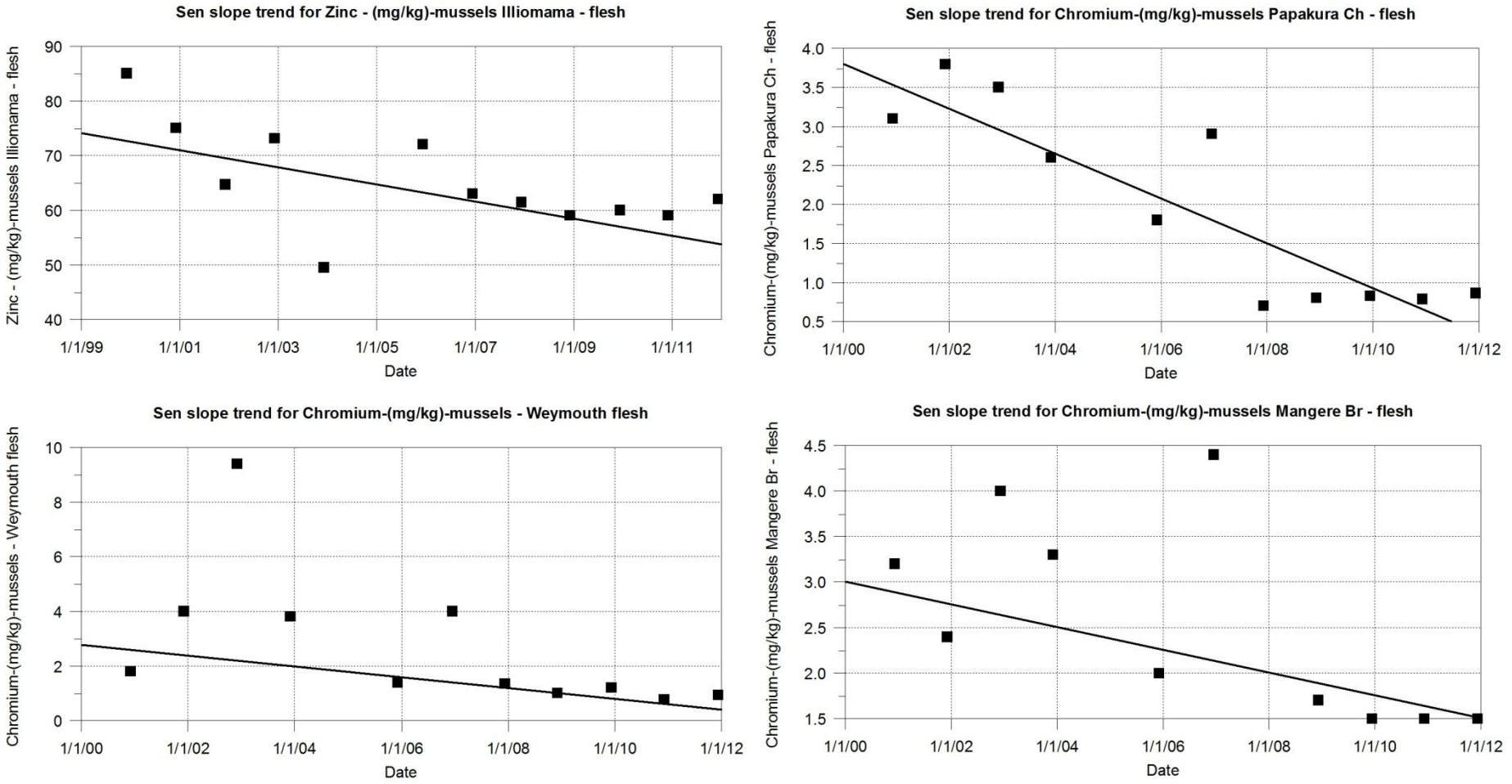


Figure 5-3 Significant and meaningful trends in heavy metals at mussel sites. Trends are clockwise from top left: zinc at Illiomama; chromium at Papakura Channel; chromium at Mangere Bridge; chromium at Weymouth. Trends are 2000-2011 for all except Illiomama (1999-2011). Data points are median values from five replicates.

5.3.2 Organics

To put the organics trend data in perspective, it is important to understand when these chemicals were prohibited from use. The use of persistent organochlorine pesticides (those specifically relating to the SCMP: DDTs; chlordanes; lindane; dieldrin; hexachlorobenzene) was progressively restricted by a succession of legislation, so that, by the mid-1970s their use had effectively ceased in agriculture and horticulture. All persistent organochlorine pesticides were formally deregistered in 1989 (Buckland*, et al.* 1998). Even though the input had effectively ceased prior to the establishment of the SCMP, the persistence of these contaminants provides a legacy residual in the environment that takes decades to diminish. Nevertheless, concentrations are expected to reduce over time, unless fresh sources of these contaminants are released, for example, by mobilisation and re-suspension of previously contained contaminated sediments.

PCBs were progressively phased out later than organochlorine pesticides, between 1986 and 1995 (Buckland*, et al.* 1998). PAHs are a diffuse, continuing, and likely increasing source of urban pollution associated primarily with anthropogenic activity such as motor vehicle emissions, roading materials such as coal tar, and wood and coal burning fires (Kelly 2007).

5.3.2.1 Oyster Organics 1987-2011

1987-2011 Dry weight

Organics in oysters (dry weight) are all declining over the 1987-2011 time period, and for most contaminants, the declining trends are significant and meaningful (Table 5-6). Out of the four sites, fewest significant and meaningful trends were observed at Cornwallis.

Table 5-6 Summary of organics trends in oysters (dry weight) from 1987 to 2011.

	Grannys Bay	Pahurehure	Hingaia	Cornwallis
Lipid content (% DW)	↓	↓	↓	↑
Limited suite DDTs	↓	↓	↓	↓
Extended suite DDTs	↓	↓	↓	↓
Limited suite Chlordanes	↓	↓	↓	↓
Extended suite Chlordanes	↓	↓	↓	↓
Limited suite PAHs	↓	↓	↓	↓
Extended suite PAHs	↓	↓	↓	↓
Limited suite PCBs	↓	↓	↓	↓
Extended suite PCBs	↓	↓	↓	↓
Dieldrin	↓	↓	↓	↓

Significant and meaningful trends have been highlighted in blue with darker blue for trends consistent over both time periods (see Table 5-8); non-significant trends are not highlighted; no trends for Mill Bay (2008/2009 only); lindane (no trend data).

Selected examples of significant and meaningful decreasing trends of organic contaminant suites for oysters are illustrated in Figure 5-4. Trends for all lipid content and extended suite organics are provided for reference in Appendix E (Figure Appendix 5).

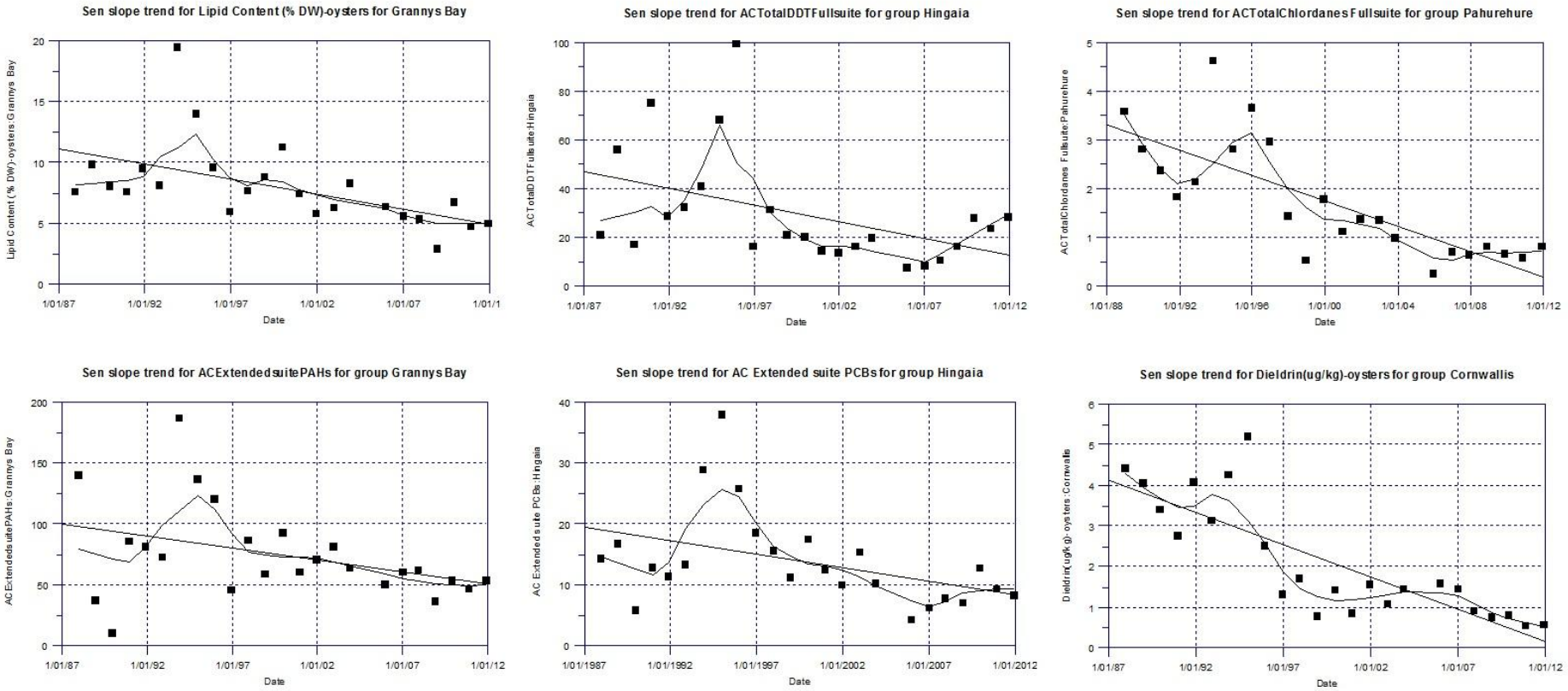


Figure 5-4 Significant and meaningful trends in lipid content and selected organic contaminant suites at oyster sites (1987-2011). Note Pahurehure (1988 to 2011). Data points are median values from five replicates.

1987-2011 Lipid normalised

All oyster lipid normalised trends for the 1987-2011 time period were declining (many were significant and meaningful), with the exception of extended suite PAHs at Grannys Bay which were increasing, however the increase was not statistically significant (Table 5-7).

Table 5-7 Summary of organics trends in oysters (lipid normalised) from 1987 to 2011.

1987-2011	Grannys Bay	Pahurehure	Hingaia	Cornwallis
Limited suite DDTs	↓	↓	↓	↓
Extended suite DDTs	↓	↓	↓	↓
Limited suite Chlordanes	↓	↓	↓	↓
Extended suite Chlordanes	↓	↓	↓	↓
Limited suite PAHs	↓	↓	↓	↓
Extended suite PAHs	↑	↓	↓	↓
Limited suite PCBs	↓	↓	↓	↓
Extended suite PCBs	↓	↓	↓	↓
Dieldrin	↓	↓	↓	↓

Significant and meaningful trends have been highlighted in blue with darker trends consistent over both time periods (see Table 5-9); non-significant trends are not highlighted; no trends for Mill Bay (2008/2009 only); lindane (no trend data).

Comparison of trends in dry weight data with those in lipid normalised data shows that there was little difference in trend direction. The exception to this was Grannys Bay, as described above. There were, however, fewer significant and meaningful trends in the lipid normalised data (23) than in the dry weight data (26).

5.3.2.2 Oyster Organics 1999-2011

1999-2011 Dry weight

There are declining trends, many of them significant and meaningful, in the majority of compounds over the 1999-2011 time period (Table 5-8). Unlike metals trends, many of the significant and meaningful trends detected in the 1999-2011 organics trends data were also detected in the full time series (1987-2011), suggesting trends from the shorter time period adequately reflect overall trends in the programme.

Comparing the dry weight trends for the two time periods shows that there are a greater number of significant and meaningful trends (26) for the full time series (Table 5-6) than in the shorter time series (16) (Table 5-8). Also, some of the trends for the shorter time period were in a different direction to those for the longer time period, e.g., limited and total suites of DDTs at Hingaia and Pahurehure were declining over the 1987-2011 period, but increasing over the 1999-2011 time period. This is not surprising as the greatest decreases in contaminant concentrations occurred prior to 1999, after which concentration changes have become much less pronounced and in some cases have slightly increased (see Figure 5-4). Over both time periods, lipid content was increasing at Cornwallis, but decreasing at Hingaia, Grannys Bay (significant and meaningful) and

Pahurehure. Trends over shorter time periods need to be set in the context of the longer time periods, as they may indicate a recent reduction or increase of contaminant inputs that are not present in the long term trend data.

Table 5-8 Summary of organics trends in oysters (dry weight) from 1999 to 2011.

1999-2011	Grannys Bay	Pahurehure	Hingaia	Cornwallis
Lipid content (%DW)	↓	↓	↓	↑
Limited suite DDTs	↓	↑	↑	↓
Extended suite DDTs	↓	↑	↑	↓
Limited suite Chlordanes	↓	↓	↓	↓
Extended suite Chlordanes	↓	↓	↓	↓
Limited suite PAHs	↓	↓	↓	↓
Extended suite PAHs	↓	↓	↓	↓
Limited suite PCBs	↓	↓	↓	↓
Extended suite PCBs	↓	↓	↓	↑
Dieldrin	↓	↓	↓	↓

Significant and meaningful trends have been highlighted in blue with darker trends consistent over both time periods (see Table 5-6); non-significant trends are not highlighted; no trends for Mill Bay (2008/2009 only); lindane (no trend data).

1999-2011 Lipid normalised

There were 14 increasing lipid normalised trends (out of 36) for the 1999-2011 time period. All DDT trends were increasing (meaningfully at Hingaia), along with extended suite PAHs and both PCB suites at Grannys Bay, limited suite PCBs and dieldrin at Hingaia and dieldrin at Pahurehure (Table 5-9).This is in contrast to the longer term lipid normalised trends, which were all decreasing except Grannys Bay extended suite PAHs (Table 5-7).

Table 5-9 Summary of organics trends in oysters (lipid normalised) from 1999 to 2011.

1999-2011	Grannys Bay	Pahurehure	Hingaia	Cornwallis
Limited suite DDTs	↑	↑	↑	↑
Extended suite DDTs	↑	↑	↑	↑
Limited suite Chlordanes	↓	↓	↓	↓
Extended suite Chlordanes	↓	↓	↓	↓
Limited suite PAHs	↓	↓	↓	↓
Extended suite PAHs	↑	↓	↓	↓
Limited suite PCBs	↑	↓	↑	↓
Extended suite PCBs	↑	↓	↓	↓
Dieldrin	↓	↑	↑	↓

Significant and meaningful trends have been highlighted in blue (decreasing) or red (increasing); non-significant trends are not highlighted; All significant and meaningful reducing trends observed in 1999-2011

time period were also observed in 1987-2011 time period (see Table 5-7); no trends for Mill Bay (2008/2009 only); lindane (no trend data).

As for the dry weight data, there are fewer significant and meaningful trends in lipid normalised data (10) over the shorter time period (Table 5-9) compared to the full time series (23) (Table 5-7). Also, trends in some compounds changed direction, e.g., limited and total DDTs were declining over the longer time period, but for the shorter time period were increasing at all sites, with a significant and meaningful increase at Hingaia. Trends in dieldrin also changed direction at Hingaia and Pahurehure between the two time periods: there was a significant and meaningful decline in dieldrin for the longer time period but an increase (though not significant) for the shorter time period. The differences observed in the number of significant trends and in trend directions again highlight the importance of examining shorter term trends in the context of longer term trends.

Comparison shows that there are fewer meaningful and significant trends in lipid normalised data than in dry weight data for the period 1999-2011. At Cornwallis, Grannys Bay and Hingaia, trends in DDT were declining in dry weight data, while in lipid normalised data, trends in DDT were increasing at Cornwallis and Grannys Bay, and meaningfully and significantly increasing at Hingaia. Dieldrin was declining in dry weight data at Hingaia and Pahurehure but increasing in lipid normalised data, while trends in PCBs were declining in dry weight data and increasing for lipid normalised data at Grannys Bay and Hingaia. PAHs were also declining at Grannys Bay in dry weight data, but were increasing in lipid normalised data. As with the mussels, the lipid content of the oysters is not stable. Looking at the trends in lipids, for both the longer and shorter time periods lipid content was increasing at Cornwallis, and decreasing at Grannys Bay, Hingaia and Pahurehure. The fact that lipid content has been changing over time and questions have arisen as to the robustness of the lipid measurement procedure (see section 3.2.3), lipid normalised data may not be suitable for long term temporal trends.

5.3.2.3 Mussel Organics 1999-2011

1999-2011 Dry weight

There were overall declining trends in most compounds for this time period (Table 5-10). There were significant, meaningful declining trends for chlordanes (limited and extended suites), PCBs (limited and extended suites) and dieldrin at most sites. None of the trends for the dry weight pre-deployment mussels were significant.

Selected examples of significant and meaningful decreasing trends of organic contaminant suites for mussel are illustrated in Figure 5-5. Trends for all lipid content and extended suite organics are provided for reference in Appendix E (Figure Appendix 7).

Table 5-10 Summary of organics trends in mussels (dry weight) from 1999 to 2011.

	Tamaki	Upper Harbour	Chelsea	Illiomama	Mangere Bridge	Weymouth	Papakura Channel	PD
Lipid Content	↓	↓	↓	↑	↓	↓	↓	↓
Limited suite DDTs	↓	↑	↓	↑	→	↓	↓	↑
Extended suite DDTs	↓	↓	↓	↓	↓	↓	↓	↑
Limited suite Chlordanes	↓	↓	↓	↓	↓	↓	↓	→
Extended suite Chlordanes	↓	↓	↓	↓	↓	↓	↓	→
Limited suite PAHs	↓	↑	↓	↓	↓	↓	↓	↓
Extended suite PAHs	↓	↑	↓	↓	↑	↓	↓	↓
Limited suite PCBs	↓	↓	↓	↓	↓	↓	↓	↑
Extended suite PCBs	↓	↓	↓	↓	↓	↓	↓	↑
Dieldrin	↓	↓	↓	↓	↓	↓	↓	↑

Significant and meaningful trends have been highlighted in blue (decreasing); non-significant trends are not highlighted; all data are dry weight; → designates median value of 0; lindane (no trend data); PD = pre-deployment mussels.

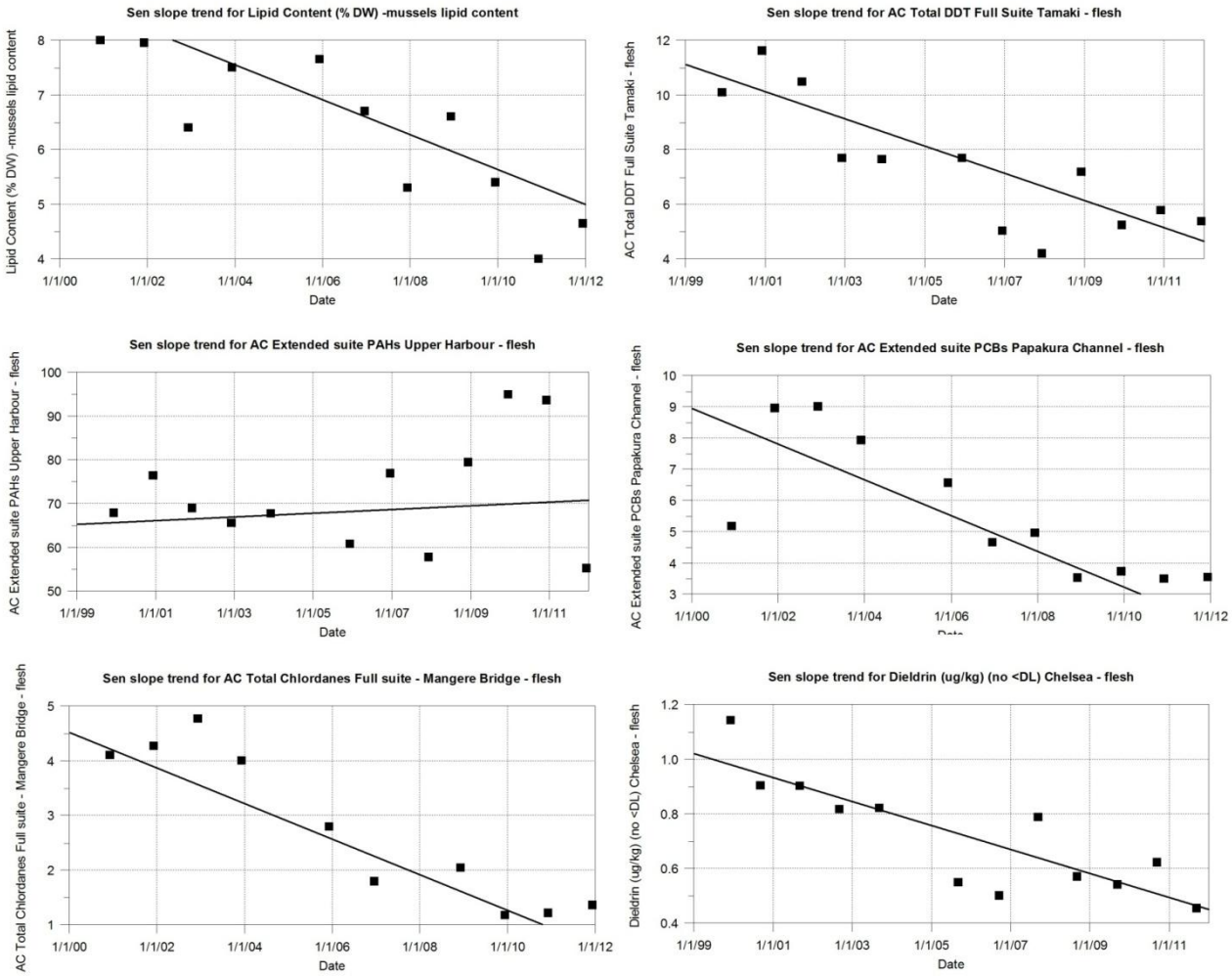


Figure 5-5 Trends in lipid content and selected organic contaminant suites at selected mussel sites (1999-2011). All trends are significant and meaningful except PAHs. Data points are median values from five replicates.

1999-2011 Lipid normalised

As for dry weight data, most trends were declining. There were significant, meaningful declining trends in chlordanes at all sites except Tamaki (limited suite) and all sites except Tamaki and Illiomama (extended suite). There were significant, meaningful declining trends for PCBs at Papakura Channel (limited and extended suites) and Illiomama (extended suite). There were significant, meaningful increasing trends in PAHs at Upper Harbour (Table 5-11).

Comparing trends in dry weight data with those in lipid normalised data for the 1999 - 2011 period shows there is little disparity between the two sets of data for the significant and meaningful trends. However, as with oyster data, there were fewer significant, meaningful trends in the lipid normalised data (18) than the dry weight data (27).

Dry weight trend directions sometimes differ from those for lipid normalised data. Of the 63 dry weight trends (Table 5-10), there are 16 lipid normalised trends in the opposite direction (Table 5-11). However, none of these discrepancies are for meaningful or significant trends.

5.3.2.4 Dry weight versus lipid normalised trends

Importantly, dry weight and lipid normalised trend data are in complete agreement for significant and meaningful trends. Even though there are some anomalies between the two sets of data for trends that are not significant and meaningful, this is most likely due to compounding errors on very small changes for these temporal trends. Both contaminant and lipid measurements have inherent errors involved. Furthermore, with some doubt existing as to the robustness of the lipid measurement over time (see section 3.2.3), these anomalies are likely.

It is important to perform trend analysis of organic data on both the dry weight data and lipid normalised data. This provides extra insurance that significant and meaningful trends are correct (when in agreement) or that an error has occurred somewhere in the process (when they are not in agreement).

Table 5-11 Summary of organics trends in mussels (lipid normalised) from 1999 to 2011.

	Tamaki	Upper Harbour	Chelsea	Illiomama	Mangere Bridge	Weymouth	Papakura Channel	PD
Lipid Content	↓	↓	↓	↑	↓	↓	↓	↓
Limited suite DDTs	↓	↑	↑	↑	↓	↑	↓	↓
Extended suite DDTs	↓	↑	↑	↑	↓	↓	↓	↓
Limited suite Chlordanes	↓	↓	↓	↓	↓	↓	↓	→
Extended suite Chlordanes	↓	↓	↓	↓	↓	↓	↓	→
Limited suite PAHs	↑	↑	↑	↓	↑	↑	↓	↓
Extended suite PAHs	↑	↑	↓	↓	↑	↑	↓	↓
Limited suite PCBs	↓	↑	↓	↓	↑	↓	↓	↓
Extended suite PCBs	↓	↑	↓	↓	↓	↓	↓	↓
Dieldrin	↑	↓	↓	↓	↓	↓	↓	↓

Significant and meaningful trends have been highlighted in red (increasing) and blue (decreasing); non-significant trends are not highlighted; all data are dry weight; → designates median value of 0; lindane (no trend data); PD = pre-deployment mussels.

5.4 Contaminant temporal trend analysis using censored data methods

The dataset for both oysters and mussels contained a large number of censored data points, that is, data that were below the detection limit (Table 5-12). This was particularly true for metals data prior to 2005, after which the analytical laboratory was changed from AgResearch to Watercare. Lower detection limits were subsequently reported by Watercare, resulting in fewer censored data points. In section 5.3, substitution methods were used for the censored data, i.e., replacement of data below the detection limit with half the limit of detection (for metals) and zero (for organics). However, the detection limits change considerably over the period of monitoring and for each sample analysed, this substitution process could affect the trend analysis, resulting in unreliable results.

An alternative method known as the Akritas-Theil-Sen (ATS) nonparametric regression method was therefore also used for trend analysis of arsenic, cadmium, chromium and lead, as these data sets regularly contained over 10% censored (below detection limit) data (up to 69% for lead).

Table 5-12 Number of censored data points for oysters and mussels at each site.

	Arsenic			Cadmium			Chromium			Lead		
Site	N.	N. cen	% cen	N.	N. cen	% cen	N.	N. cen	% cen	N.	N. cen	% cen
Oysters												
Grannys Bay	122	19	16	122	13	11	122	13	11	122	64	52
Pahurehure	117	16	14	117	11	9	117	21	18	117	66	56
Hingaia	120	19	16	120	12	10	120	23	19	120	75	63
Cornwallis	118	14	12	118	26	22	118	32	27	118	82	69
Mussels												
Tamaki	55	5	9	55	9	16	55	0	0	55	10	18
Upper Harbour	49	1	2	49	6	12	49	0	0	49	6	12
Chelsea	78	8	10	78	13	17	78	3	4	78	28	36
Illiomama	62	5	8	62	8	13	62	3	5	62	15	24
Mangere Bridge	49	7	14	49	8	16	49	0	0	49	12	24
Weymouth	59	10	17	59	12	20	59	2	3	59	16	27
Papakura Channel	61	11	18	61	12	20	61	2	3	61	14	23

Copper and zinc were always detected so were not analysed by censored data methods; N. = total number; N. cen = number of censored data; % cen = % censored data.

Results from the Akritas-Theil-Sen trend analysis (Table 5-13) indicated significant trends in arsenic concentrations at five sites, with significant and meaningful increases at Cornwallis oyster site and Tamaki and Upper Harbour mussel sites; a significant increase at Chelsea mussel site, and a significant and meaningful decrease at Pahurehure oyster site. There were also significant and meaningful trends in cadmium concentrations at five sites: decreasing trends at three oyster sites (Grannys Bay, Hingaia and Pahurehure) and increasing trends at two mussel sites (Mangere Bridge and Weymouth). There were significant and meaningful decreasing chromium

concentrations at one oyster site (Pahurehure) and five mussel sites (Chelsea, Mangere Bridge, Papakura Channel, Weymouth and Upper Harbour). Lead had the most censored data and a significant and meaningful trend was only detected at Upper Harbour mussel site, where concentrations are increasing.

Table 5-13 Summary of metal trends in oysters and mussels using the Akritas-Theil-Sen nonparametric regression method.

	Arsenic		Cadmium		Chromium		Lead	
Site	P value	RSKSE	P value	RSKSE	P value	RSKSE	P value	RSKSE
Oysters								
Grannys Bay	0.28	0.47	0	-2.93	0.075	-1.75	0.6	-1
Pahurehure	0.004	-1.04	0.009	-1.07	0.003	-3.37	0.62	-0.47
Hingaia	0.34	0.29	0.007	-1.06	0.062	-2.9	0.73	-0.22
Cornwallis	0.038	1.08	0.21	-0.89	0.29	-1.47	0.86	-0.37
Mussels								
Tamaki	0.001	3.59	0.094	-4.41	0.54	-1.54	0.15	1.89
Upper Harbour	0.002	3.62	0.542	-1.19	0.018	-4.55	0.05	2.87
Chelsea	0.011	0.95	0.213	-1	0.035	-2.58	0.51	-1.83
Illiomama	0.33	1.26	0.717	-1.03	0.624	-5.51	0.95	0
Mangere Bridge	0.32	1.16	0.015	4.68	0	-8.14	0.42	-1.23
Weymouth	0.33	-0.96	0	7.5	0	-11.85	0.55	-1.3
Papakura Channel	0.59	0.67	0.059	2.86	0	-15.88	0.6	0.91

Significant increasing trends have been highlighted in red (meaningful and significant increase) and yellow (significant increase); significant decreasing trends are shown in blue (meaningful and significant decrease).

Similarly lindane concentrations in both oysters and mussels have regularly been below detection limits. Trend analysis using censored data methods suggests that there has been a statistically significant decrease in lindane concentrations (lipid normalised) at all four oyster sites and at the Tamaki mussel site (Table 5-14).

Table 5-14 Summary of lindane trends in oysters and mussels using the Akritas-Theil-Sen nonparametric regression method.

				Lindane	
Site	n	N.cen	% cen	P value	ATS slope
Oysters					
Grannys Bay	120	69	58	0.0003	-0.0044
Pahurehure	114	76	67	0	-0.0047
Hingaia	120	78	65	0	-0.0035
Cornwallis	118	80	68	0	-0.0072
Mussels					
Tamaki	61	43	70	0.0217	-0.0018
Upper Harbour	60	49	82	0.4161	-0.0017
Chelsea	61	42	69	0.2888	-0.0022
Illiomama	63	56	89	0.6047	-0.0013
Mangere Bridge	50	23	46	0.0958	0.0007
Weymouth	47	36	77	0.8471	-0.0002
Papakura Channel	55	40	73	0.7914	-0.0002

Significant trends have been highlighted in blue (decreasing).

5.5 Comparison of trend analysis methods

Results from trend analyses of arsenic, cadmium, chromium and lead were compared between the Time Trends method (section 5.3) and the Akritas-Theil-Sen (ATS) regression method (section 5.4) (Table 5-15).

For oysters, the full time series (1987-2011) were compared. There was full agreement between both methods, i.e., all the trends were in the same direction. The only difference was that the ATS method was more sensitive, with 6 significant and meaningful trends compared with 2 for the Time Trends method.

For mussels (1999-2011), there were some differences between the results for the Time Trends and ATS methods however there were no differences in trend direction where trends were significant and meaningful. Trends in cadmium were mostly in the same direction with the exception of Chelsea, Illiomama and Upper Harbour, which for Time Trends were increasing but for the ATS method were decreasing. Trends in arsenic were in opposite directions at Illiomama and Papakura Channel, declining by the Time Trends method and increasing by the ATS method. Trends in lead were increasing at Tamaki, Papakura Channel and Upper Harbour for the ATS method, but were declining using the Time Trends method. Trends data for lead should be taken in context of the high percentage of undetected data for (up to 69%).

Table 5-15 Comparison of trend results for the Akritas-Theil-Sen and Time Trends methods.

	Arsenic		Cadmium		Chromium		Lead	
Site	ATS	TT	ATS	TT	ATS	TT	ATS	TT
Oysters								
Grannys Bay	↑	↑	↓	↓	↓	↓	↓	↓
Pahurehure	↓	↓	↓	↓	↓	↓	↓	↓
Hingaia	↑	↑	↓	↓	↓	↓	↓	↓
Cornwallis	↑	↑	↓	↓	↓	↓	↓	↓
Mussels								
Tamaki	↑	↑	↓	↓	↓		↑	↓
Upper Harbour	↑	↑	↓	↑	↓	↓	↑	↓
Chelsea	↑	↑	↓	↑	↓	↓	↓	↓
Illiomama	↑	↓	↓	↑	↓	↓	→	↓
Mangere Bridge	↑	↑	↑	↑	↓	↓	↓	↓
Weymouth	↓	↓	↑	↑	↓	↓	↓	↓
Papakura Channel	↑	↓	↑	↑	↓	↓	↑	↓

ATS = (Akritas-Theil-Sen); TT = (Time Trends); significant increasing trends have been highlighted in red (meaningful and significant increase) and yellow (significant increase); significant decreasing trends are shown in blue (meaningful and significant decrease)

As with oyster data, there were more significant trends in mussels for the ATS method (11) than for the Time Trends method (4).

No comparisons could be made between the two different methods for lindane as it was not included in the Time Trends analyses.

5.6 Condition data trends

There were no significant trends in either the mussel or oyster condition data over the 2006-2011 time period. Based on the RSKSE values, overall oyster condition improved at Hingaia, Pahurehure and Grannys Bay, and declined at Cornwallis (Table 5-16). For mussels, based on the RSKSE values, overall condition declined at Mangere Bridge and Papakura Channel, and improved at Chelsea, Illiomama, and Weymouth (> 1% change per year), and improved slightly at Tamaki and Upper Harbour (< 1% per year) (Table 5-17).

Table 5-16 RSKSE values for oyster condition data 2006 – 2011.

Site	Oyster Condition RSKSE
Grannys Bay	1.19
Pahurehure	6.4
Hingaia	7.69
Cornwallis	-9.92

No trends for Mill Bay (2008/2009 data only).

Table 5-17 RSKSE values for mussel condition data 2006 – 2011.

Site	Mussel Condition RSKSE
Tamaki	0.15
Upper Harbour	0.13
Chelsea	2.36
Illiomama	1.46
Mangere Bridge	-3.34
Weymouth	1.45
Papakura Channel	-3.94

5.7 Multivariate trends

5.7.1 Summary

Temporal changes based on the combined influence of key metals, dieldrin, and extended suites of chlordanes, DDTs, PCBs and PAHs were examined using nonmetric multi-dimensional scaling (NMDS) ordination. Distance-based linear modelling (DistLM) was used to quantitatively model the relationship between the multivariate contaminant data, and the predictor variables of year of sampling. To provide a suitable number of different groups, years were grouped into approximately 5-yearly groups for oysters and 3-yearly groups for mussels. Year was a significant predictor of the combined contaminant concentrations for all sites except Illiomama mussel site, explaining a high proportion of variance (Table 5-18).

Table 5-18 Summary of the proportion of variance explained by year using distance-based linear modelling.

Site	Proportion of variance (%) explained by year (DistLM)
Oysters	
Grannys Bay	18
Pahurehure	22
Hingaia	21
Cornwallis	26
Mussels	
Tamaki	24
Upper Harbour	20
Chelsea	26
Illiomama	NS
Mangere Bridge	21
Weymouth	25
Papakura Channel	27

NS = not significant.

5.7.2 Oyster sites

For the oyster data, there were no obvious trends over time based on the combined influence of contaminants when all sites were examined together (data not shown). There were considerable between-site differences, so each site was examined separately in turn.

5.7.2.1 Cornwallis

There seems to be some trend over time at Cornwallis as the data for the 1990s group closer together and the more recent data from the 2000s onwards group together (Figure 5-6).

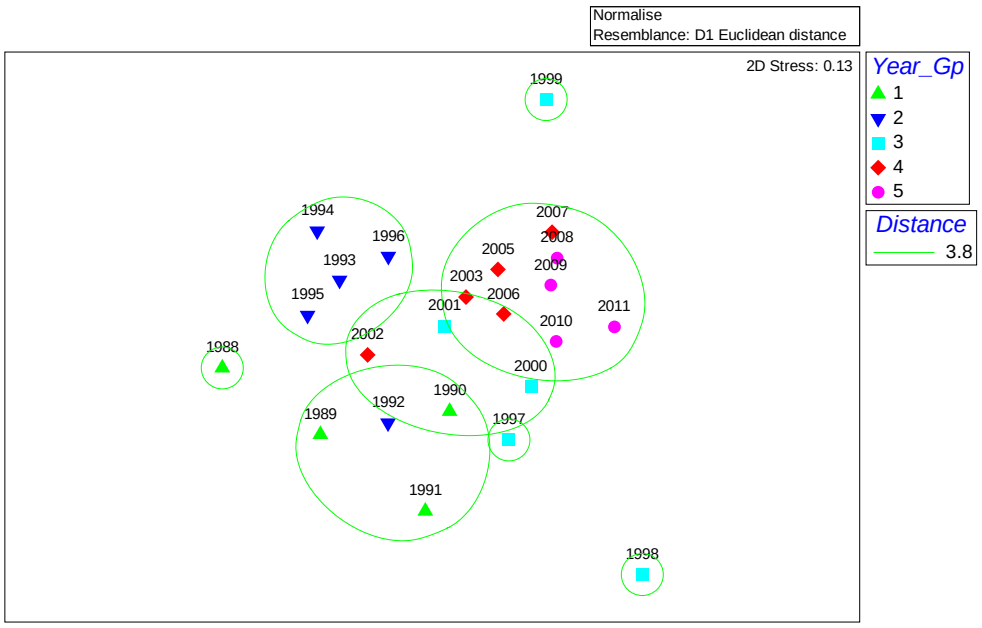


Figure 5-6 NMDS plot of contaminants by year at Cornwallis from 1988 to 2011.

5.7.2.2 Grannys Bay

At Grannys Bay, recent data from 2003 to 2011 group close together, as do data from 1988 to 1992. However data from 1993 to 2002 appear to be very scattered (Figure 5-7).

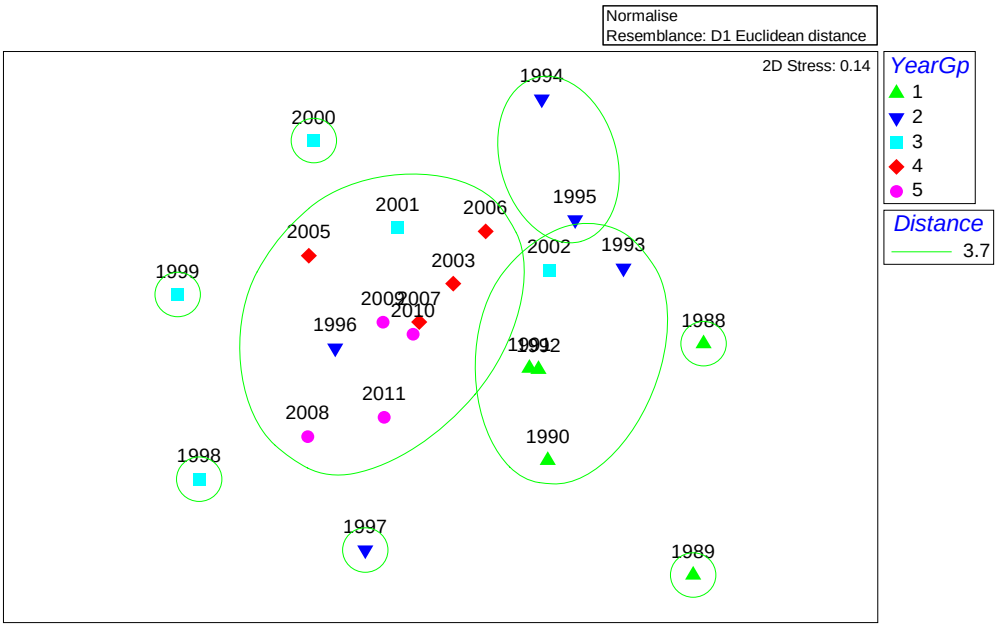


Figure 5-7 NMDS plot of contaminants by year at Grannys Bay from 1988 to 2011.

5.7.2.3 Pahurehure

At Pahurehure the groupings appear to be stronger than at Granny Bay. Data from 2003 onwards are shown as a distinctive group in Figure 5-8 as are data from 1992 to 1996. As for the other sites, data for the late 1990s appear to be quite scattered.

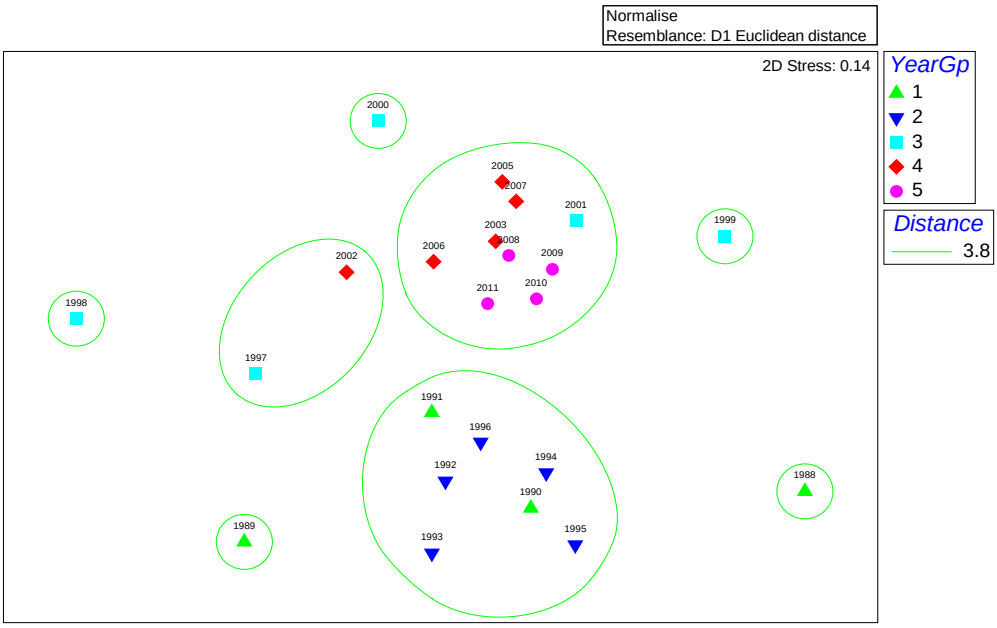


Figure 5-8 NMDS plot of contaminants by year at Pahurehure from 1988 to 2011.

5.7.2.4 Hingaia

At Hingaia, the data shows a very similar pattern to that for Pahurehure, with data from 2003 onwards and data from 1992 to 1996 showing distinctive groupings (Figure 5-9).

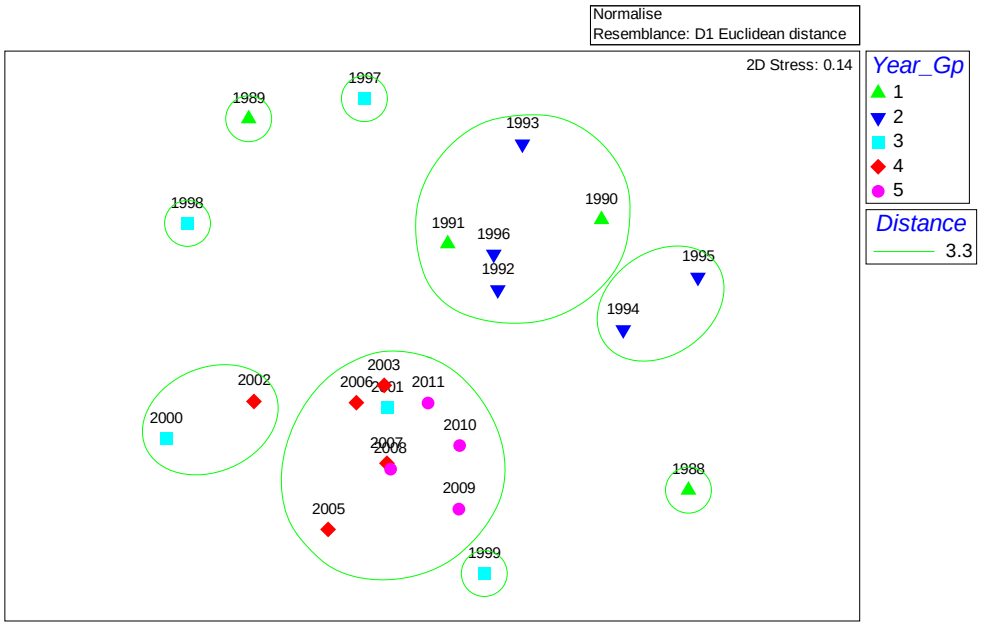


Figure 5-9 NMDS plot of contaminants by year at Hingaia from 1988 to 2011.

5.7.3 Mussel sites

For the mussel sites there are fewer years of data than for the oysters as the programme has only been running since 1999 for east coast sites (and 2000 for Manukau sites). Data from 1999 was excluded due to the presence of outliers for cadmium. Unlike oysters, there were no distinct patterns over time for mussels, presumably due to insufficient data points - and so no results are presented.

5.8 Summary of status based on trends

Differences in contaminant trends and the combination of contaminant and condition trends between sites (not including the pre-deployment site) are shown in the principal component analysis (PCA) plots below (Figure 5-10 and Figure 5-11). Sites that plot close together are more similar than sites that are further apart. Figure 5-10 indicates that there are differences in the contaminant trends in oysters, grouped in the upper left area of the plot, compared to mussels, grouped in the lower right area. The trends at Hingaia and Pahurehure oyster sites appear to be similar, as are the trends at Weymouth and Tamaki mussel sites. The vectors overlaid on the plot suggest that the difference between trends in mussels and oysters is primarily due to differences in the metals, which may be driven by species-specific uptake rates. Similar to the summary of status based on current values, the axis explaining most of the variability (axis 1) is not affected by the differences between oysters and mussels and is driven by trends in DDT, chlordane, dieldrin, PAHs and PCBs.

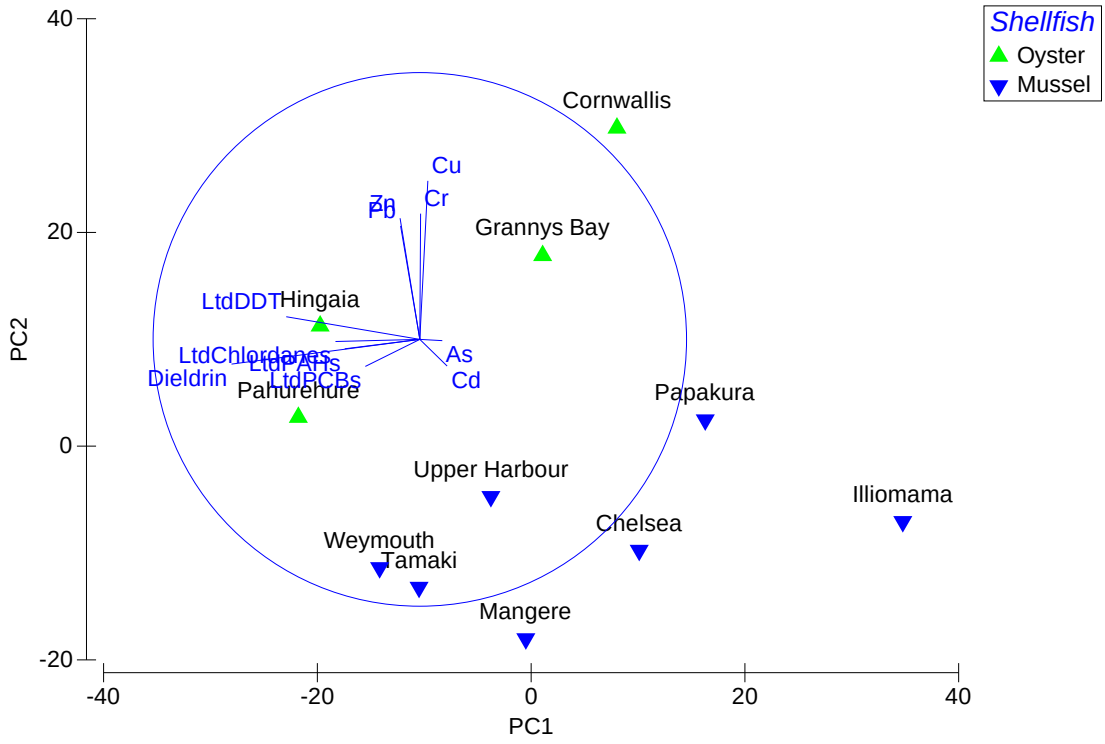


Figure 5-10 PCA of trends in contaminants for oysters and mussels.

When contaminants and condition are assessed in combination, the sites again appear to group together by shellfish type (Figure 5-11), with oyster sites at the top left, and mussel sites at the lower right. This is very similar to the plot for contaminants alone (Figure 5-10) suggesting the trends in contaminants dominate this analysis. Again, the axis explaining most of the variability (axis 1) is not affected by the differences between oysters and mussels.

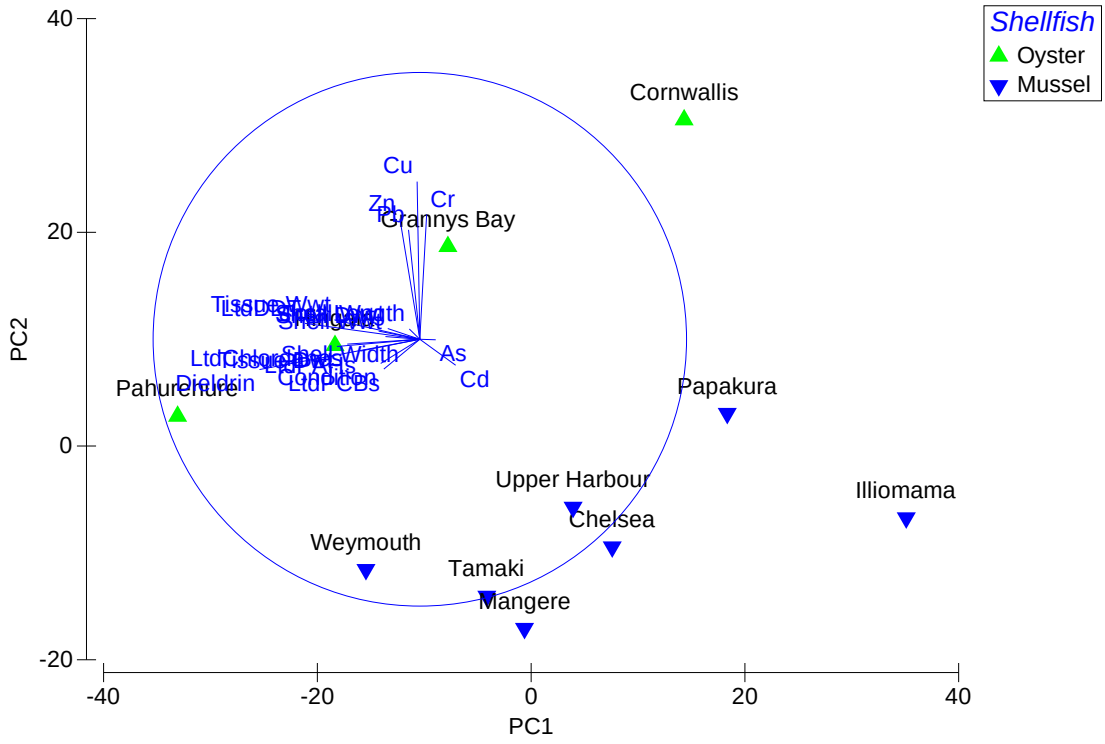


Figure 5-11 PCA of trends in condition and contaminants.

Comparisons between condition and contaminant trends were assessed using the correlation coefficient Kendall's tau, based on separate resemblance matrices for condition and contaminant trends. This provided a P-value of 0.30, indicating there is no significant correlation between the trends in contaminant concentrations and the trends in condition.

Comparisons between the contaminant trends for oysters and mussels, using Kendall's tau, provided a P-value of 0.24, indicating there is no significant correlation between the trends in oysters and the trends in mussels. This may be partly due to the small size of the data set, with only four oyster sites and seven mussel sites and no common sites between the two species.

Comparisons between the condition trends for oysters and mussels, using Kendall's tau, provided a P-value of 0.028, indicating there is a significant correlation between the condition trends in oysters and the trends in mussels. However, as the condition trends were not statistically significant (see section 5.6), this has little relevance for trend analysis.

6.0 Comparisons

6.1 Comparison of mussel and oyster data in the Manukau Harbour

6.1.1 Current status

Current contaminant status for mussels and oysters has been compared for sites in the Manukau Harbour. There are no common mussel and oyster sites, so mussel sites that are in closest proximity to oyster sites were used for comparisons; specifically Papakura Channel mussel site with Cornwallis oyster site; Mangere Bridge mussel site with Grannys Bay oyster site; and Weymouth mussel site with both Pahurehure Inlet and Hingaia oyster sites (Table 6-1).

Overall, median concentrations of contaminants are higher in oysters than mussels, with the exception of lead, and lindane which are lower in oysters than mussels. For endosulfan there is no clear pattern.

The differences in concentrations between oysters and mussels at nearby sites are mostly statistically significant with a few exceptions. PAHs are higher in oysters than mussels, but only statistically significant for two of the comparisons (Pahurehure oyster site with Weymouth mussel site; Hingaia oyster site with Weymouth mussel site). Lindane was lower in oysters than mussels at all sites, with the difference statistically significant between all pairs except Grannys Bay oyster site and Mangere Bridge mussel site.

Box plot comparisons between sites are contained in Appendix G.

Table 6-1 Summary of differences in metal and organic contaminants between oysters and mussels in the Manukau Harbour.

	Oyster	Mussel	P-value for difference	Oyster	Mussel	P-value for difference	Oyster	Oyster	Mussel	P-value for difference Pahure vs Weymouth	P-value for difference Hingaia vs Weymouth
Parameter	Cornwallis	Papakura Channel		Grannys Bay	Mangere Bridge		Pahurehure	Hingaia	Weymouth		
Arsenic	13	8.7	**1.1×10^{-5}**	9.7	6.8	**2.3×10^{-6}**	8.6	9.2	8.3	0.31	**0.0011**
Cadmium	0.95	0.41	**7.7×10^{-6}**	1.2	0.62	**2.0×10^{-6}**	1.4	1.6	0.56	**2.9×10^{-6}**	**3.3×10^{-6}**
Chromium	0.82	0.82	0.87	0.91	1.5	**3.6×10^{-5}**	0.58	0.66	0.95	**0.00090**	**0.00057**
Copper	110	4.5	**7.6×10^{-6}**	870	5.9	**2.3×10^{-6}**	310	420	4.3	**3.3×10^{-6}**	**3.3×10^{-6}**
Lead	0.24	0.44	**7.7×10^{-6}**	0.68	1.2	**4.1×10^{-5}**	0.46	0.42	0.67	**0.00022**	**1.1×10^{-5}**
Zinc	1500	66	**7.7×10^{-6}**	4000	71	**2.3×10^{-6}**	2400	2300	68	**3.2×10^{-6}**	**3.2×10^{-6}**
DDT	6.3	5.1	**5.3×10^{-8}**	27.2	22.1	**6.7×10^{-9}**	24	25	9.2	**1.3×10^{-8}**	**1.3×10^{-8}**
Dieldrin	101	40	**0.00076**	550	211	**0.0090**	253	344	54	**3.4×10^{-6}**	**3.4×10^{-6}**
Chlordanes	5.5	1.9	**3.3×10^{-5}**	33.5	23.9	**3.6×10^{-5}**	8.8	7.9	1.7	**3.1×10^{-6}**	**3.4×10^{-6}**
Endosulfan	0.02	0.00	**0.0018**	0.02	0.03	0.57	0.09	0.14	0.03	**9.0×10^{-6}**	**5.0×10^{-6}**
PCBs	90	64	**1.6×10^{-6}**	570	400	**4.5×10^{-7}**	161	133	87	**1.3×10^{-8}**	**1.6×10^{-5}**
PAHs	154	171	0.86	976	931	0.23	769	542	304	**1.3×10^{-8}**	**1.5×10^{-7}**
Lindane	0.2	0.8	**0.00061**	0.8	2.0	0.094	0.2	0.3	1.0	**0.00015**	**0.0025**

All organics suites are full suites; data is median from 2009-2011; units are mg/kg dry weight (metals), and lipid normalised (organics).

6.1.2 Trends

Table 6-2 summarises the trends in the data for oyster and mussel sites in the Manukau Harbour for the 1999-2011 time period. Interestingly, the closest agreement in temporal trends (10 out of 12 variables in the same direction) between species was in the outer harbour sites (Cornwallis oyster site and Papakura Channel mussel site).The Papakura Channel mussel site had 9 of 12 trends observed consistent with the mussel site further up the channel at Weymouth. Conversely, only 7 trends in the same direction occurred for the two oyster sites within the Weymouth tidal creek system (Pahurehure and Hingaia) and only 3 trends in the same direction occurred for sites in the Mangere area (Grannys Bay oyster site and Mangere Bridge mussel site).

Table 6-2 Summary of trends in data for oysters and mussels in the Manukau Harbour from 1999 to 2011.

	Oyster	Mussel	Oyster	Mussel	Oyster	Oyster	Mussel
	Cornwallis	Papakura Channel	Grannys Bay	Mangere Bridge	Pahurehure	Hingaia	Weymouth
Condition	↓	↓	↑	↓	↑	↑	↑
Arsenic	↑	↑	↑	↓	↑	↓	↑
Cadmium	↑	↑	↓	↑	→	↑	↑
Chromium	↓	↓	↓	↓	↓	↓	↓
Copper	↓	↓	↑	↓	↑	↓	↓
Lead	↓	↓	↓	↑	↓	↓	→
Zinc	↑	↓	↑	↓	↑	↑	↓
DDT	↑	↓	↑	↓	↑	↑	↓
Chlordanes	↓	↓	↓	↓	↓	↓	↓
PAHs	↓	↓	↓	↑	↓	↓	↑
PCBs	↓	↓	↑	↓	↓	↑	↓
Dieldrin	↓	↓	↓	↓	↑	↑	↓

↑ = increasing trend, ↓ = decreasing trend, → = median value zero; condition is based on data from 2006-2011; organic data are lipid normalised limited suites; for mussels pre-deployment subtracted data has been used; red and blue shading designates significant trends.

Condition was site specific and trends in condition were not significant. Mussel condition was improving at one site, and declining at two sites. Oyster condition was improving at three sites, and declining at one site.

There were few significant trends in organic compounds over the 1999-2011 time period. Trends for the same organic compounds are often in different directions for oyster and mussels at nearby sites, suggesting different uptake methods, and perhaps different sources (even though sites are

close together). Chlordanes however were declining, and mostly significantly, at all but one site. DDTs were increasing in oysters at all sites, but were decreasing in mussels at all sites. The effect of the upgrade to Mangere WWTP in 2001 on contaminant trends was observed mostly at Grannys Bay and is discussed in more detail in section 6.3.6.

There were few significant trends in metals in either oysters or mussels. There were significant declining trends in chromium at the three mussel sites. Chromium was declining at oyster sites, though the decrease was not statistically significant. For other metals, there was no consistent pattern towards increasing or decreasing trends in both oysters and mussels, possibly because sampling does not occur at the same sites, or because of different responses. Indeed, trends in mussels were sometimes the opposite of those in oysters, e.g., zinc was increasing in mussels at all sites, but decreasing in oysters at all sites.

It is difficult however to compare trend results for oysters and mussels because sampling was not carried out at the same sites. Furthermore, oysters are in their native environment, whereas the mussels have been deployed. Some of the changes in the mussels may be attributable to adjusting to a new environment. However, the similarity in trends for Cornwallis oyster site and Papakura Channel mussel site suggest that it would be worthwhile to sample some sites with both oysters and mussels to determine to what degree variations in trends are dependent on differences in species uptake of the contaminants.

6.2 Relationship between climate cycles and shellfish contaminants and condition

6.2.1 Introduction

In this section climate variables are compared graphically and by correlation analysis to shellfish condition, PCA scores (as calculated in section 5.7) - based on contaminant concentrations - and contaminant concentrations, to investigate whether climate has any effect on the shellfish contaminant concentrations. The climate variables used in this analysis are (see section 2.6 for further details):

- **Z1** – the difference between pressure in Auckland and Christchurch which indicates westerly wind patterns.
- **SOI** – the Southern Oscillation Index.
- **Rainfall** – the total rainfall.
- **Air temperature** – mean, minimum and maximum daily air temperature.
- **Wind exposure** – fetch distance, wind speed and duration calculated for each site.

For Z1, SOI and air temperature, the mean of these values were calculated for a three-month period prior to sampling (oysters) or the three-month period of deployment (mussels). For rainfall and wind exposure, the sum of these values was calculated for the three-month periods.

6.2.2 Climate variables

An exploratory analysis of the Pearson correlation between the climate variables (Figure 6-1) indicated that the 30-day mean daily mean temperature, the 30-day mean daily minimum temperature and the 30-day mean daily maximum temperature were highly correlated. The 30-day mean daily mean temperature was used for further analyses and the other two temperature variables were excluded.

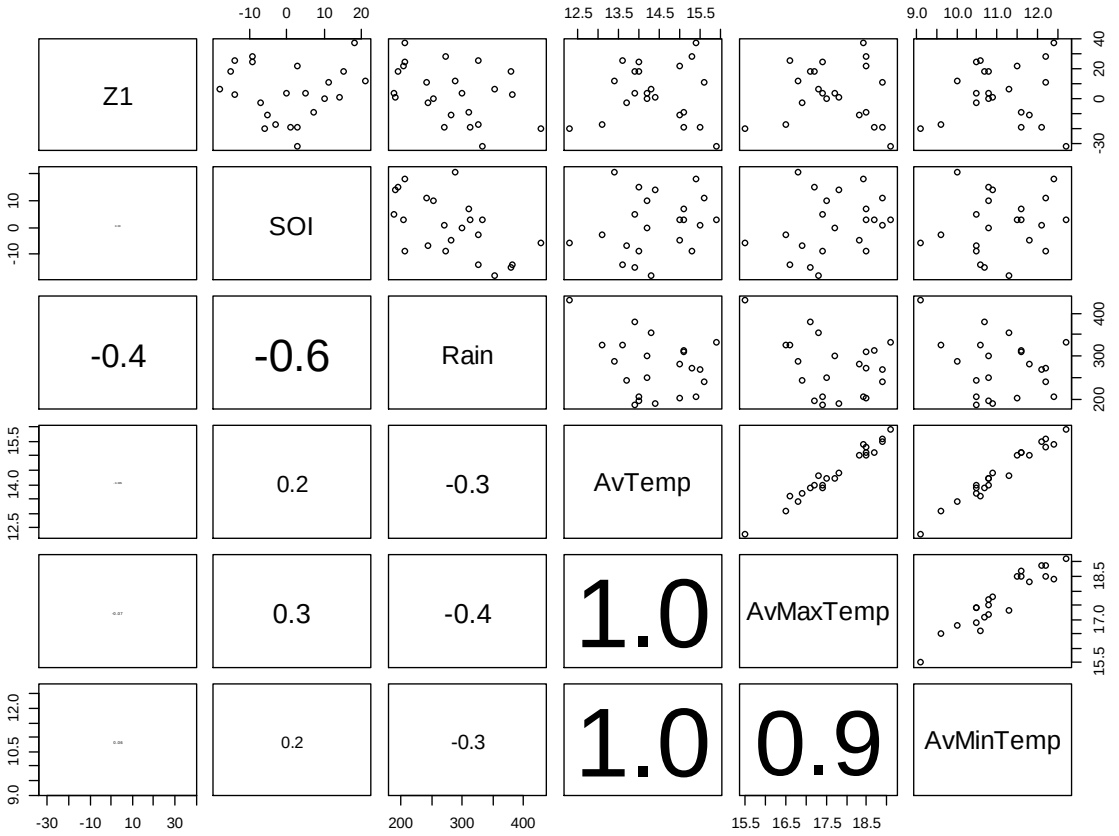


Figure 6-1 Correlation of climate variables.
Note: Named variable at left of each row of scatter plots is y-axis. Named variable at bottom of each column of scatter plots is x-axis. Correlation coefficients are presented in lower left side of matrix. Font size for correlation coefficient indicates strength of relationship. Z1 is the pressure difference between Auckland and Christchurch; SOI is Southern Oscillation Index; Rain is rainfall at Auckland Airport; AvTemp is mean daily mean temperature; AvMaxTemp is mean daily maximum temperature; AvMinTemp is mean daily minimum temperature.

6.2.3 PCA1 score and condition

For most of the oyster and mussel sites, the PCA1 score was only weakly correlated to climate variables (see Appendix H). The strongest correlation coefficients were at Pahurehure oyster site where there was a correlation between PCA1 score and total rainfall of -0.6, and a correlation coefficient of 0.5 with SOI. At Hingaia oyster site there was a correlation between PCA1 score and SOI of 0.5 and with PCA1 score and total rainfall of -0.5. At the other oyster sites and at all the mussel deployment sites, the strongest correlation coefficients were 0.4 or less.

There were stronger relationships between shellfish condition and climate variables, although it is important to note that this analysis was conducted over a short time period (from 2006). The strongest relationship was at Grannys Bay oyster site where shellfish condition was negatively related to wind exposure with a correlation coefficient of -0.9; however there were no other sites where wind was strongly related (all correlation coefficients 0.5 or less).

At several sites shellfish condition was related to total rainfall. At both the Upper Harbour and Weymouth mussel deployment sites, there was a positive correlation of 0.8 between shellfish condition and total rainfall over the deployment period. A similar, but weaker, relationship (0.6) was measured for the oyster site of Grannys Bay. In contrast, at Cornwallis oyster site, the correlation was in the opposite direction to that found for Upper Harbour and Weymouth mussel sites and Grannys Bay oyster site, with a correlation coefficient to total rainfall of -0.6.

At several sites, shellfish condition was somewhat related to SOI, with correlation coefficients of -0.7 at Cornwallis oyster site and Upper Harbour mussel site but in the opposite direction at Mangere Bridge mussel site (correlation coefficient 0.7) and Papakura Channel mussel site (correlation coefficient 0.6). At Pahurehure and Hingaia oyster sites and Illiomama mussel site, shellfish condition was negatively correlated to Z1 with correlation coefficients of -0.7, -0.6 and -0.6, respectively.

6.2.4 Individual contaminants

For the individual contaminants or organic suites there were no consistently strong relationships between contaminants and climate variables. No graphical correlations of climate variables to contaminants are presented in this report as, due to their size, they are not descriptive.

At the Illiomama mussel reference site, there were several contaminants with relatively strong relationships to mean temperature, which was negatively correlated to both arsenic and lead (correlation coefficient of -0.8), positively correlated to cadmium (0.7), and positively correlated to zinc (0.6). At the Chelsea mussel site, mean temperature was related to cadmium (-0.8) and DDT (0.7). The only other site with relatively strong relationships with mean temperature was Mangere Bridge mussel site, with a correlation coefficient of 0.7 to DDT.

SOI showed negative correlations with chromium and PAHs at multiple sites. SOI was related to chromium at Grannys Bay (-0.5), Hingaia (-0.5) oyster sites and Tamaki (-0.7), Upper Harbour (-0.5) and Weymouth (-0.6) mussel sites. SOI was related to PAHs at Grannys Bay and at Pahurehure (-0.5) oyster sites. As with the PCA1 scores, the direction of the relationships with SOI was not always consistent between sites or contaminants. For example, at Illiomama mussel site the correlation coefficient for SOI and chlordane was 0.5 whereas it was -0.5 for SOI and dieldrin. Furthermore, at the Mangere Bridge mussel site, DDT was correlated to SOI with a correlation coefficient of 0.5, whereas at the Papakura Channel mussel site the correlation between DDT and SOI was negative (-0.6).

Finally, there were several sites with relatively strong relationships between Z1 and individual contaminants. At Papakura Channel mussel site, Z1 was related to copper (0.7). At Tamaki mussel site, Z1 was related to chromium (0.6), dieldrin (-0.7) and DDT (-0.6). Z1 was related to copper at both Upper Harbour (0.6) and Weymouth (0.7) mussel sites.

Kelly (2007) noted a positive correlation between SOI and copper and zinc at Hingaia and Pahurehure oyster sites for data from 1987 to 1998, but not from 1999 to 2005 and not at other monitoring sites. With the inclusion of data up to 2011, SOI was not found to be positively related to these metals at these two sites. However, copper was related to the Z1 score at Weymouth, a nearby site. This suggests that although climate cycles may have some influence on contaminant concentrations, there are also other factors that influence these concentrations, which make the effect of climate less distinct.

6.3 Comparison of results against other SCM programmes

6.3.1 Overview

Generally, the current status of mussel and oyster contamination from the Auckland region is considered low by US NS&T criteria and comparable to data from the French Réseau National d'Observation (RNO) de la Qualité du Milieu Marin data.

National trends in the US were for metals to show no overall trends while organics showed an overall decrease. In France, trends were generally unchanged or decreased. Around the Auckland region the majority of trends were unchanged or decreased, with the exception of increases in cadmium in mussels, arsenic in oysters (1987-2011 and 1999-2011), zinc in oysters (1999-2011), PAHs in oysters (1999-2011) and lindane in oysters (1999-2011).

6.3.2 NS&T Status Comparisons

Selected contaminant data for mussels and oysters were compared with data from the 2008 US Mussel Watch Programme report (Kimbrough*, et al.* 2008). Median data for each site and median data for both species was tabulated and compared with NS&T low, medium and high categories, derived from the most recent published data (2004-2005) (Table 6-3). Note the NS&T categories are ranges and the values quoted in Table 6-3 are the maximum value for each category.

All mussel contaminant data were in the NS&T low category (Table 6-3). In contrast to the SCMP, where mussels are deployed, NS&T mussels are harvested from in-situ populations.

Most oyster contaminant data were in the NS&T low category, with the exception of the heavy metals As, Cu, Pb and Zn (Table 6-3). Oyster As data were in the NS&T medium category at Cornwallis and Mill Bay. Oyster copper data were in the NS&T high category at Grannys Bay and medium category at Hingaia, Pahurehure and across the whole species (median data). Oyster lead and zinc concentrations were in the NS&T medium category at Grannys Bay.

Table 6-3 Comparison of selected shellfish contaminants with data from US National Status & Trends Mussel Watch Program.

Mussels	As	Cd	Cu	Pb	Zn	DDT	Chlordanes	Dieldrins	PAHs	PCBs
Tamaki	8	0.4	12	1.7	93	5	0.8	1.6	73	23
Upper Harbour	8	0.5	8	1.6	82	10	0.5	0.7	68	19
Chelsea	9	0.5	8	1.6	81	8	0.4	0.5	65	18
Illiomama	9	0.4	5	0.9	60	6	0.4	0.5	25	11
Mangere Bridge	7	0.6	6	1.2	71	11	0.7	1.3	38	20
Weymouth	8	0.6	4	0.7	68	2	0.1	0.5	11	4
Papakura Channel	9	0.4	5	0.4	66	2	0.2	0.3	9	3
Pre-Deployment	7	0.9	4	0.5	72	1	0.1	0.4	7	1
Mussels (Median)	8	0.5	6	1.2	71	6	0.4	0.6	37	14
NS&T low	11	3	16	3	139	112	8	8	1187	153
NS&T medium	22	9	39	6	320	286	20	34	4434	478
NS&T high	41	20	857	13	11500	520	49	95	7561	1413
Oysters	**As**	**Cd**	**Cu**	**Pb**	**Zn**	**DDT**	**Chlordanes**	**Dieldrins**	**PAHs**	**PCBs**
Grannys Bay	10	1.2	870	0.7	4000	32	0.9	1.5	42	25
Pahurehure	9	1.4	310	0.5	2400	18	0.5	1.9	51	10
Hingaia	9	1.6	420	0.4	2300	27	0.4	1.9	34	7
Cornwallis	13	1	110	0.2	1500	10	0.4	0.7	17	8
Mill Bay	12	0.6	83	0.2	890	14	0.4	0.8	17	8
Oysters (Median)	10	1.2	310	0.4	2300	21	0.4	1.6	38	9
NS&T low	11	3	211	0.5	3260	34	7	5	828	38
NS&T medium	22	6	636	0.9	9165	105	21	30	2511	87
NS&T high	57	15	1660	2.2	18950	202	55	65	10717	157

Site values are median data from 2009-2011; Mill Bay 2009 data only; metals data are mg/kg dry weight; organics data are μg/kg dry weight; chromium and lindane were not covered by NS&T Mussel Watch report. Auckland data colour coded according to NS&T categories where applicable.

6.3.3 French RNO Status Comparisons

Selected contaminant data for mussels and oysters were compared with data from the latest French RNO report (RNO 2006) (Table 6-4). RNO provided median dry weight data from 2000-2004 (except for Cr 2001-2004 and Ni 2003-2004) for in-situ mussels in the Manche-Atlantique region (west and north of France) and Mediterranean (Mediterranean sea) and in-situ oysters in the Manche-Atlantique region (RNO 2006).

Shellfish contaminant status data from Auckland was generally comparable with RNO data. Of note, lindane, PCB153 and fluoranthene were markedly lower at Auckland sites than RNO sites, and DDT was markedly higher in oysters from Auckland (median 21.4 μg/kg) compared with those from Manche-Atlantique (7.1 μg/kg) (Table 6-4).

Table 6-4 Comparison of selected shellfish contaminants with data from French Réseau National d'Observation de la Qualité du Milieu Marin (RNO).

Mussels	Cd	Cr	Cu	Pb	Zn	DDT	Lindane	PCB153	Fluoranthene
Tamaki	0.4	1.1	12	1.7	93	5.5	0.07	7.1	9.2
Upper Harbour	0.5	0.9	7.6	1.6	82	10	0.05	5.7	8.5
Chelsea	0.5	1	7.6	1.6	81	8.2	0.04	5.5	9.5
Illiomama	0.4	0.6	5	0.9	60	6	0.03	3.5	3.7
Mangere Bridge	0.6	1.5	5.9	1.2	71	10.8	0.1	5.4	4.3
Weymouth	0.6	1	4.3	0.7	68	2.4	0.05	1.2	1.1
Papakura Channel	0.4	0.8	4.5	0.4	66	2.3	0.05	1.1	1.1
Pre-Deployment	0.9	0.2	3.6	0.5	72	0.6	0.04	0.2	0.8
Mussels (Median)	0.5	1	5.9	1.2	71	5.8	0.06	4.3	4.3
Manche-Atlantique (RNO)	0.6	1.2	6.7	1.4	85	5.3	0.7	19.4	21.4
Mediteranean (RNO)	0.7	0.8	6.8	1.8	152	15.1	0.36	18.7	13.2
Oysters	**Cd**	**Cr**	**Cu**	**Pb**	**Zn**	**DDT**	**Lindane**	**PCB153**	**Fluoranthene**
Grannys Bay	1.2	0.9	870	0.7	4000	31.9	0.09	10.1	7.9
Pahurehure	1.4	0.6	310	0.5	2400	17.8	0.04	3.3	9.2
Hingaia	1.6	0.7	420	0.4	2300	26.6	0.03	2.8	5.8
Cornwallis	1	0.8	110	0.2	1500	9.6	0.05	3	3.9
Mill Bay	0.6	0.7	83	0.2	890	14.3	0.03	3.3	3.8
Oysters (Median)	1.2	0.7	310	0.4	2300	21.4	0.05	3.3	6.3
Manche-Atlantique (RNO)	1.8	0.9	190	1.4	2310	7.1	0.82	20.7	34.7

Site values are median data from 2009-2011 for Auckland and median data from 2000-2004 for RNO (except Cr 2001-2004; Ni 2003-2004). Metals data are mg/kg dry weight; organics data are μg/kg dry weight; Arsenic (As) was not covered by RNO. Auckland data colour coded white are below RNO values, while data colour coded purple exceed data for RNO Manche-Atlantique and colour coded orange exceed RNO Mediteranean, where applicable.

6.3.4 NS&T Trends Comparisons

The NS&T report provides trends for over 200 monitoring sites nationwide, with data from 1986 to 2005. The overall trends were:

- *"There was no overall national trend for metals nationally. Metal trends varied by site and region with 27 individual sites exhibiting a significant decreasing trend and 9 individual sites exhibiting a significant increasing trend. Individually arsenic, cadmium and zinc showed a decreasing national trend while copper and lead showed no overall trend".*
- *"Overall there was a decreasing national trend for organics. 133 individual sites exhibited a significant decreasing trend while 0 individual sites exhibited a significant increasing trend".*

The median RSKSE for relevant contaminants or suites of contaminants from section 5.3 was compiled and compared with the NS&T mussel watch data (Table 6-5). Mussel trends data was from 1999-2011, while oyster trends data was over two periods (1987-2011 and 1999-2011). Note: NS&T trends were based on national data for 108 mussel sites and 105 oyster sites, while SCMP trends are based on regional data from 7 mussel sites and 4 oyster sites.

NS&T trends for arsenic, cadmium and zinc were decreasing nationally, which was not reflected in the SCMP, which were either decreasing, increasing or had no change depending on the species and time period for oysters (Table 6-5). Likewise, for SCMP data for copper and lead were generally decreasing, which was not reflected by NS&T data, which showed no overall trend.

SCMP organics data were in very good agreement with NS&T organics data, with overall decreasing trends. The only exception was PAHs in oysters from 1999-2011, which showed a general increase. However this shorter time period (12 years) is not consistent with that for NS&T (19 years) and may highlight a more recent spike in PAHs not shown by the longer trend period.

Table 6-5 Comparison of trends data from Auckland with US Mussel Watch Programme.

	Oysters (1987-2011)	Oysters (1999-2011)	Mussels (1999-2011)	NS&T Mussel Watch (1986-2005)
Arsenic	↑	↑	↓	↓
Cadmium	↓	→	↑	↓
Copper	↓	→	↓	→
Lead	↓	↓	↓	→
Zinc	→	↑	↓	↓
DDTs	↓	↓	↓	↓
Chlordanes	↓	↓	↓	↓
PAHs	↓	↑	↓	↓
PCBs	↓	↓	↓	↓
Dieldrin	↓	↓	↓	↓

→ designates median value of 0; ↓ = decreasing trend; ↑ = increasing trend; lindane is included in NS&T trends analyses but was not included in the SCMP trends analysis due to many non-detects prior to 2009.

6.3.5 RNO Trends Comparisons

RNO provided trends data up to ca. 1999 which have been categorised into percentage up, down and no change (Table 6-6). The period covered by the RNO trends varies by contaminant: 1979 to 1999 for metals, 1979 to 1997 for DDT and from 1994 to 1998 for PAHs. A general decrease in contaminants was observed with 86-94% of sites either down or unchanged for metals and 100% of sites down or unchanged for organics (Table 6-6).

The RNO data is now reasonably dated (latest data up to 1999), so comparisons with SCMP need to be made in that context. The SCMP trends generally reflect those seen within the RNO mussel watch programme, especially for organics (Table 6-6). The main exception is cadmium, which is increasing in SCMP mussels but mostly decreasing in RNO shellfish.

Table 6-6 Comparison of trends data from Auckland with French RNO de la Qualité du Milieu Marin programme.

	Mussels 1999-2011	Oysters 1987-2011	Oysters 1999-2011	RNO (% up)	RNO (% down)	RNO (% NC)
Cadmium	↑	↓	→	7	73	21
Lead	↓	↓	↓	4	56	40
Zinc	↓	→	↑	14	29	57
Copper	↓	↓	→	16	25	60
DDTs	↓	↓	↓	0	76	24
PAHs	↓	↓	↑	0	17	83

RNO data: 1979-1999 (metals); 1979-1997 (DDTs), 1994-1998 (PAHs). → designates median value of 0; ↓ = decreasing trend; ↑ = increasing trend; lindane is included in RNO trends analyses but was not included in the SCMP trends analysis due to many non-detects prior to 2009.

6.3.6 Mangere WWTP Trend Comparisons

Selected contaminant data for two oyster sites in the Manukau Harbour (Cornwallis and Grannys Bay) were compared with data from two oyster sites around Mangere Wastewater Treatment Plant (WWTP) (Airport and Puketutu light). Cornwallis was chosen as a reference site, far removed from Mangere WWTP but still within the Manukau Harbour. Grannys Bay was the only oyster site within close proximity to Mangere WWTP. The site of Mangere Bridge was not chosen for comparison as it was a mussel site. Mangere WWTP site data were part of a study to assess the environmental significance of the upgrade of Mangere WWTP in 2001 (Kelly 2010). Data were collected at 5 sites around Mangere WWTP, however, two sites - one inside and one outside the non-compliance zone - were chosen for ease of comparison.

Results are presented for total DDT (Figure 6-2); dieldrin (Figure 6-3); total chlordane (Figure 6-4); cadmium (Figure 6-6); copper (Figure 6-7); lead (Figure 6-8) and zinc (Figure 6-9).

In general, contaminant concentrations in oysters at Grannys Bay were higher than Cornwallis, while Puketutu light had higher oyster contaminant concentrations than Airport.

The most significant spike in concentrations observed across the 2 Mangere WWTP sites after the 2001 upgrade was for DDT (Figure 6-2). This spike was mirrored by Grannys Bay oysters and - to

a lesser extent - Cornwallis oysters. Grannys Bay oyster DDT concentrations were comparable with 4 sites around Mangere WWTP (not shown), with the exception of Airport which had markedly lower concentrations. Airport site had similar oyster DDT concentrations to the reference site Cornwallis.

Dieldrin (Figure 6-3) and chlordane (Figure 6-4) concentrations also appeared to spike at Grannys Bay and Puketutu light after 2001, however no noticeable change was observed at Cornwallis or Airport.

The spikes in concentration of total DDT, dieldrin and total chlordane observed after decommissioning of Mangere WWTP in 2001 have subsequently reduced and returned to levels at or below those prior to the decommissioning (Figure 6-5).

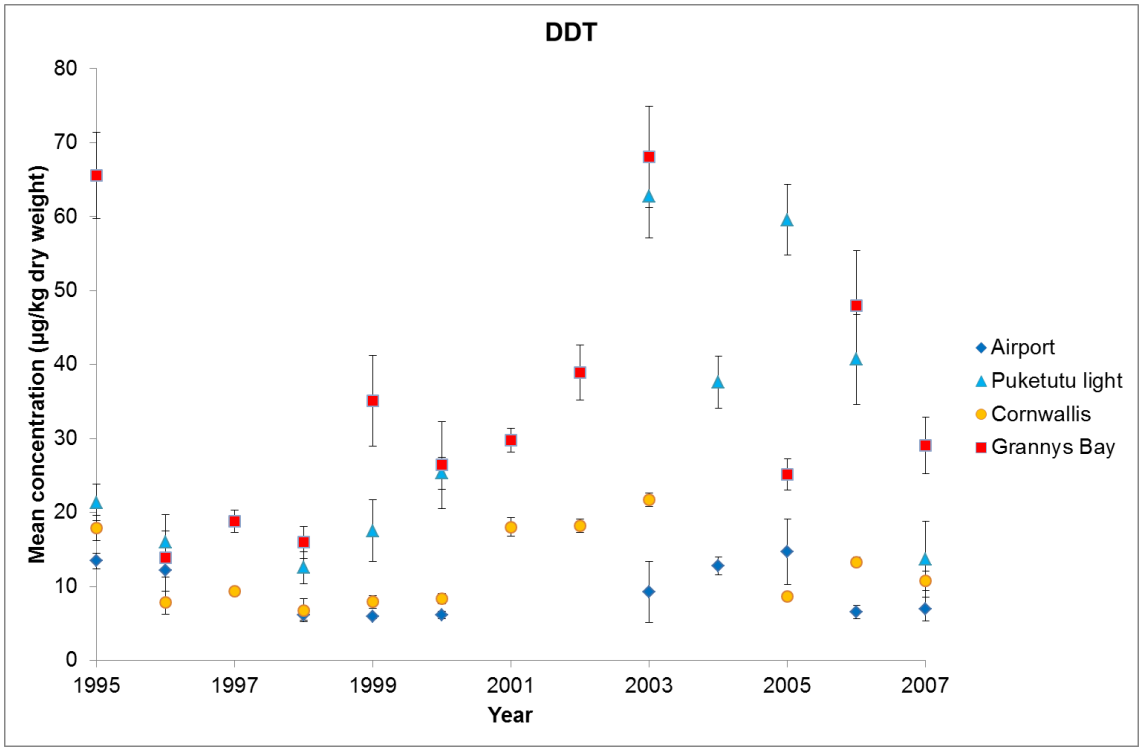


Figure 6-2 Comparison of DDT concentrations over time between two Mangere WWTP oyster sites and two SCMP oyster sites. Error bars represent one standard deviation about the mean.

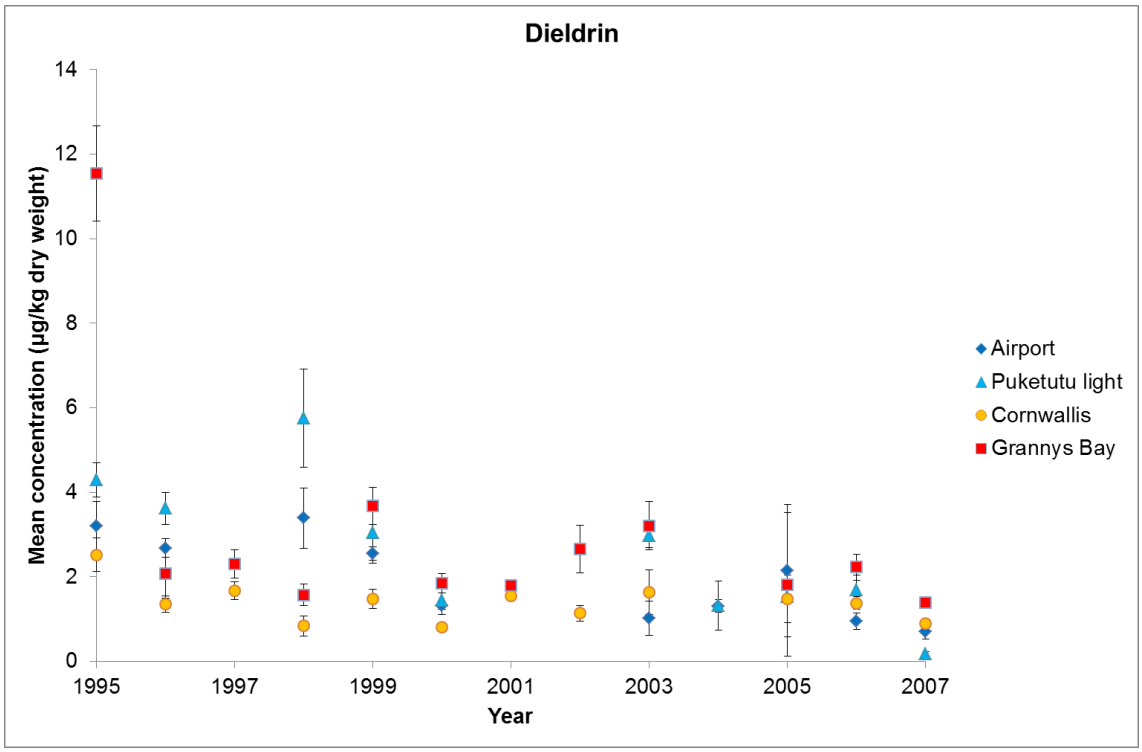


Figure 6-3 Trend comparison of dieldrin concentrations between two Mangere WWTP oyster sites and two SCMP oyster sites. Error bars represent one standard deviation about the mean.

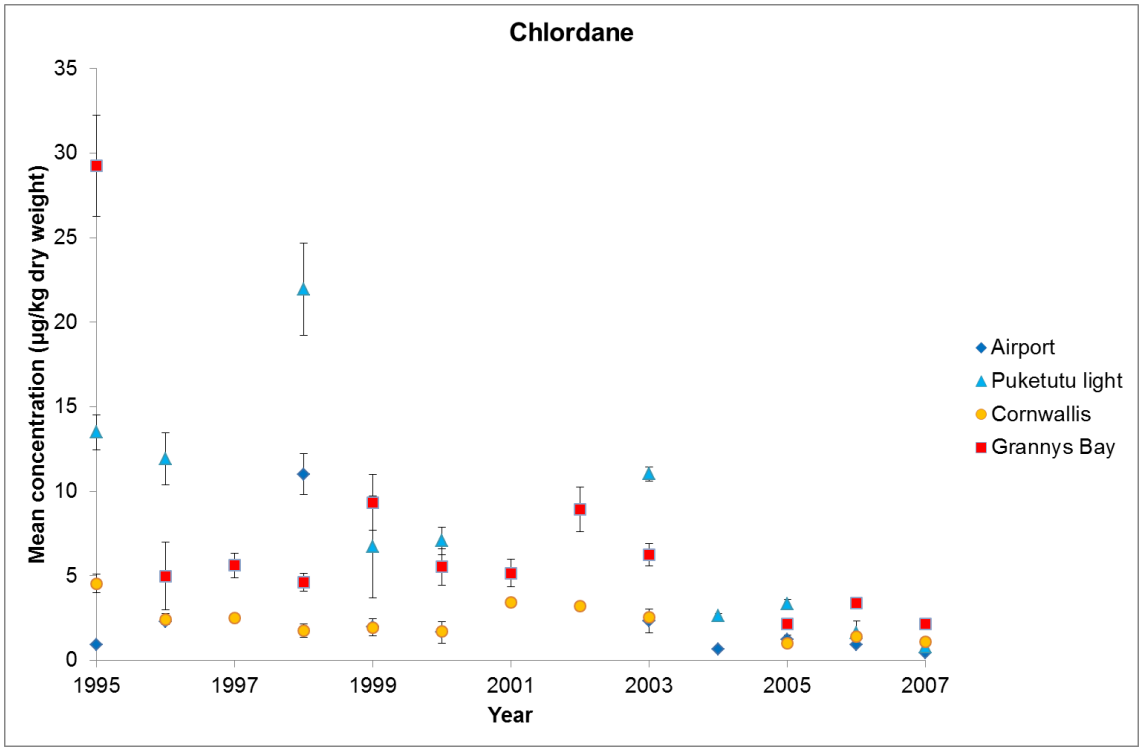


Figure 6-4 Trend comparison of chlordane concentrations between two Mangere WWTP oyster sites and two SCMP oyster sites. Error bars represent one standard deviation about the mean.

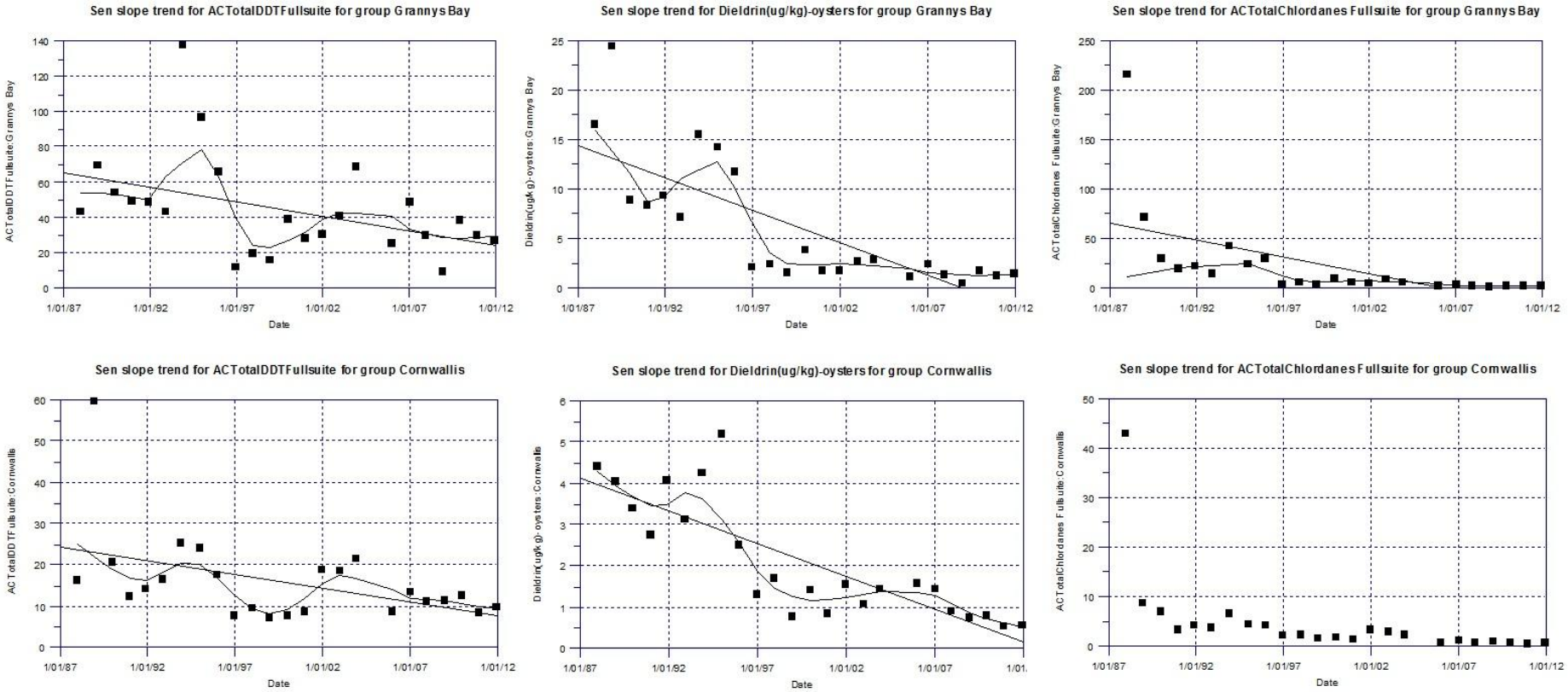


Figure 6-5 DDT, dieldrin and chlordane trend data (1987-2012) for Grannys Bay and Cornwallis oyster sites. DDT and chlordane are total suites.

Metals data appeared to be highly variable prior to 1999, with lead especially problematic. A lead outlier in 1998 data for Cornwallis was removed from median calculations. Lead data for Grannys Bay and Cornwallis in 1999 was not included as no data was available.

In general, there were no clear patterns in metal concentrations. At Grannys Bay, cadmium appeared to spike after 2001 (Figure 6-6), copper (Figure 6-7) and zinc (Figure 6-9) were effectively unchanged and lead (Figure 6-8) highly variable.

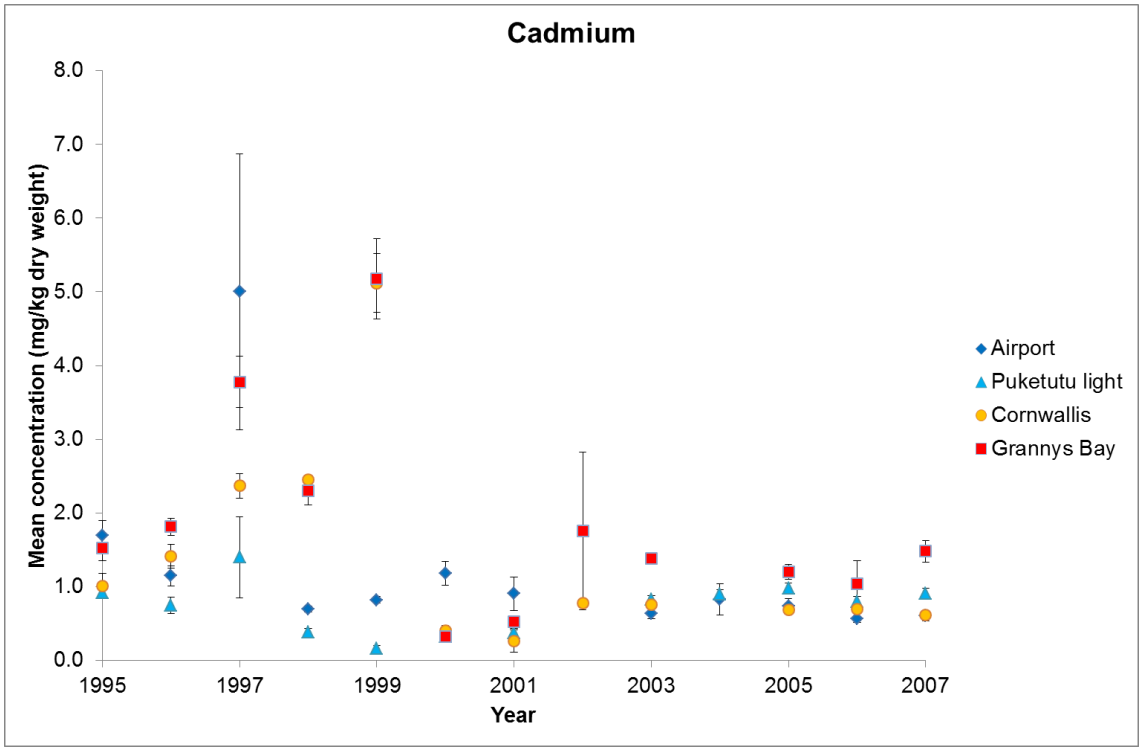


Figure 6-6 Trend comparison of cadmium concentrations between two Mangere WWTP oyster sites and two SCMP oyster sites .Error bars represent one standard deviation about the mean.

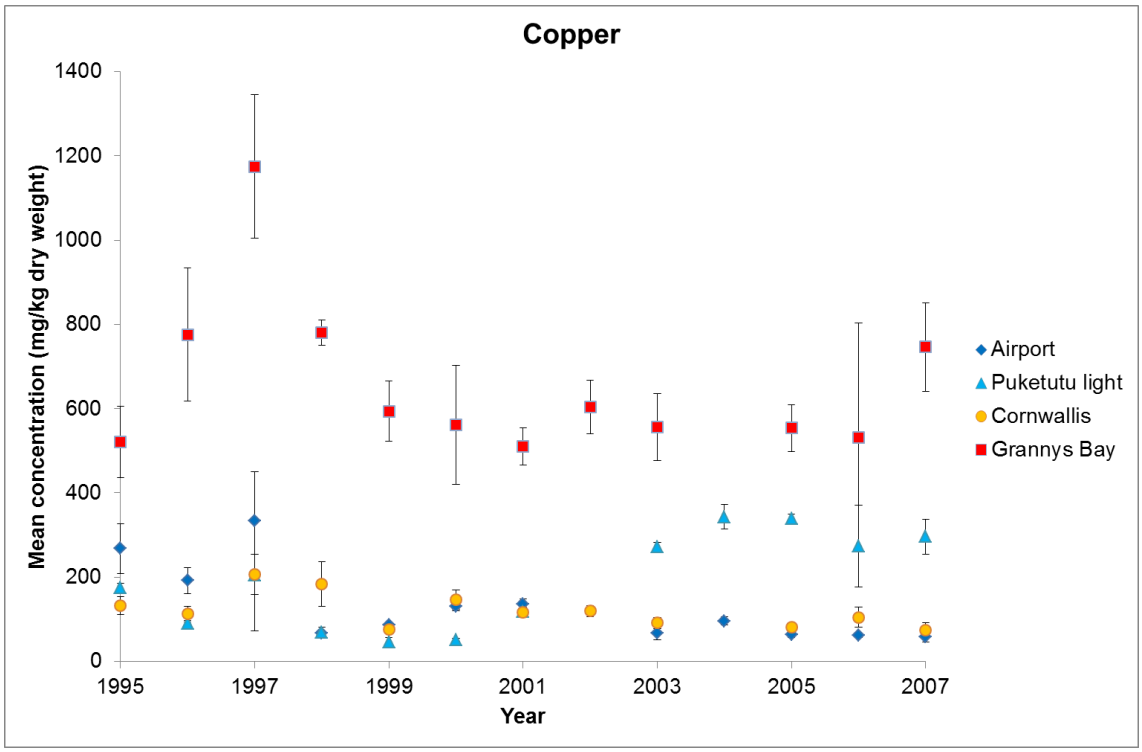


Figure 6-7 Trend comparison of copper concentrations between two Mangere WWTP oyster sites and two SCMP oyster sites. Error bars represent one standard deviation about the mean.

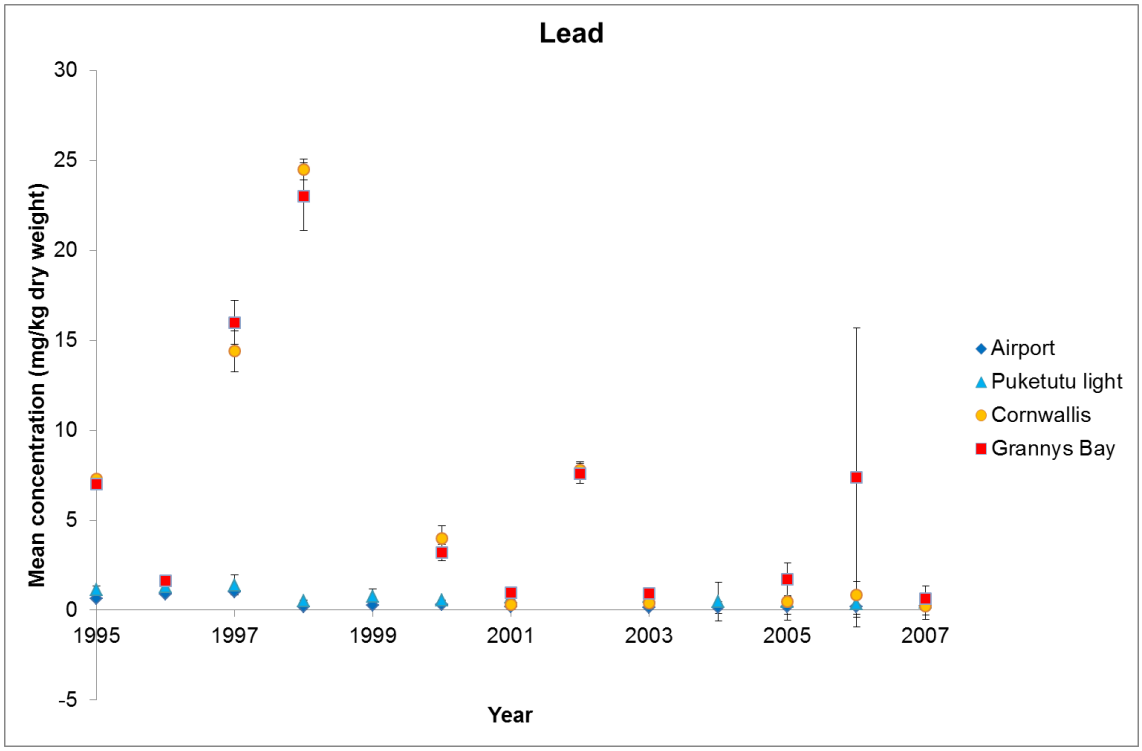


Figure 6-8 Trend comparison of lead concentrations between two Mangere WWTP oyster sites and two SCMP oyster sites. Error bars represent one standard deviation about the mean.

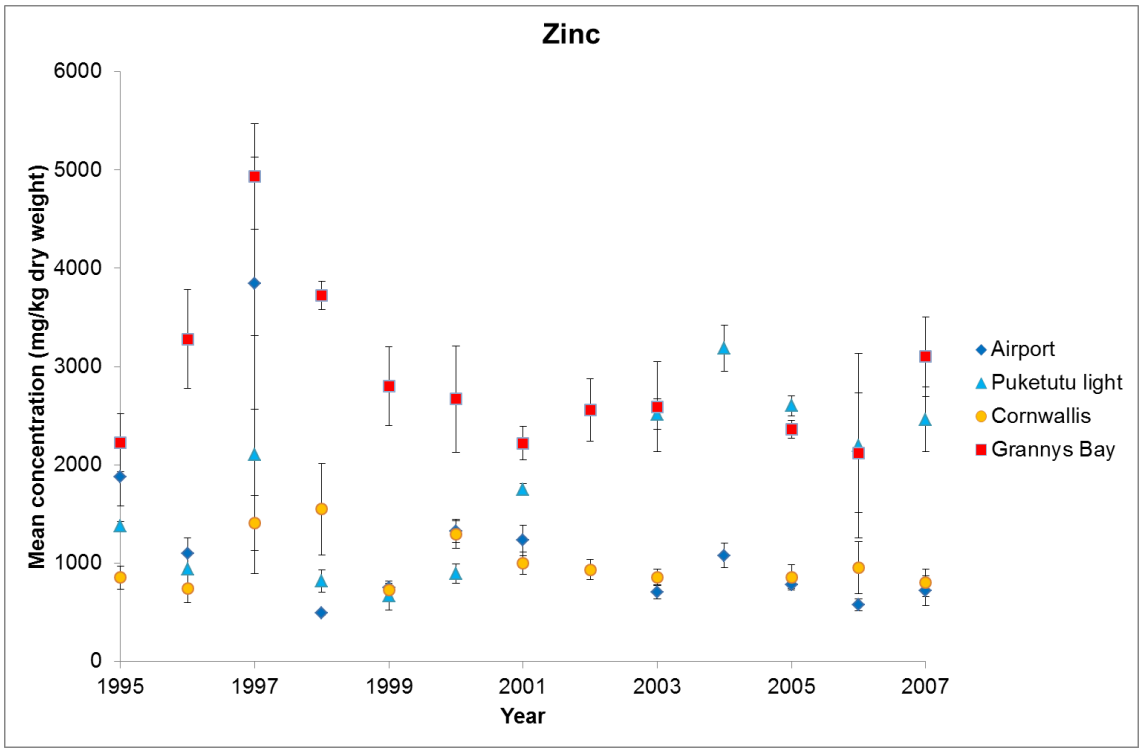


Figure 6-9 Trend comparison of zinc concentrations between two Mangere WWTP oyster sites and two SCMP oyster sites. Error bars represent one standard deviation about the mean.

6.4 Comparison of results with relevant guidelines

Current wet weight data (2009-2011) for the six key heavy metals (As, Cd, Cr, Cu, Pb, Zn) at each site are presented in Table 6-7. Data for arsenic, cadmium and lead were compared with Food Standards Australia New Zealand (FSANZ) Standard 1.4.1 (FSANZ 2011) and European Commission (EC) regulation No 1881/2006 (European Commission 2006). As stated in the methodology section, inorganic arsenic (AS_i) was conservatively estimated at 3% of the total arsenic (AS_{tot}) concentration. All three metal concentrations were well below the guidelines (Table 6-7).

Table 6-7 Comparisons of current weight wet metals concentrations (mg/kg) with relevant guidelines.

	Arsenic$_{tot}$	**Arsenic$_i$**	**Cadmium**	**Chromium**	**Copper**	**Lead**	**Zinc**
Mussels							
Tamaki	1.16	0.03	0.06	0.18	1.81	0.28	15
Upper Harbour	1.13	0.03	0.07	0.13	1.15	0.23	12
Chelsea	1.44	0.04	0.08	0.19	1.32	0.27	14
Illiomama	1.72	0.05	0.07	0.13	0.97	0.17	12
Mangere Bridge	1.06	0.03	0.09	0.23	0.94	0.18	11
Weymouth	1.31	0.04	0.09	0.16	0.69	0.10	11
Papakura Channel	1.64	0.05	0.08	0.15	0.81	0.08	12
Pre-deployment	1.12	0.03	0.12	0.03	0.58	0.11	11
Oysters							
Grannys Bay	1.01	0.03	0.12	0.09	86.84	0.07	433
Pahurehure	1.02	0.03	0.16	0.08	39.84	0.05	306
Hingaia	0.94	0.03	0.15	0.07	42.33	0.04	244
Cornwallis	2.34	0.07	0.15	0.17	19.92	0.04	241
Mill Bay	2.24	0.07	0.12	0.17	15.46	0.03	180
FSANZ	NA	1	2	NA	NA	2	NA
EC	NA	NA	1	NA	NA	1.5	NA

Mill Bay 2009 data only; FSANZ data for molluscs; EC data for bivalve molluscs.

Current organic wet weight concentrations (2009-2011) were compared with FSANZ Standard 1.4.2 (FSANZ 2012), with the exception of benzo[a]pyrene which was compared with EC regulation No 1881/2006 (European Commission 2006) and total PCBs which were compared with FSANZ Standard 1.4.1 (FSANZ 2011) (Table 6-8). FSANZ Standard 1.4.2 contains Maximum Residue Limits (MRL) for single organic contaminants (lindane) or suites of contaminants (DDT, aldrin/dieldrin, heptachlor, chlordane, BHC - note BHC is the sum of all isomers of 1,2,3,4,5,6-hexachlorocyclohexane, other than lindane). These standards are only designated for Australia, however they were used in this case as there were no national standards to compare against.

Organics data from the shellfish monitoring programme were extremely low compared with guideline values, usually less than 1% of the guideline value. The exception was benzo[a]pyrene which had mussel concentrations around 9-10% of the guideline at Chelsea, Tamaki and Upper Harbour (Table 6-8).

Table 6-8 Comparisons of current weight wet organics concentrations (μg/kg) with relevant guidelines.

	DDT	Aldrin/Dieldrin	Heptachlor	Chlordane	HCB	Lindane	BHC	Benzo[a]pyrene	PCBs
Mussels									
Tamaki	0.78	0.28	0.01	0.08	0.06	0.01	0.08	0.86	4.98
Upper Harbour	1.38	0.1	0.01	0.04	0.06	0.01	0.08	0.86	3.35
Chelsea	1.35	0.09	0.01	0.04	0.06	0.01	0.09	1.01	3.62
Illiomama	0.95	0.1	0.01	0.04	0.04	0.01	0.1	0.37	2.43
Mangere Bridge	1.52	0.19	0.01	0.08	0.03	0.02	0.13	0.24	3.88
Weymouth	0.38	0.07	0.01	0.02	0.03	0.01	0.11	0.08	0.76
Papakura Channel	0.41	0.06	0.01	0.02	0.04	0.01	0.13	0.07	0.77
Pre-deployment	0.08	0.06	0.01	0.02	0.02	0.01	0.08	0.03	0.15
Oysters									
Grannys Bay	3.11	0.16	0	0.08	0.004	0.01	0.002	0.13	3.54
Pahurehure	2.18	0.24	0	0.03	0.01	0.01	0.005	0.16	1.65
Hingaia	2.46	0.19	0	0.02	0.003	0.004	0.005	0.09	1.08
Cornwallis	1.7	0.12	0.01	0.04	0.01	0.01	0.009	0.04	1.82
Mill Bay	2.64	0.15	0	0.05	0.002	0.01	0.0004	0.08	1.52
FSANZ	1000	100	50	50	100	1000	10	NA	500
EC	NA	NA	NA	NA	NA	NA	NA	10	NA

BHC all isomers of 1,2,3,4,5,6-hexachlorocyclohexane, other than lindane; Mill Bay 2009 data only; FSANZ data for molluscs; EC data for bivalve molluscs; FSANZ PCB guideline for fish.

6.5 Comparison of shellfish contaminant status and trend data with other programme data

6.5.1 Sediment Contaminant Data

Sediment quality data is available through three monitoring programmes operated by Auckland Council, namely the State of Environment (SoE) programme, the Regional Discharges Project (RDP) and the Upper Waitemata Harbour (UWH) programme. Several of the same contaminants are monitored in the shellfish contaminant and the sediment quality monitoring programmes, including copper, lead, zinc and PAHs.

The location of these sites in comparison to the shellfish contaminant monitoring sites is presented in Figure 6-10. The closest sediment quality site to each shellfish site has been used in this comparison of programmes (Table 6-9).

Table 6-9 Sediment quality monitoring sites used in comparison with shellfish contaminant monitoring programme.

Shellfish site	Sediment quality site	Monitoring Programme
Mussels		
Tamaki	Bowden	RDP
Upper Harbour	Outer Main Channel	UWH
Chelsea	Chelsea	RDP
Illiomama	Te Matuku	SOE
Mangere Bridge	Mangere Cemetery	SOE
Weymouth	Pahurehure Middle	RDP
Papakura Channel	None	
Oysters		
Grannys Bay	Hillsborough	RDP
Pahurehure	Pahurehure Papakura	SOE
Hingaia	None	
Cornwallis	Mill Bay	RDP
Mill Bay	Mill Bay	RDP

Mill Bay 2009 data only.

Although organochlorine pesticides (OCPs) and PCBs have been measured in sediments around Auckland, these analyses have been for the SoE programme only, in 2007 for OCPs (Reed and Gadd 2009) and 2003 for both OCPs and PCBs (Reed and Webster 2004). At about half the sites analysed, the OCPs and PCBs were below the detection limits used by the analytical laboratories. There are only two sites where OCPs and PCBs have been measured that are located near to shellfish sites. On this basis, there is no way to compare the concentrations of OCPs and PCBs in sediment and shellfish. Similarly, there is inadequate sediment quality data to establish whether there are any meaningful trends in the concentrations of OCPs and PCBs over time.

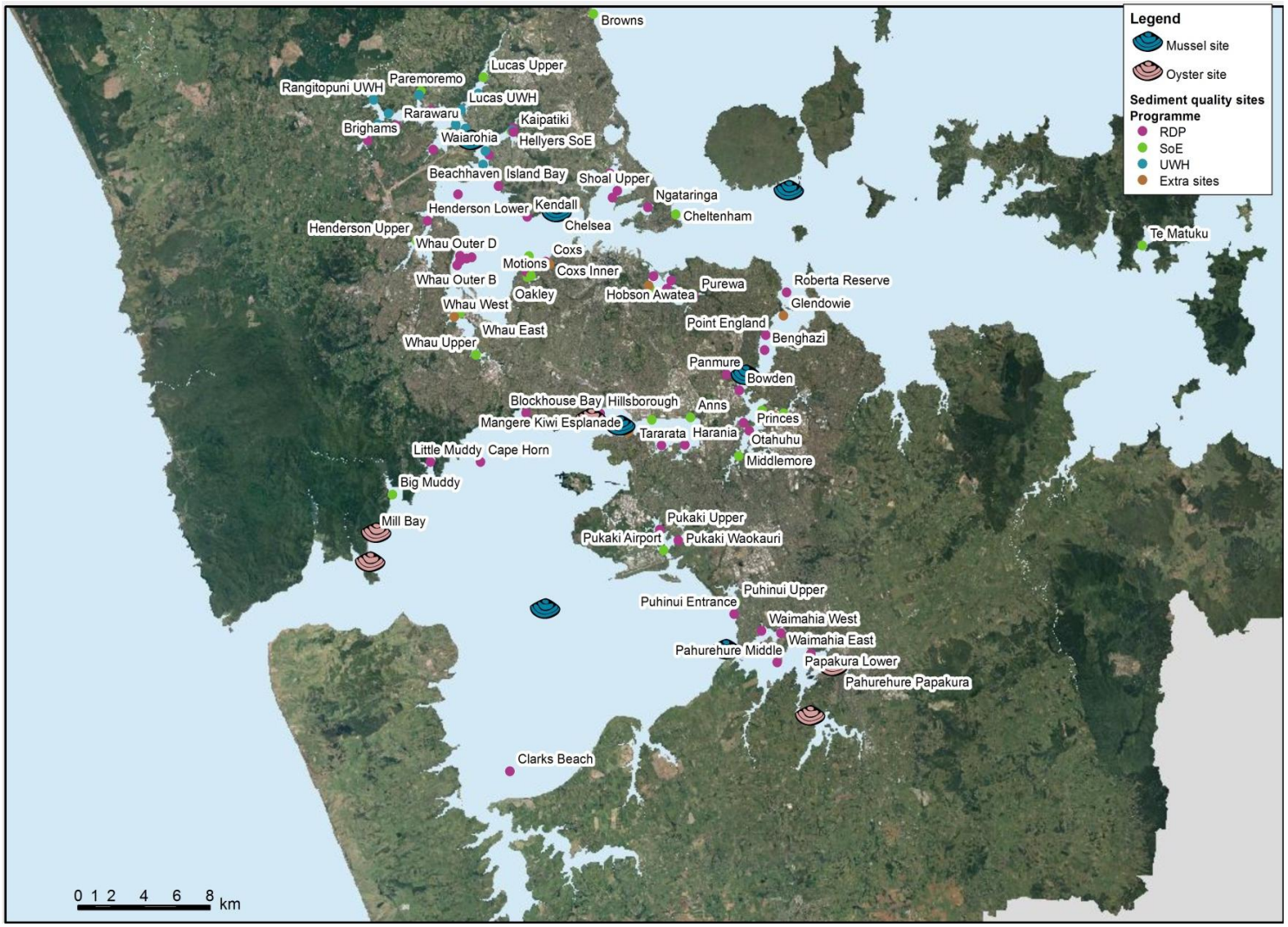
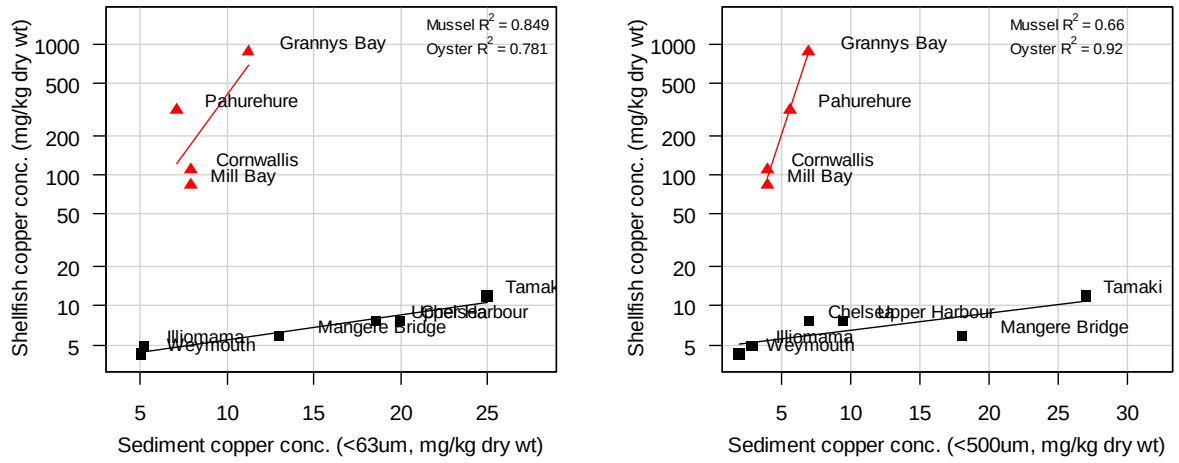
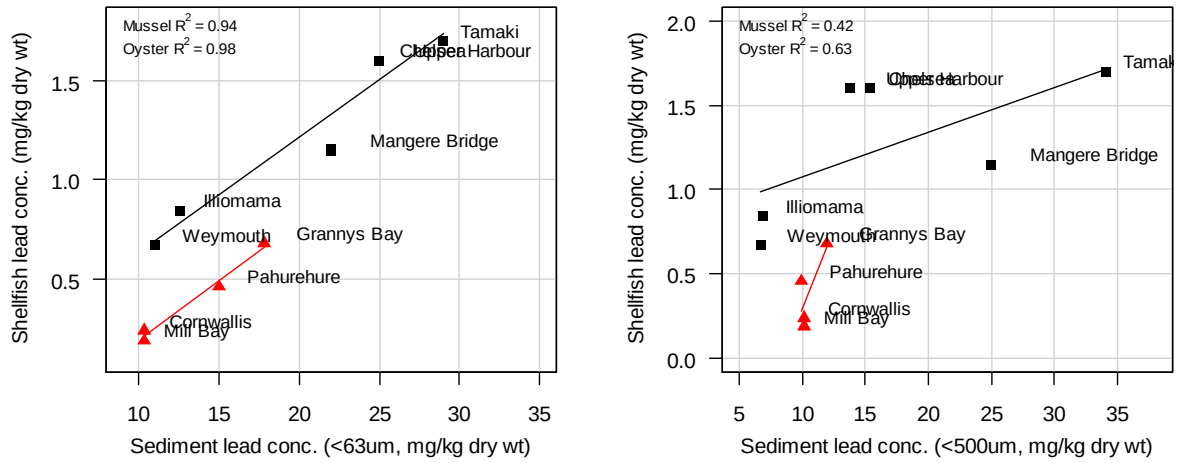


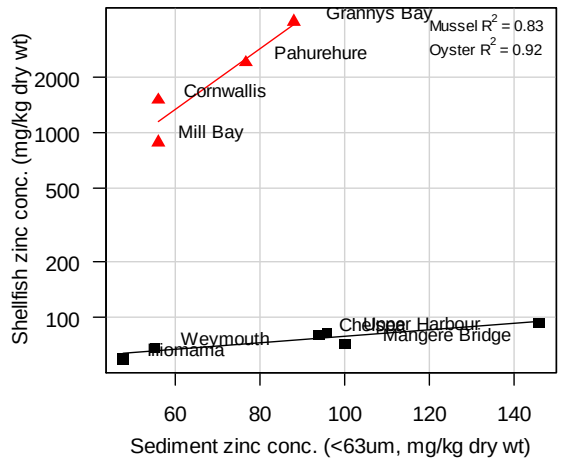
Figure 6-10 Location of sediment quality monitoring sites in comparison to SCM programme oyster and mussel sites.

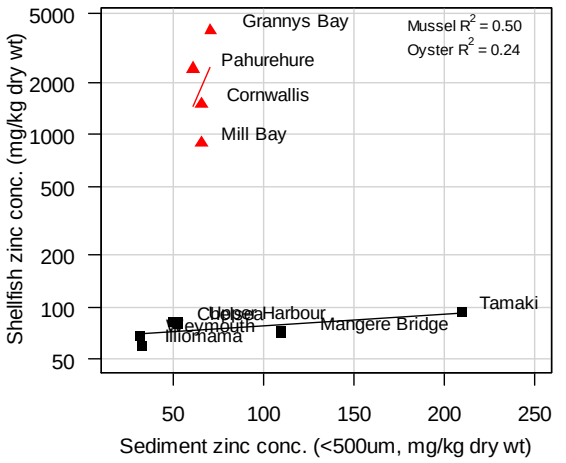
6.5.1.1 Status

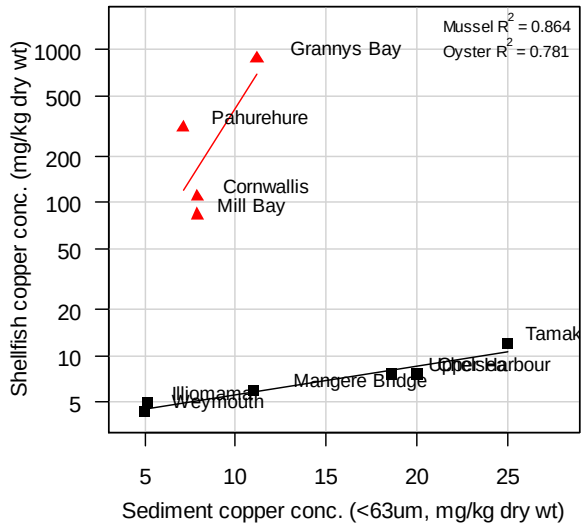
A graphical comparison of the sediment metal concentrations (2009-2011) compared to the shellfish metal concentrations (2009-2011) indicates very strong correlations for all three metals when oysters and mussels are considered separately (Figure 6-11). The correlations are strongest for the metal concentrations in the <63 µm fraction of the sediment. R^2 values for these ranged from 0.78 (copper in oysters) to 0.98 (lead in both species).

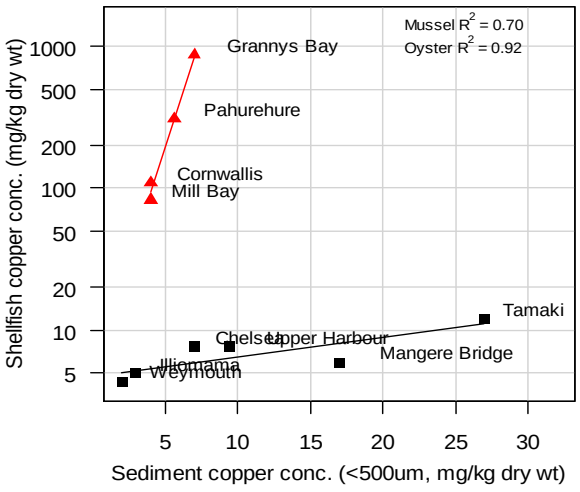


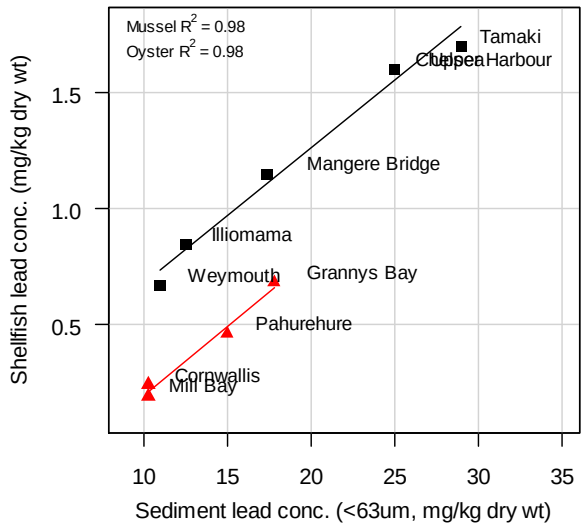


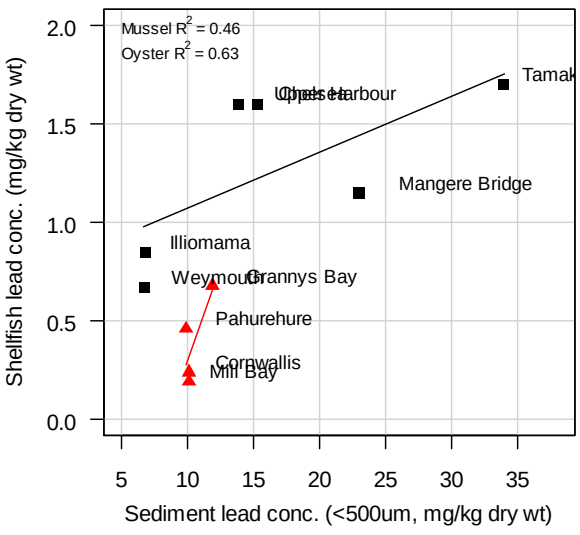

Mussel R2 = 0.83
Oyster R2 = 0.92
Grannys Bay
Pahurehure
Cornwallis
Mill Bay
Weymouth
Mangere Bridge
Shellfish zinc conc. (mg/kg dry wt)
Sediment zinc conc. (<63um, mg/kg dry wt)


Mussel R2 = 0.50
Oyster R2 = 0.24
Grannys Bay
Pahurehure
Cornwallis
Mill Bay
Tamaki
Mangere Bridge
Shellfish zinc conc. (mg/kg dry wt)
Sediment zinc conc. (<500um, mg/kg dry wt)


Mussel R2 = 0.864
Oyster R2 = 0.781
Grannys Bay
Pahurehure
Cornwallis
Mill Bay
Mangere Bridge
Weymouth
Shellfish copper conc. (mg/kg dry wt)
Sediment copper conc. (<63um, mg/kg dry wt)


Mussel R2 = 0.70
Oyster R2 = 0.92
Grannys Bay
Pahurehure
Cornwallis
Mill Bay
Tamaki
Mangere Bridge
Weymouth
Shellfish copper conc. (mg/kg dry wt)
Sediment copper conc. (<500um, mg/kg dry wt)


Mussel R2 = 0.98
Oyster R2 = 0.98
Tamaki
Mangere Bridge
Illiomama
Weymouth
Grannys Bay
Pahurehure
Cornwallis
Mill Bay
Shellfish lead conc. (mg/kg dry wt)
Sediment lead conc. (<63um, mg/kg dry wt)


Mussel R2 = 0.46
Oyster R2 = 0.63
Mangere Bridge
Illiomama
Weymouth
Grannys Bay
Pahurehure
Cornwallis
Mill Bay
Shellfish lead conc. (mg/kg dry wt)
Sediment lead conc. (<500um, mg/kg dry wt)

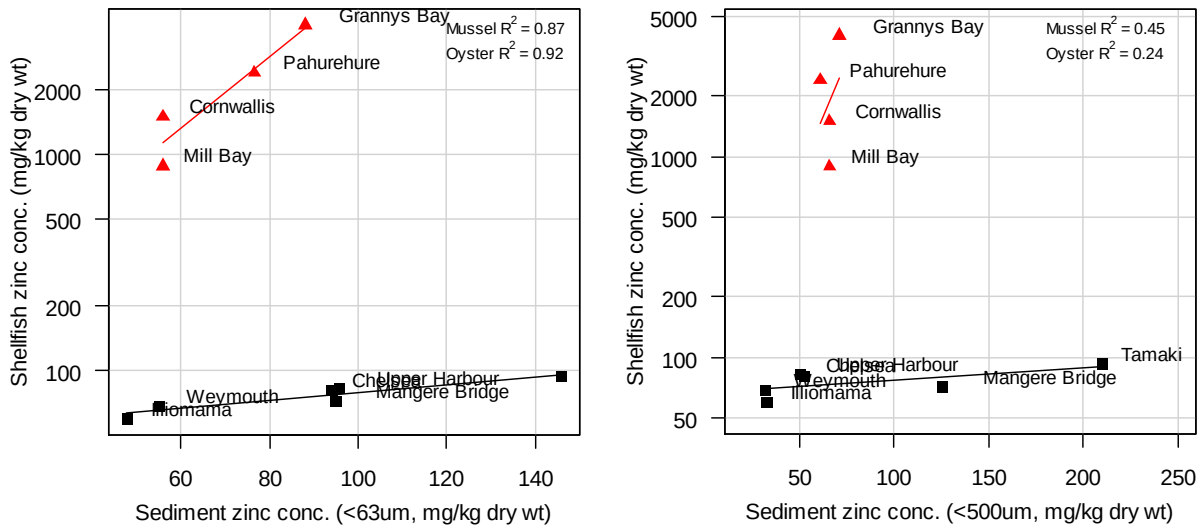


Figure 6-11 Comparison of sediment and shellfish metal concentrations (2009-2001). Red = oysters and black = mussels.

There are far fewer sediment sites where PAHs have been measured. Only four sediment sites where PAHs were measured could be located near shellfish sites. The 2009-2011 data for total PAHs in sediment (sum of 24 individual compounds) were compared to the 2009-2011 data for the full suite of PAHs in shellfish (lipid normalised), where no clear correlation was established (Figure 6-12).

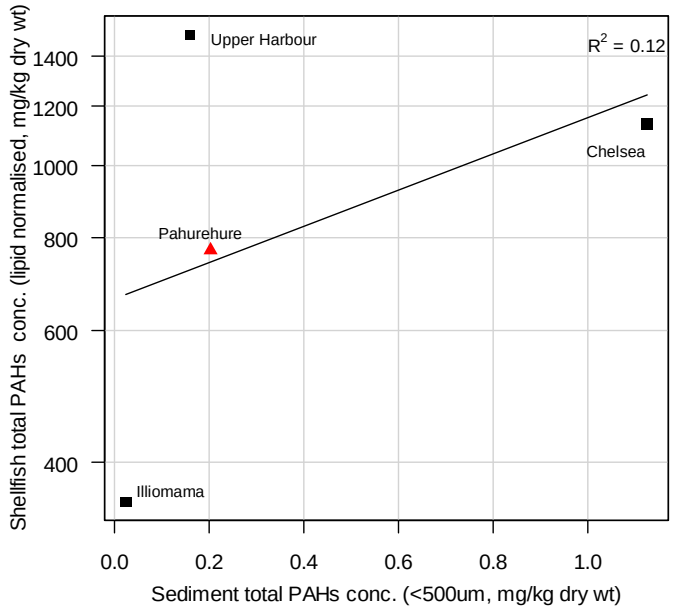


Figure 6-12 Comparison of PAH concentrations in sediment and shellfish (2009-2011).

6.5.1.2 Trends

Trends in sediment metal concentrations have recently been assessed for Auckland Council based on data up to 2010. This report (Mills*, et al.* 2012) stated that it was difficult to provide a clear summary of the current trend situation at all sites but that it appears that there has been little overall change in concentrations of metals or PAHs over the past decade. The authors did note however some small changes, specifically:

- decreasing trend in lead across most urban sites;
- mainly increasing trend in zinc;
- changes in copper are smaller and subject to greater uncertainty

Decreasing lead trends observed in sediment were consistent with those observed in the SCMP, with all mussel and oyster sites showing decreasing trends for lead (see section 5.3.1).

An increasing zinc sediment trend was also consistent with zinc shellfish trends in the SCMP with 5 out of 7 mussel sites exhibiting increasing trends; all oyster sites (1999-2011 time period) and 2 out of 4 oyster sites (1987-2011 time period) showing increasing trends. Interestingly, a significant decrease in zinc was observed in mussels from Illiomama, however this is a reference site with much reduced urban influence than the other sites.

Copper is generally decreasing in shellfish, with 6 out of 7 mussel sites; all four oyster sites (1987-2011 time period) and 2 out of 4 oyster sites (1999-2011 time period) showing decreasing trends.

6.5.2 Benthic Health Programme

The Auckland Council Benthic Health Programme (BHP) assesses the health status of macrobenthic communities based on Benthic Health Model (BHM) and Traits- Based functional Index (TBI) scores. Separate models have been created for two of the key environmental contaminants in Auckland area estuaries: sediment mud content (percent silt+clay) and sediment heavy metal concentrations (copper, lead and zinc). The TBI is a functional traits based index developed for use in AC's State of the Environment reporting. Health scores are: <0.2 (extremely good); 0.2 – 0.4 (good); 0.4 – 0.6 (moderate); 0.6 – 0.8 (poor); >0.8 (unhealthy with low resilience) (Hewitt*, et al.* 2012).

Sites monitored as part of this programme do not generally coincide with the shellfish monitoring sites, however there were general correlations between benthic health and shellfish site ranking (see section 4.4.1).

Chelsea had a moderate benthic health ranking and a mussel site ranking of 4/7. Upper Waitemata harbour benthic scores were generally in the poor to unhealthy category while the only shellfish site in the area (Upper Harbour Bridge mussel site) had a 5/7 site ranking. Rankings for Grannys Bay oyster site (4/4) and Mangere Bridge 6/7) reflect the unhealthy status of two benthic health sites in Mangere Inlet area. The benthic site in the northern

Manukau harbour (CH133: (Hewitt*, et al.* 2012)) with an extremely good health rating was in closest proximity to Cornwallis oyster site (site ranking 1/4) and Papakura mussel site (1/7).

Although there is limited overlap of sites between the BHP and the SCMP they effectively produce similar outputs, i.e. the measurement (SCMP) or effects (BHP) of bioavailable contaminants in the environment. As such, there is the potential for the BHP (in conjunction with the Sediment Monitoring Programme to *potentially* replace the SCMP in the future. This is discussed in more detail in the following review report (Stewart*, et al.* 2013)

6.5.3 Saline Water Quality

The saline water quality monitoring programme collects water samples from 27 sites around Auckland. The location of these sites in comparison to the shellfish contaminant monitoring sites is presented in Table 6-10 and Figure 6-13. The closest saline water quality site to each shellfish site has been used in this comparison of programmes.

Table 6-10 Saline water quality monitoring sites used in comparison with shellfish contaminant monitoring programme.

Shellfish site	Saline water quality site
Mussels	
Tamaki	Panmure
Upper Harbour	Hobsonville Jetty
Chelsea	Chelsea
Illiomama	None
Mangere Bridge	Mangere Bridge
Weymouth	Weymouth
Papakura Channel	Manukau Harbour @ Mouth
Oysters	
Grannys Bay	Mangere Bridge
Pahurehure	Weymouth
Hingaia	Weymouth
Cornwallis	Shag Point
Mill Bay	Shag Point

Mill Bay 2009 data only.

The shellfish PCA1 score from the multivariate status analysis (comparison of differences between sites) has been used as a summary statistic to compare to water quality variables measured in the saline water quality programme during the three-month deployment period for mussels and for a three-month period prior to sampling for oysters. A graphical analysis of the relationship between PCA1 score and water quality (Figure 6-14) shows only very weak relationships. The maximum R^2 value was 0.34, between nitrate-N+nitrite-N and the PCA score.

Figure 6-13 Location of saline water quality sites compared to oyster and mussel monitoring sites.

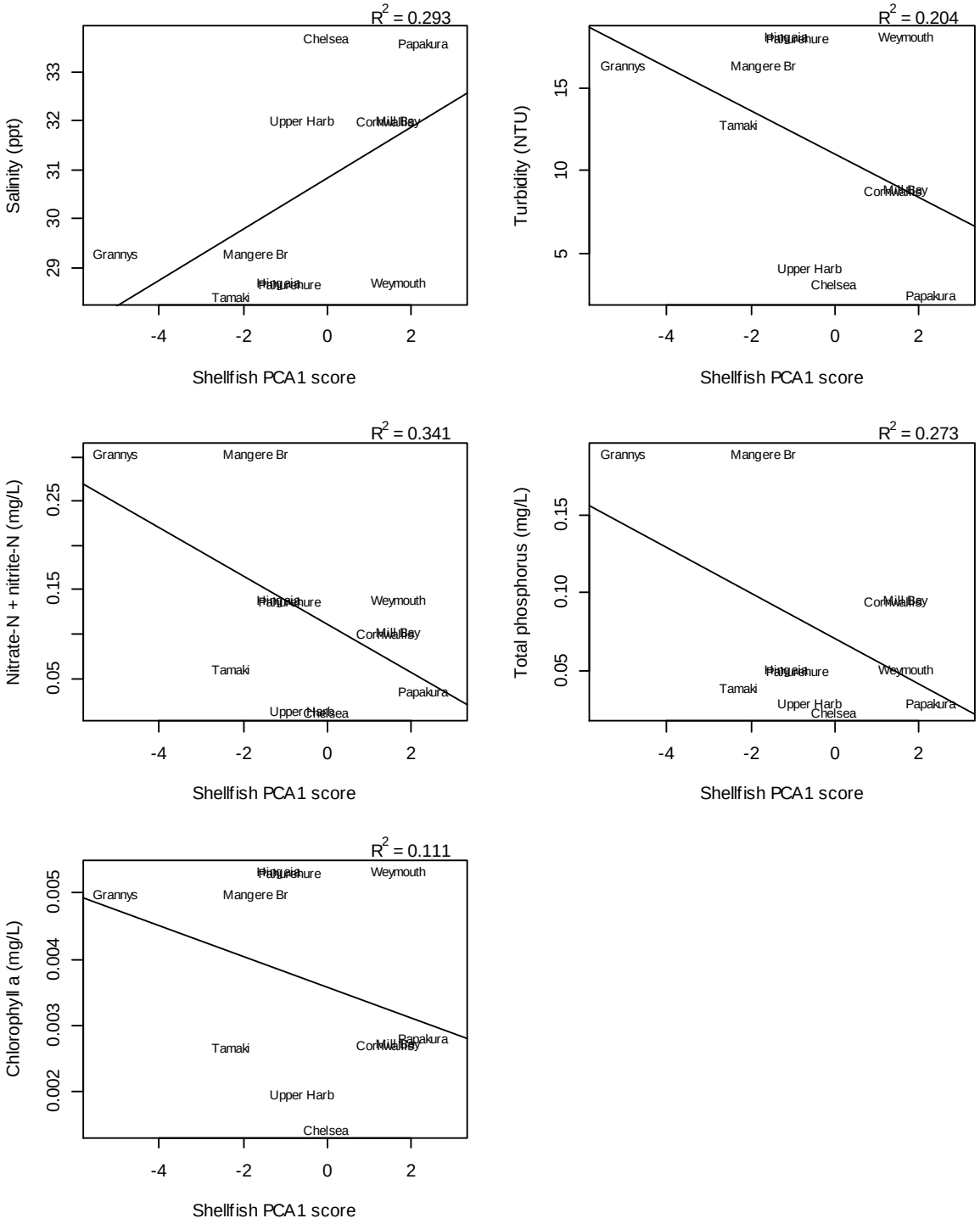


Figure 6-14 Comparison of saline water quality variables to PCA1 score for oysters and mussels.

A recent masters degree thesis performed a multivariate analysis of water quality in the Auckland region, finding that the first three principal components corresponded to three distinct aspects of water quality; microbial, nutrients and sedimentation (Seers 2011).

Analysis of trends in water quality from 1993-2010 indicated that various aspects of water quality had improved at many of the sites. Bacterial water quality has generally improved or stabilised within the Waitemata harbour and been more variable in the Manukau harbour with improvements at Mangere Bridge and Puketutu Point but increased faecal coliform counts at Weymouth.

Waitemata harbour sites have shown an improvement in nutrient water quality from around 2005. In the Manukau harbour, nutrient water quality was declining until around 2001 where it has shown marked improvement since then. Sediment water quality has generally been improving in the Waitemata and Manukau harbours. The Mangere Wastewater Treatment Plant upgrade directly coincided with the dramatic improvement in the microbial and nutrient water quality at the Manukau sites (Seers 2011).

It is difficult to establish a link between saline water quality and shellfish contaminant concentrations as water quality measures are transient, while shellfish contaminant concentrations are time integrated. However, decreased suspended solids in the water column (due to increased sediment water quality) would likely correlate to lower loads of sediment bound contaminants to the shellfish and hence lower concentrations measured in shellfish over time. This has been observed for all organic contaminants (except PAHs) but not for metals which are far more variable. Therefore, reduced suspended solids are not a good proxy for determining long term bioavailable contaminants.

7.0 Summary

7.1 QA

QA procedures and data were assessed, to determine whether changing analytical laboratories in 2005 (metals) and 2009 (organics) had any significant effect on the data. Metals have been analysed by Watercare Laboratory Services Ltd since 2005 (previously AgResearch), while organics have been analysed by AsureQuality Limited since 2009 (previously NIWA). For both current laboratories, QA procedures are comprehensive and provide sufficient information to measure analytical performance for the SCMP. An assessment of organics QA data has revealed that there were no significant changes as a consequence of changing analytical laboratories. This assessment was not possible for metals as no QA data is available prior to 2005. However, a change to the digestion procedure was implemented in 2011. This change does not appear to significantly affect the results for samples from the SCMP.

Recommendations arising from the QA assessment are:

- Re-assess why a shelf temperature of 25-30°C is used for freeze drying, with possible implications in the loss of volatile contaminants;
- Consider using a certified reference material (CRM) that contains levels of organic contaminants which more closely resemble the range observed in shellfish from the Auckland region;
- Decrease the spike concentration for PAHs by at least ten-fold (10 ng) to produce a spiked PAH data set which is in a similar range to real samples;
- AC to request blank data for PAH analyses;
- Confirm that the procedure used to measure %lipid is robust and reliable for future organic contaminant analyses;
- Consider conducting a small pilot study to measure if there are any significant differences between levels of contaminants (for both metals and organics) when extracting either wet tissue or freeze-dried tissue.
- We strongly recommend long-term storage of tissue samples (dried or frozen) for future investigations and retrospective analysis of e.g., emerging contaminants.

7.2 Current Status

Results for current status are:

- Based on a combined average contaminant score, mussel sites decreased in quality in the order: Pre-deployment; Papakura Channel; Illiomama; Weymouth; Chelsea; Upper Harbour; Mangere Bridge; Tamaki. The site ranking for mussels is very similar to the ranking provided in 2007 (Kelly 2007), suggesting only minimal relative change has occurred since that time.
- Based on the combined average contaminant score, oyster sites decreased in quality in the order: Cornwallis; Hingaia; Pahurehure; Grannys Bay. The ranking of oyster sites is unchanged from that provided in 2007 (Kelly 2007).

- For condition:
    - Oyster condition was highest at Cornwallis and lowest at Grannys Bay.
    - Mussel condition was substantially higher at Illiomama compared to the other sites and was lowest at Mangere Bridge. The condition index for the pre-deployment mussels was generally lower than the monitoring sites.
    - Pre-deployment mussel condition appears to have some effect on contaminant tissue concentrations, probably increasing variability and therefore decreasing the ability to detect trends.
- For heavy metals:
    - Arsenic concentrations were similar among both species with highest levels in Cornwallis oysters and lowest levels in Mangere Bridge mussels.
    - Cadmium concentrations were approximately twice as high in oysters compared to mussels and were highest in oysters at Hingaia. Lowest cadmium concentrations were measured in mussels at Tamaki and Illiomama.
    - Chromium concentrations were similar in oysters and mussels, were lowest at the Hingaia and Pahurehure oyster sites and the Illiomama mussel site and highest at Mangere Bridge mussel site.
    - Lead concentrations were around 3 times higher in mussels than in oysters and were substantially lower at Cornwallis than at all other sites. Highest concentrations of lead were measured at Upper Harbour, Chelsea and Tamaki mussel sites.
    - Copper concentrations were a factor of 50 times higher in oysters than in mussels and for oysters were highest at Grannys Bay and lowest at Cornwallis. Lowest copper concentrations were for pre-deployment mussels and at Weymouth and Papakura Channel mussel sites.
    - Zinc concentrations were a factor of 30 times higher in oysters than in mussels. For oysters, zinc concentrations were highest at Grannys Bay and lowest at Cornwallis.
    - Pre-deployment mussels generally had lower arsenic, chromium, copper and lead, similar zinc, and higher cadmium concentrations than monitoring sites.
- For organics:
    - Species specific differences between organic contaminant concentrations in mussels and oysters were much smaller than was observed for metals.
    - Of the oyster sites, Grannys Bay generally had the highest concentrations of organic contaminants, Hingaia and Pahurehure had intermediate concentrations, and Cornwallis consistently had the lowest concentrations.
    - Of the mussel sites, Mangere Bridge, Tamaki and Upper Harbour had the highest concentrations of most organochlorine contaminants. Total PAHs were highest at Tamaki.
- The only strong correlations between contaminants exhibited across the two species were zinc with cadmium, copper and DDT; copper with DDT; lead with PAHs; and chlordane with PCBs.
- Multivariate analysis was used to summarise the status of the sites. Differences between shellfish type (oyster vs. mussels) generally occurred along the second most important axis, with the most important axis summarising differences in contaminant status which

were unassociated with differential uptake rates of the two species. Variables most strongly related to these differences were DDT, chlordane, copper, and PCBs.

- Multivariate analysis linking contamination and condition to land-use suggest sites of the same category (reference (primarily indigenous forest), urban, semi-urban) generally group together, with the most significant difference being between urban sites and reference sites.

Current contaminant status for mussels and oysters was compared for sites in the Manukau Harbour. Overall, median concentrations of contaminants are higher in oysters than mussels, with the exception of lead and lindane, which are lower in oysters than mussels.

7.3 Trends

Trend comparisons between raw mussel contaminant data and pre-deployment subtracted contaminant data revealed pre-deployment subtraction is not a useful approach for trend analysis (particularly for metals) and, as such, all trends were undertaken on raw mussel data.

Contaminant temporal trend analysis was undertaken on dry weight data for oysters at two time periods - 1987 to 2011 (lifetime of SCMP) and from 1999 to 2011 (to compare with mussels), using the NIWA developed statistical tool “Time Trends”. Generally there were a greater number of significant and meaningful trends for the full time series than in the shorter time series. There was also a lack of concordance between meaningful trends observed for oyster metal concentrations for the two time periods, but much closer concordance for organic suites.

A summary of the heavy metal trends were:

- For mussels, increasing trends were observed for arsenic (4 out of 7 sites), cadmium (6/7) and zinc (5/7), while decreasing trends were observed for chromium (6/7), copper (6/7) and lead (7/7).
- For oysters (1987-2011 only), increasing trends were observed for arsenic(3 out of 4 sites), while decreasing trends were observed for cadmium (4/4), chromium (4/4), copper (4/4) and lead (4/4). Zinc was increasing at two sites and decreasing at two sites.

A summary of organics trends were:

- For both species, generally organic contaminant levels have decreased over all time periods analysed, although PAHs did show some minor increases over the shorter time periods.
- Lipid content has declined at all sites except Illiomama, suggesting that it may not be a suitably stable variable to use in standardising the data.

An alternative trend analysis method, known as the Akritas-Theil-Sen (ATS) nonparametric regression method, was also used for highly censored (less than detection level) data. Comparisons with the Time Trends analysis suggested that the ATS method was more sensitive with good agreement between the two methods for oysters, but less agreement for mussels.

Condition trend analysis was only possible on data from 2006-2011, which suggested no significant change in condition has occurred over this time period.

Distance-based linear modelling (DistLM) was used to quantitatively model the relationship between the multivariate contaminant data, and the predictor variables of year of sampling. Year was a significant predictor of the combined contaminant concentrations for all sites except Illiomama, explaining a high proportion of variance. There were no obvious trends over time based on the combined influence of contaminants when all sites were examined together. When sites were examined individually there were considerable between-site differences for oysters but not for mussels.

Differences in contaminant trends and the combination of contaminant and condition trends between sites were examined by principal component analysis (PCA), which indicated differences in the contaminant trends in oysters and mussels, and that trends in contaminants - and not condition - dominate this analysis. However, similar to the summary of status based on current values, the axis explaining most of the variability is not affected by the differences between oysters and mussels and is driven by trends in organic suites.

Analysis using the correlation coefficient Kendall's tau suggested:

- There is no statistically significant correlation between the trends in contaminant concentrations and the trends in condition.
- There is no statistically significant correlation between the trends in oysters and the trends in mussels.
- There is a significant correlation between the condition trends in oysters and the condition trends in mussels. However, as the condition trends were not statistically significant, this has little relevance for trend analysis.

Trend comparisons were undertaken between oyster and mussel sites in the Manukau Harbour as this is the only harbour where there are both oyster and mussels sites, albeit no sites contain both species. There were few meaningful comparable trends in either metals or organics and no condition trends were meaningful. However, some similarities in trends suggest that it would be worthwhile to sample some sites with both oysters and mussels (for metals at least) to determine to what degree variations in trends are dependent on differential uptake of contaminants by each species.

There were no strong correlations between climate variables and contaminants or PCA scores but there were some correlations between shellfish condition and climate variables, although condition data were only available from 2006.

7.4 SCMP comparisons

The SCMP contaminant data were compared to the United States (US) National Status & Trends (NS&T) mussel watch programme and the French Réseau National d'Observation (RNO) de la Qualité du Milieu Marin:

- Generally, the current status of mussel and oyster contamination from the Auckland region is comparable to the RNO data and considered low by US NS&T criteria, with a few exceptions for oyster concentrations of copper, arsenic, lead and zinc which were occasionally in medium or high categories.

- Generally SCMP trends reflect those seen within the RNO mussel watch programme and the NS&T mussel watch programme (for organics), but differ for metals.

Selected organics and metal oyster concentrations were compared with data from oyster sites around Mangere wastewater treatment plant (WWTP) to assess the environmental significance of the upgrade of Mangere WWTP in 2001. Generally, where a spike in concentrations was observed in Mangere WWTP sites after 2001, these were mirrored at Grannys Bay and occasionally (and to a lesser extent) at Cornwallis. Concentrations have since returned to at or below those prior to the upgrade.

Shellfish wet weight contaminant concentrations were compared with relevant national and international guidelines for human consumption. All three relevant metal concentrations were well below these guidelines. Organics data were extremely low compared with guideline values, usually less than 1% of the guideline value. The exception was benzo[a]pyrene which had mussel concentrations around 9-10% of the guideline at Chelsea, Tamaki and Upper Harbour. No consideration was given to bacterial or viral factors when assessing human health implications of consuming these shellfish, as this is outside the scope of the SCMP.

Shellfish contaminant status and trend results were compared (where possible) with nearby sediment contaminant, benthic health and saline water quality sites. Strong correlations were observed between shellfish concentrations and sediment concentrations for copper, lead and zinc. Generally, decreasing lead, increasing zinc and variable copper trends in sediment were consistent with shellfish data. Only very weak relationships were observed between shellfish PCA scores and saline water quality. There were very few nearby benthic health programme sites, although a general relationship was observed between benthic health and shellfish site rankings where sites were available.

7.5 Discussion and Future of the SCMP

The SCMP provides information on bioaccumulative and bioavailable contaminants that cannot (at present) be directly obtained by other monitoring programmes. The SCMP complements, and only partially overlaps with the Saline Water Quality Programme, the Sediment Contaminant Monitoring Programme and the Benthic Ecology Programme - to provide a holistic assessment of environmental contamination in the Auckland region. There is the *potential* to replace the SCMP in the future with a combination of sediment and benthic health monitoring, but further assessment should be carried out before this is considered.

The SCMP has been in existence for over a quarter of a century and provides an important long term historical dataset. Contaminant concentrations can be assessed by benchmarking against international shellfish monitoring programmes and national and international food safety guidelines. Temporal contaminant trends can be used to assess the environmental consequence of banning specific contaminants and assessing broad scale land-use changes in upstream catchments.

The SCMP has seen many changes throughout its lifetime. Any changes to the programme have been based on sound scientific knowledge to ensure that it has a maximum chance of improving the relevance of the outputs. Changes would not be possible without periodical assessments of the current contaminant status and trends over time and thorough reviews of the programme.

Many of the changes put in place have resulted in improvements to the quality of the data outputs, through introduction of new sites and species (mussels), changes to the analytical suites of contaminants, and improvements in data quality as analytical laboratory capabilities mature.

Of course, like all monitoring programmes, the SCMP has to evolve further in the future to remain relevant. A review of the SCMP for the future would need to assess the relevance of:

- The suitability of maintaining two different species - with the associated variance and logistical issues that arise from this.
- Are the current monitoring sites sufficient to provide contaminant information for the whole Auckland region? For example, are new areas that are subjected to intensive land-use changes sufficiently covered to assess the environmental impacts of those changes?
- Many legacy contaminant concentrations have now reduced in the environment to the extent where many are now only detected due to improved analytical technology. Their continued inclusion in analytical suites - especially in light of new "emerging" contaminants now becoming more relevant - needs to be assessed.

Added to this are increasing budgetary constraints and an ever pressing need to ensure the SCMP is providing quality information. As such, the review should also concentrate on other alternatives to assess what aspects could be reduced or removed and still maintain the required information. This could include assessing how the frequency of monitoring affects the ability to perform future trend analysis; assessing how a reduction of replicates affects the variability of the data; and whether there are any viable alternatives that could replace the SCMP in the future.

Potential implications of these discussed changes are covered in much more detail in the associated programme review report (Stewart*, et al.* 2013).

8.0 Acknowledgements

The authors thank Marcus Cameron and Peter Williams from Auckland Council for preparation of SCMP data into usable format for analysis and Marcus Cameron and Megan Carbines for reviews of drafts. We thank Judi Hewitt from NIWA Hamilton for assistance with statistical analyses. We also thank Robyn Abernathy and Steve Money from Watercare Services Ltd, and Phil Bridgen of AsureQuality Limited, for their assistance with aspects of QA methodology.

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Appendix A Descriptions of contaminants, their sources and impacts

Information for Appendix A was taken primarily from two sources.

Information on sources and potential human health effects was obtained from the US Agency for Toxic Substances and Disease Registry (ATSDR) online portal (ATSDR 2012) and US EPA Integrated Risk Information System (IRIS) (US EPA 2012), respectively.

Most region specific information was taken from Appendix A of Auckland Council Technical Publication TP332 (Kelly 2007), from which much information was referenced from reports of the Australian and New Zealand Environment and Conservation Council (ANZECC) Australian and New Zealand Guidelines for Fresh and Marine Water Quality (Vol 1-3) (ANZECC 2000). These guidelines have not been updated at this time. Where this information was not available, it was obtained from the Ministry for the Environment (MfE) website (MfE 2012), or the Ministry for Primary Industries (MPI) website (MPI 2012).

Key Metals

Total Arsenic (As)

Arsenic is a naturally occurring element widely distributed in the Earth's crust. In the environment, arsenic is combined with oxygen, chlorine, and sulfur to form inorganic arsenic compounds. Arsenic also forms organic arsenic compounds (ATSDR 2012). Total arsenic consists of both organic and inorganic forms. Inorganic arsenic is classified by the US EPA as a carcinogen (US EPA 2012).

The predominant commercial use of arsenic in the Auckland region is by timber treatment companies for wood preservation (Kelly 2007). Other examples of its use include:

- Herbicides and insecticides.
- Lead-acid batteries.
- Small amounts of pure arsenic metal are used in the manufacture of semiconductors for the computing and electronic industries.

Heavy industries such as mining, smelting, pulp and paper production, glass manufacturing, cement manufacturing may also release arsenic to the environment.

Natural sources include volcanoes, ground water, and hydrothermal vents.

Arsenic has acute and chronic toxicity to many aquatic organisms (ANZECC 2000).

Cadmium (Cd)

Cadmium is a natural element in the Earth's crust. It is usually found as a mineral combined with other elements such as oxygen (cadmium oxide), chlorine (cadmium chloride), or sulfur (cadmium sulfate, cadmium sulfide). All soils and rocks, including coal and mineral fertilizers, contain some cadmium. Cadmium does not corrode easily and has many uses, including batteries, pigments, metal coatings, and plastics (ATSDR 2012).

The US EPA classifies cadmium as a probable human carcinogen (US EPA 2012) Cadmium can also be toxic to aquatic organisms at very low concentrations. It may exist in a number of forms which influence its toxicity, bioavailability and mobility in the environment. Cadmium is accumulated by many aquatic organisms with bio-concentration factors in the order of 100 – 100,000 (ANZECC 2000). There is also some evidence to suggest that cadmium is also accumulated through the food chain (ANZECC 2000).

Chromium (Cr)

Chromium is a naturally occurring element found in rocks, animals, plants, and soil. It can exist in several different forms. Depending on the form it takes, it can be a liquid, solid, or gas. The most common forms are Cr(0), Cr(III), and Cr(VI). No taste or odour is associated with chromium compounds. The metal chromium, which is the Cr(0) form, is used for making steel. Cr(VI) and Cr(III) are used for chrome plating, dyes and pigments, leather tanning, and wood preserving (ATSDR 2012).

Cr (VI) is the most toxic form to humans. It has been classified as a known or likely human carcinogen by the inhalation route but unclassified by the oral route. Cr(III) is not classified as a human carcinogenic risk (US EPA 2012).

Chromium is accumulated by marine and freshwater organisms. Bio-concentrations factors range from 100 – 1,000. There is little evidence that cadmium is accumulated through the food chain (ANZECC 2000).

Copper (Cu)

Copper is a metal that occurs naturally throughout the environment, in rocks, soil, water, and air. Copper is an essential element in plants and animals (including humans). Copper is used to make many different kinds of products like wire, plumbing pipes, and sheet metal. Copper is also combined with other metals to make brass and bronze pipes and taps (ATSDR 2012).Copper is widely used in the electrical, construction, plumbing, and automotive industries, in antifouling paints, in horticultural sprays and as a trace element in some stock foods and supplements (Kelly 2007).

Aquatic organisms have widely varying sensitivities to copper. Algae in particular are sensitive to relatively low copper concentrations, hence its use in algaecides and antifoulants. It is readily accumulated by plants and animals with bioconcentration factors ranging from 100 – 26,000 being recorded (ANZECC 2000).

Natural sources of copper in aquatic environments include the weathering of copper minerals and native copper. However, by far the greatest source of copper is from anthropogenic activities.

Lead (Pb)

Lead is a naturally occurring bluish-grey metal found in small amounts in the Earth's crust. Lead can be found in all parts of our environment. Much of it comes from human activities including burning fossil fuels (particularly petrol containing tetraethyl lead additives), mining and manufacturing. Lead has many different uses. It is used in the production of batteries, ammunition, metal products (solder and pipes), weights and sinkers and devices to shield X-rays. Because of health concerns, lead from paints and ceramic products, caulking, and pipe solder has been dramatically reduced in recent years (ATSDR 2012).

Historically the major source of lead in New Zealand was from fuel additives. However, lead was withdrawn as a petrol additive in 1996. Other sources include industrial processes, paints, pigments, batteries and shot pellets (Kelly 2007).

Lead can damage the nervous system, kidneys, and reproductive system (ATSDR 2012). The US EPA has classified lead as a probable human carcinogen (US EPA 2012).

Lead is acutely and chronically toxic to aquatic life at very low concentrations. It is accumulated by molluscs and may be passed up the food chain. There is evidence of lead bio-concentration at higher trophic levels (Kelly 2007).

Zinc (Zn)

Zinc is an essential element for plants and animals and is not particularly toxic to humans, although it can be harmful at high concentrations. Zinc toxicity to aquatic biota is highly variable with some organisms being very sensitive to zinc levels and others being particularly tolerant. Many organisms accumulate zinc to relatively high concentrations.

Zinc is a ubiquitous element in urban areas. Examples of its use include: galvanising, the production of alloy materials, in plasticizers for synthetic rubbers such as tyres and in paint manufacture (Kelly 2007).

Organic Contaminants

PAHs (Polycyclic Aromatic Hydrocarbons)

PAHs are compounds formed by the incomplete combustion of organic material. Natural background levels of PAHs are found in the environment from events such as forest fires and volcanic activities. However, the most significant sources are from anthropogenic activity such as motor vehicle emissions, roading materials such as coal tar, and wood and coal burning fires (Kelly 2007).

There are more than 100 different PAHs. PAHs generally occur as complex mixtures (for example, as part of combustion products such as soot), not as single compounds (ATSDR 2012).

The health effects of individual PAHs are not exactly alike, ranging from non-toxic to extremely toxic. The US EPA has determined that the following 7 PAHs are probable human carcinogens (ATSDR 2012):

- benz[a]anthracene
- benzo[a]pyrene
- benzo[b]fluoranthene
- benzo[k]fluoranthene
- chrysene
- dibenz[a,h]anthracene
- indeno[1,2,3-c,d]pyrene.

Many PAHs are chronically and/or acutely toxic to a range of aquatic organisms. Their toxicity can be magnified significantly by photo activation with UV light (ANZECC 2000).

Aldrin and Dieldrin

Aldrin and dieldrin are insecticides with similar chemical structures. Aldrin rapidly breaks down to dieldrin in the body and in the environment. Exposure to aldrin and dieldrin occurs mostly through eating contaminated foods, such as root crops, fish, or seafood. Aldrin and dieldrin accumulate in the body after years of exposure and can affect the nervous system (ATSDR 2012).The US EPA has classified dieldrin as a probable human carcinogen (US EPA 2012).

In New Zealand, aldrin and dieldrin were introduced in 1954 for use as stock remedies in sheep sprays or dips for controlling sheep ectoparasites. Aldrin was used to control horticultural pests such as wireworm, soldier fly and black vine weevil, and in limited quantities, to control household spiders. Dieldrin was used for controlling carrot rust fly, crickets and armyworm and was also used for timber preservation (mostly in plywood glues) and to mothproof carpets (Buckland*, et al.* 1998). Dieldrin was deregistered as a pesticide in 1989 and permits for its use in horticulture and agriculture have been revoked. Use of dieldrin for commercial pest control in buildings did not require a permit and it is possible that old stocks are still used for this application (Kelly 2007).

Dieldrin generally exhibits high to very high toxicity to aquatic species (ANZECC 2000).

Lindane

Lindane (γ-HCH) is one of eight isomers formed during the manufacture of technical grade (crude) hexachlorocyclohexane (HCH), also known erroneously as benzene hexachloride (BHC). Technical grade HCH typically contained about 10–15% of γ-HCH as well as the alpha (α), beta (β), delta (δ), and epsilon (ε) forms. It is used as an insecticide on fruit, vegetables, and forest crops (ATSDR 2012).

In New Zealand, lindane was used as an insecticide in agriculture for the control of lice on cattle, ectoparasites (lice, keds and blowflies) in sheep and grass grub in pasture. Lindane was also used for insect control on vegetable and fruit crops, and as an active component of fly sprays, flea control and carpet moth products for household use. Technical grade HCH was not officially used

in New Zealand, although many dip sites show evidence of the use of crude HCH (Buckland*, et al.* 1998). Lindane was deregistered in 1990 (Kelly 2007).

Exposure to lindane happens mostly from eating contaminated food or by breathing contaminated air in the workplace. Exposure to high levels of lindane can cause blood disorders, dizziness, headaches, seizures, and changes in the levels of sex hormones. The US EPA has determined there is not enough evidence to determine whether lindane is a human carcinogen (US EPA 2012).

Lindane has moderate to high toxicity to aquatic organisms, although some molluscs are less sensitive (ANZECC 2000).

DDT (dichlorodiphenyltrichloroethane)

Dichlorodiphenyltrichloroethane (DDT) is a pesticide that was used extensively throughout the world to control insects that affect agriculture and horticulture. It is still used in some countries as a control measure for insects, such as mosquitoes, that carry malaria. DDT was used largely as an insecticide to control grass grubs and porina caterpillars in New Zealand, with its use restricted in 1970 and finally banned in 1989 (Taylor*, et al.* 1997). DDT breaks down in the environment to dichlorodiphenyldichloroethylene (DDE) and dichlorodiphenyldichloroethane (DDD), all of which persist for years.

Exposure to DDT, DDE, and DDD occurs mostly from eating foods containing low concentrations of these compounds, particularly meat, fish and poultry. High levels of DDT can affect the nervous system causing excitability, tremors and seizures. In women, DDE can cause a reduction in the duration of lactation and an increased chance of having a premature baby (ATSDR 2012). DDT is classified by US EPA as a probable human carcinogen (US EPA 2012).

DDT is highly toxic to most aquatic species (ANZECC 2000).

Chlordane

Technical chlordane is a mixture of chlordane and many related chemicals, of which the composition varies. Exposure to chlordane occurs mostly from eating contaminated foods, such as root crops, meats, fish, and shellfish, or from touching contaminated soil. High levels of chlordane can cause damage to the nervous system or liver (ATSDR 2012). The US EPA classes technical chlordane as a probable human carcinogen (US EPA 2012).

In New Zealand, chlordane was used as a broad spectrum agricultural insecticide, in the timber industry as a treatment against termites and borer, and as an insecticide in glues used for the manufacture of plywood, finger jointed and laminated timber (Buckland*, et al.* 1998).

Chlordane is highly toxic to aquatic organisms (ANZECC 2000).

PCBs (Polychlorinated biphenyls)

Polychlorinated biphenyls (PCBs) are mixtures of up to 209 individual chlorinated compounds, referred to as congeners. PCBs have been used as coolants and lubricants in transformers, capacitors, and other electrical equipment because they have low flammability and are good electrical insulators (ATSDR 2012).

Exposure to PCBs can be via multiple pathways. Skin exposure can occur via old electrical devices (>30 years old) that leak small amounts of PCBs and in the workplace where contact may be made with equipment or devices containing PCBs. Ingestion of PCBs is largely via contaminated food (fish, meat and dairy) and drinking contaminated well water, while inhalation exposure can occur by breathing air near hazardous waste sites (ATSDR 2012).

Health effects that have been associated with exposure to PCBs include acne-like skin conditions in adults and neurobehavioral and immunological changes in children (ATSDR 2012). The US EPA classifies PCBs as a probable human carcinogen (US EPA 2012).

PCBs cause a variety of acute and chronic toxicity effects on aquatic biota (ANZECC 2000).

In March 1986, the New Zealand Customs Department placed a prohibition on importing PCBs, and later that year regulations to control the importation of PCBs were promulgated as an amendment to the Toxic Substances Regulations 1983. In 1988, a further amendment to the Toxic Substances Regulations 1983 prohibited the use and storage of PCBs with effect from 1 January 1994. Following two extensions, this regulation came into effect on 1 August 1995 (Buckland*, et al.* 1998).

Hexaclorobenzene (HCB)

Hexachlorobenzene was widely used in the US as a pesticide to protect the seeds of onions and sorghum, wheat, and other grains against fungus until 1965 (ATSDR 2012). In New Zealand HCB was used experimentally between 1970 and 1972 as a seed-dressing fungicide for cereal grain (MfE 2012). HCB has been classified as a probable human carcinogen (US EPA 2012).

Endosulfan

Endosulfan is an active ingredient present in some pesticide formulations used on crops to control insects. Endosulfan has been registered for use in New Zealand since the 1960s. In December 2008, ERMA New Zealand withdrew all approvals for products containing endosulfan under the HSNO Act. Endosulfan is an organochlorine pesticide but is not listed as a POP under the Stockholm Convention. Endosulfan has shown no potential to accumulate over time in animals. It is more water soluble than other organochlorines, such as DDT, and is less persistent in the body because it metabolises quickly (MPI 2012).

Endosulfan has not been assessed by the US EPA for carcinogenicity, however rat studies note reduced body weight gain in males and females, increased incidence of marked progressive glomerulonephrosis and blood vessel aneurysms in males (US EPA 2012).

Endrin

Endrin was used as a pesticide to control insects, rodents, and birds. Endrin has not been produced or sold for general use in the US since 1986. Little is known about the properties of endrin aldehyde (an impurity and breakdown product of endrin) or endrin ketone (a product of endrin when it is exposed to light) (ATSDR 2012). Only small amounts of endrin was ever used in New Zealand (MfE 2012).

The US EPA has determined that endrin is not classifiable as to human carcinogenicity, due to insufficient evidence (US EPA 2012).

Mirex

Mirex was used to control fire ants, and as a flame retardant in plastics, rubber, paint, paper, and electrical goods from 1959 to 1972 (ATSDR 2012). Mirex does not appear to have been used in any significant amounts in New Zealand due to its omission from the list of historical usage of persistent organochlorine pesticides in New Zealand (MfE 2012). Mirex has not been assessed by the US EPA for carcinogenicity, however rat studies noted liver cytomegaly, fatty metamorphosis, angiectasis and thyroid cystic follicles.

Appendix B List of analyses on mussels performed over the period of the programme with associated laboratory providers

Table Appendix 1. Key of terms used in Appendix B and C.

General Key	
*	Limited suite totals (see TP332 for further details)
^	Extended suite totals (See TP332 for further details)
NS&T	Used in US National Status and Trends Totals (See TP332 for further details)
Key Metal	6 key metals for trends analysis
	Analysis carried out in that year

Lab Provider Key	
Key	Laboratory
ARA Water Lab	ARA Water Laboratory
DSIR	DSIR Grassland Division
AgResearch	AgResearch, Grassland Research Centre
Watercare	Watercare Laboratory Services
Coastal Aquatic	Coastal Aquatic Systems Limited
Ruakura S&P	Ruakura Soil and Plant Research Laboratories
MAF	MAF Technology, Ruakura Agriculture Centre
HortRes	HortResearch, Ruakura Agricultural Centre
NIWA	NIWA, Hamilton
AsureQuality	AsureQuality, Wellington

Table Appendix 2. Inorganic Data for Mussels.

ANALYSIS	Key Metal	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Inorganics		**AgResearch**					**N/A**	**Watercare**						
Calcium														
Magnesium														
Potassium														
Sodium														
Sulphur														
Aluminium														
Arsenic	✓													
Boron														
Cadmium	✓													
Chromium	✓													
Cobalt														
Copper	✓													
Iron														
Lead	✓													
Manganese														
Molybdenum														
Nickel														
Selenium														
Silicon														
Strontium														
Tin														
Zinc	✓													
Phosphorus														

Table Appendix 3. Condition Data for Mussels.

ANALYSIS	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Condition	**N/A**	**Watercare**				**N/A**		**Coastal Aquatic**					
Shell length													
Shell width													
Total wet weight													
Shell wet weight (blotted dry)													
Shell wet weight (air dried 24hrs)													
Shell dry weight													
Tissue wet weight													
Tissue dry weight													
Condition Index (Watercare)													
Condition Index (CASL)													

Table Appendix 4. DDT and other OCP data for Mussels.

ANALYSIS	*	^	NS&T	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
				NIWA					N/A	NIWA				AsureQuality		
Lipid																
Lipid Content (% DW)																
DDTs																
o,p'-DDE (= 2,4'-DDE)		✓														
p,p'-DDE (= 4,4'-DDE)	✓	✓														
o,p'-DDD (= 2,4'-DDD)		✓														
p,p'-DDD (= 4,4'-DDD)	✓	✓														
o,p'-DDT (= 2,4'-DDT)		✓														
p,p'-DDT (= 4,4'-DDT)	✓	✓														
Chlordanes																
alpha Chlordane (cis)	✓	✓	✓													
gamma Chlordane (trans)	✓	✓														
Heptachlor		✓	✓													
Heptachlor epoxide		✓	✓													
Cis-nonachlor		✓														
Trans-nonachlor		✓	✓													
Other OCPs																
Aldrin																
b-BHC (Beta-HCH)																
d-BHC (Delta-HCH)																
g-BHC (Gamma-HCH) - Lindane																
a-BHC (= Alpha-HCH)																
Dieldrin																
Endrin																
Endrin Aldehyde																
Endrin Ketone																
Lindane - (g-BHC)																
Hexachlorobenzene																
Pentachlorobenzene (PeCB)																
Endosulfan-A																
Endosulfan-B																
Endosulfan-Sufate																
Mirex																

Table Appendix 5. PAH data for Mussels.

ANALYSIS	*	^	NS&T	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
PAHs				NIWA					N/A	NIWA				AsureQuality		
1-methylphenanthrene		✓	✓													
Anthracene		✓	✓													
benz[a]anthracene	✓	✓	✓													
Benzo(a)pyrene	✓	✓	✓													
Benzo(b)fluoranthene	✓	✓														
Benzo[e]pyrene		✓	✓													
Benzo(ghi)perylene		✓														
Benzo(k)fluoranthene		✓														
Chrysene	✓	✓	✓													
Dibenz(a,h)anthracene		✓	✓													
Fluoranthene	✓	✓	✓													
Indeno(1,2,3-cd)pyrene		✓	✓													
Perylene		✓	✓													
Phenanthrene		✓	✓													
Pyrene	✓	✓	✓													
Fluorene																
Acenaphthylene																
Acenaphthene																
2-methylphenanthrene																

Table Appendix 6. PCB data for Mussels.

ANALYSIS	*	^	NS&T	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
PCB congener				NIWA					N/A	NIWA				AsureQuality		
4+10																
8+5																
8		✓	✓													
15																
18		✓	✓													
19																
28		✓	✓													
28+31																
37																
44		✓	✓													
49		✓														
52		✓	✓													
54																
66		✓	✓													
70																
74																
77		✓														
81																
86		✓														
99																
101+90																
101		✓	✓													
104																
105		✓	✓													
110		✓														
114																
118	✓	✓	✓													
121		✓														
123																
126		✓														
128		✓	✓													
138	✓	✓	✓													
141		✓														
151		✓														
153	✓	✓	✓													
155																
156		✓														
157																
167																
169		✓														
170		✓	✓													
180	✓	✓	✓													
183																
187		✓	✓													
188																
189																
194		✓														
195		✓	✓													
196+203																
202																
205																
206		✓	✓													
208																
209		✓	✓													

Appendix C List of analyses on oysters performed over the period of the programme with associated laboratory providers

Table Appendix 7. Inorganic data for Oysters.

ANALYSIS	Key Metal	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Inorganics		**ARA Water Lab**			**DSIR**	**N/A**	**AgResearch**												**N/A**	**Watercare**						
Calcium																										
Magnesium																										
Potassium																										
Sodium																										
Sulphur																										
Aluminium																										
Arsenic	✓																									
Boron																										
Cadmium	✓																									
Chromium	✓																									
Cobalt																										
Copper	✓																									
Iron																										
Lead	✓																									
Manganese																										
Molybdenum																										
Nickel																										
Selenium																										
Silicon																										
Strontium																										
Tin																										
Zinc	✓																									
Phosphorus																										

Table Appendix 8. Condition data for Oysters.

ANALYSIS	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Condition														**Watercare**				**N/A**	**N/A**	**Coastal Aquatic**					
Shell length																									
Shell width																									
Total wet weight																									
Shell wet weight (blotted dry)																									
Shell wet weight (air dried 24hrs)																									
Shell dry weight																									
Tissue wet weight																									
Tissue dry weight																									
Condition Index (Watercare)																									
Condition Index (CASL)																									

Table Appendix 9. DDT and other OCP data for Oysters.

ANALYSIS	*	^	NS&T	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
				Ruakura S&P			MAF	N/A	HortRes	NIWA											N/A	NIWA				AsureQuality		
Lipid																												
Lipid Content (% DW)																												
DDTs																												
o,p'DDE (= 2,4'DDE)		✓																										
p,p'DDE (= 4,4'DDE)	✓	✓																										
o,p'DDD (= 2,4'DDD)		✓																										
p,p'DDD (= 4,4'DDD)	✓	✓																										
o,p'DDT (= 2,4'DDT)		✓																										
p,p'DDT (= 4,4'DDT)	✓	✓																										
Chlordanes																												
alpha Chlordane (cis)	✓	✓	✓																									
gamma Chlordane (trans)	✓																											
Heptachlor		✓	✓																									
Heptachlor epoxide		✓	✓																									
Cisnonachlor																												
Transnonachlor			✓																									
Other OCPs																												
Aldrin																												
b-BHC (Beta-HCH)																												
d-BHC (Delta-HCH)																												
g-BHC (Gamma-HCH) - lindane																												
a-BHC (= Alpha-HCH)																												
Dieldrin																												
Endrin																												
Endrin Aldehyde																												
Endrin Ketone																												
Lindane (g-BHC)																												
Hexachlorobenzene																												
Pentachlorobenzene (PeCB)																												
Endosulfan-A																												
Endosulfan-B																												
Endosulfan-Sufate																												
Mirex																												

Table Appendix 10. PAH data for Oysters.

ANALYSIS	*	>	NS&T	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
				Ruakura S&P			MAF	N/A	HortRes	NIWA											N/A	NIWA				AsureQuality		
PAHs																												
2,4,5-trichlorophenol																												
2,4,6-Trichlorophenol																												
Pentachlorophenol																												
chrysene/benz[a]anthracene																												
2,3,4,6-tetrachlorophenol																												
1-methylphenanthrene		✓	✓																									
Anthracene		✓	✓																									
benz[a]anthracene	✓	✓	✓																									
Benzo(a)pyrene	✓	✓	✓																									
Benzo(b)fluoranthene	✓	✓																										
Benzo[e]pyrene		✓	✓																									
Benzo(ghi)perylene		✓																										
Benzo(k)fluoranthene	✓	✓																										
Chrysene	✓	✓	✓																									
Dibenz(a,h)anthracene		✓	✓																									
Fluoranthene	✓	✓	✓																									
Indeno(1,2,3-cd)pyrene		✓	✓																									
Perylene		✓	✓																									
Phenanthrene		✓	✓																									
Pyrene	✓	✓	✓																									
Fluorene																												
Acenaphthylene																												
Acenaphthene																												
2-methylphenanthrene																												

Table Appendix 11. PCB data for Oysters.

ANALYSIS	*	^	NS&T	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
				Ruakura S&P			MAF	N/A	HortRes	NIWA											N/A	NIWA				AsureQuality		
PCB Congener																												
4+10																												
8+5																												
8		✓	✓																									
15																												
18		✓	✓																									
19																												
28		✓	✓																									
28+31																												
31																												
37																												
40																												
44		✓	✓																									
47																												
49		✓																										
52		✓	✓																									
54																												
66		✓	✓																									
70																												
74																												
77		✓																										
81																												
86		✓																										
87																												
99																												
101+90																												
101		✓	✓																									
104																												
105		✓	✓																									
110																												
114																												
118	✓	✓	✓																									

ANALYSIS	*	>	NS&T	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
				Ruakura S&P			MAF	N/A	HortRes	NIWA											N/A	NIWA				AsureQuality		
PCB Congener																												
121		✓																										
123																												
126		✓																										
128		✓	✓																									
138	✓	✓	✓																									
141		✓																										
151																												
153	✓	✓	✓																									
155																												
156		✓																										
157																												
167																												
169																												
170		✓	✓																									
180	✓	✓	✓																									
183																												
185																												
187		✓	✓																									
188																												
189																												
194		✓																										
195		✓	✓																									
196																												
196+203																												
201																												
202																												
205																												
206		✓	✓																									
208																												
209		✓	✓																									

Appendix D Correlations between contaminants

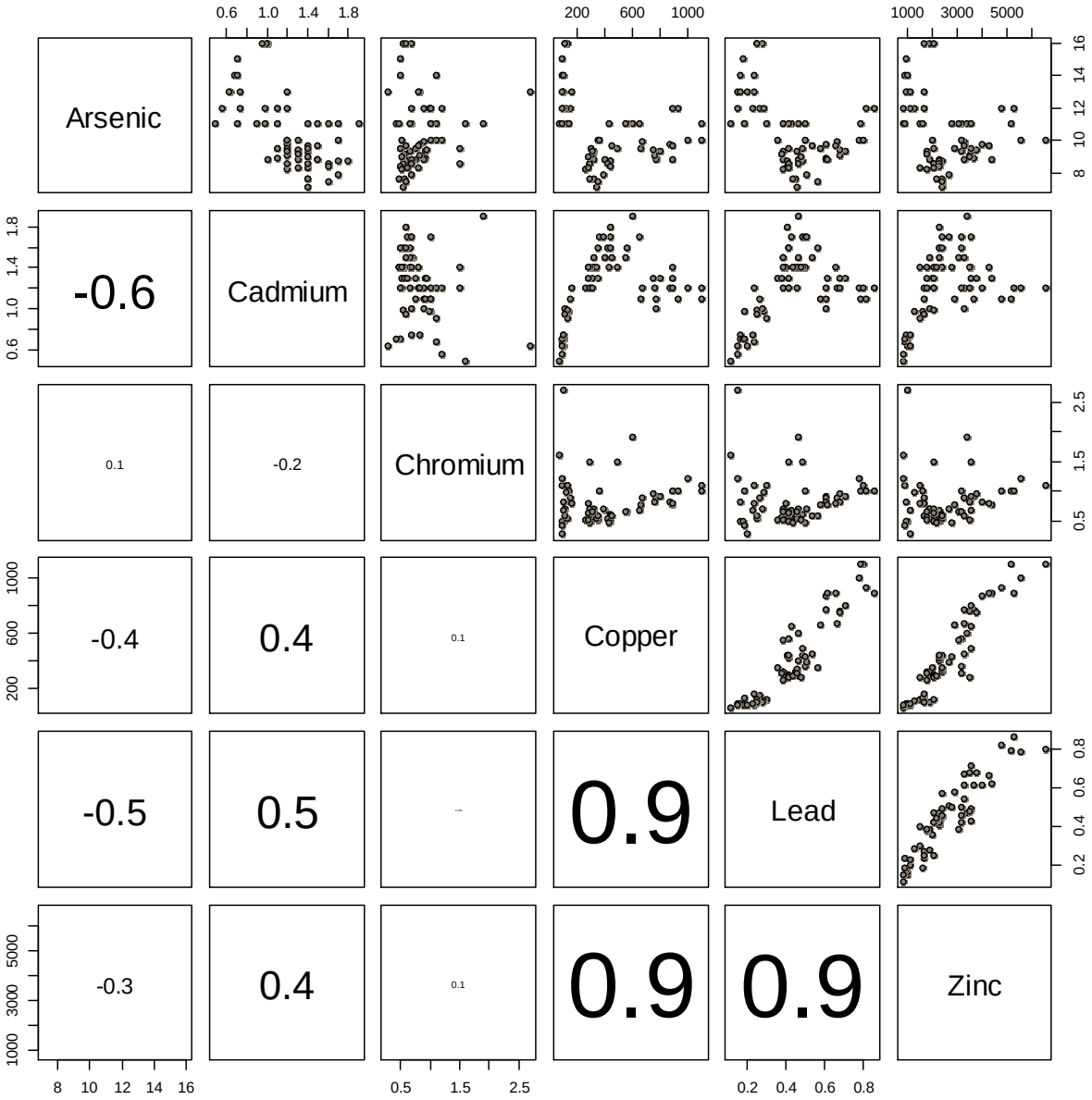


Figure Appendix 1. Scatter plots of the relationships between metals in oysters.
Note: Named variable at left of each row of scatter plots is y-axis. Named variable at bottom of each column of scatter plots is x-axis. Correlation coefficients are presented in lower left side of matrix. Font size for correlation coefficient indicates strength of relationship. Metals as dry weight.

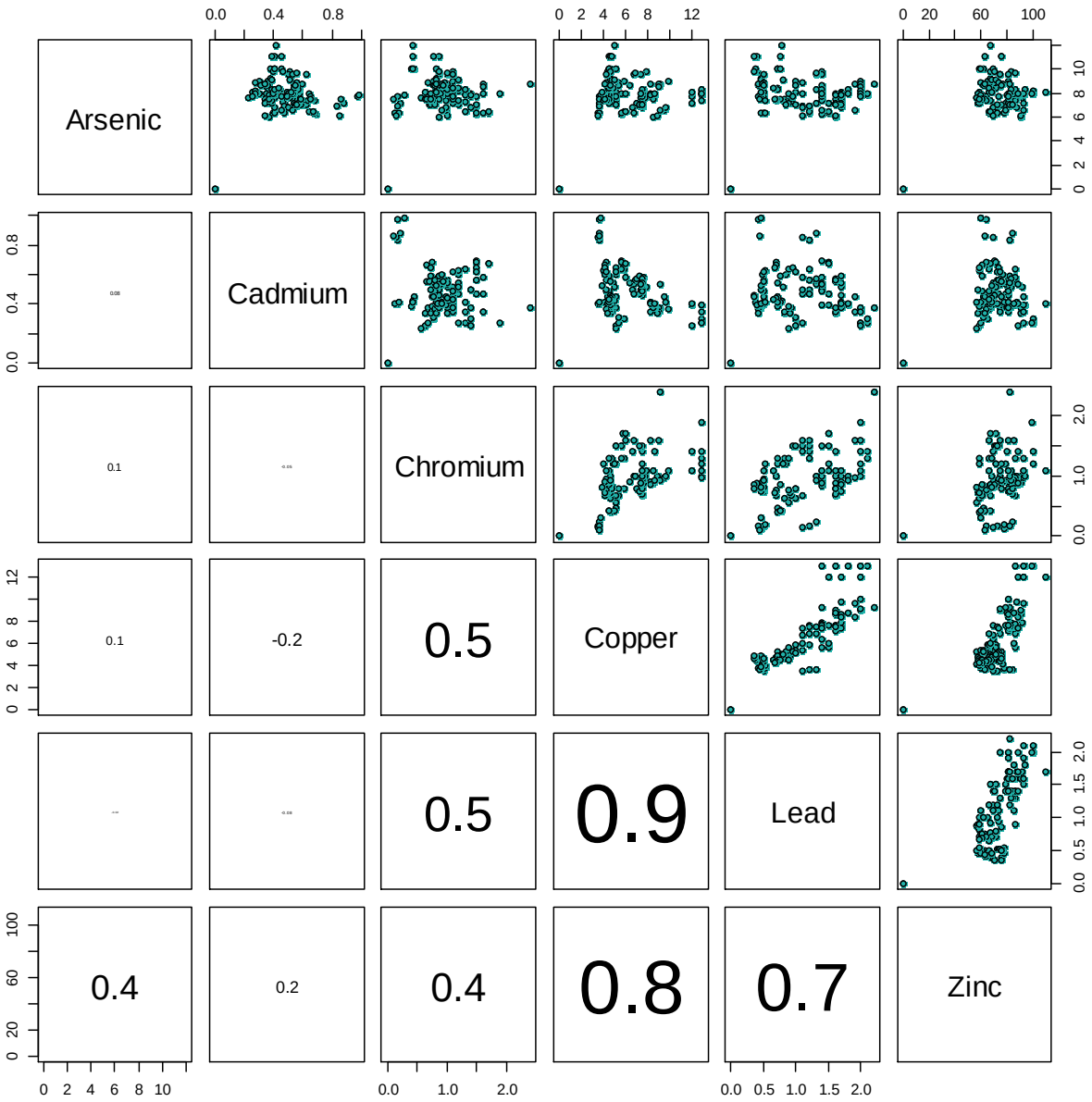


Figure Appendix 2. Scatter plots of the relationships between metals in mussels.
Note: Named variable at left of each row of scatter plots is y-axis. Named variable at bottom of each column of scatter plots is x-axis. Correlation coefficients are presented in lower left side of matrix. Font size for correlation coefficient indicates strength of relationship. Metals as dry weight.

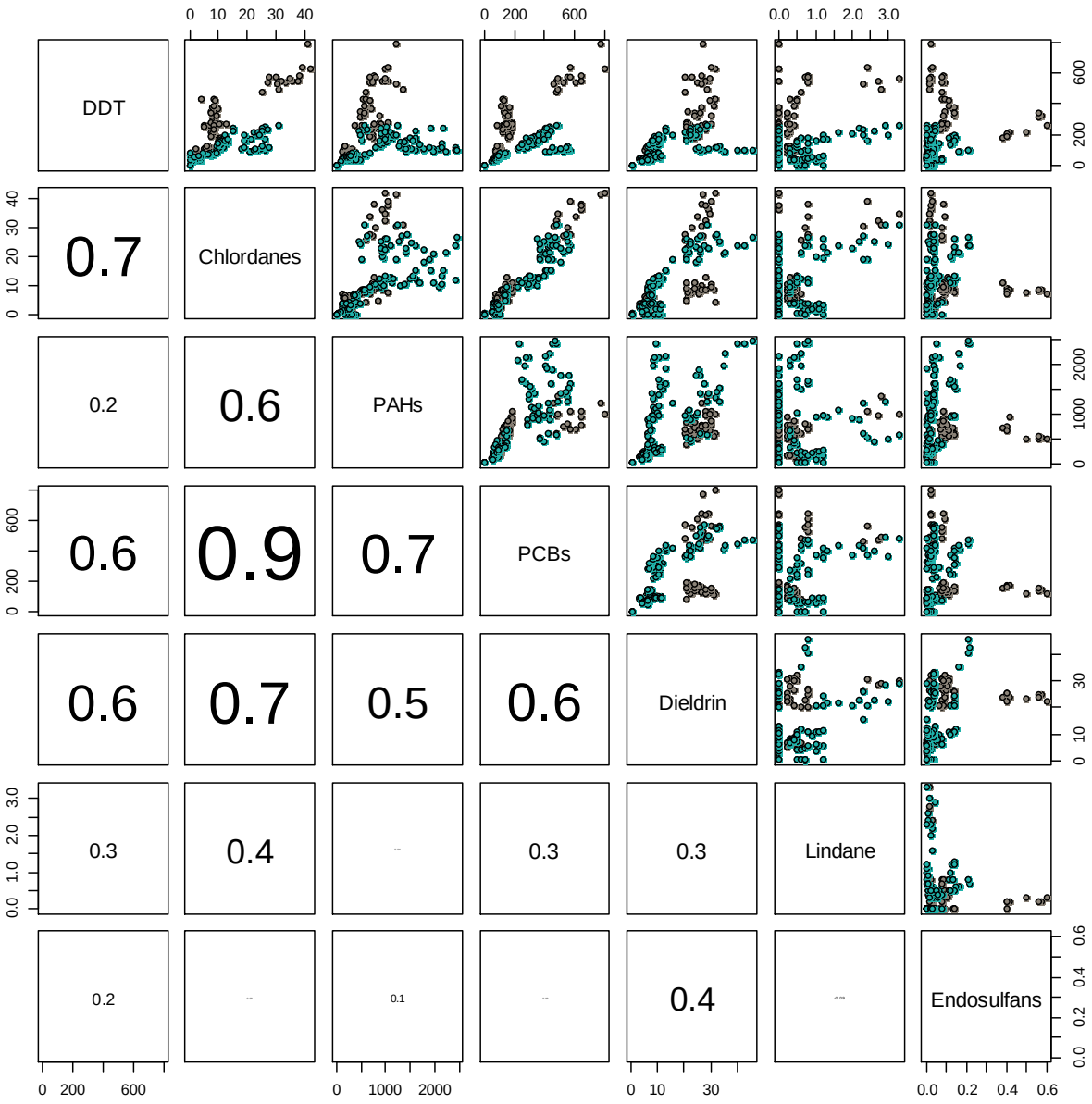
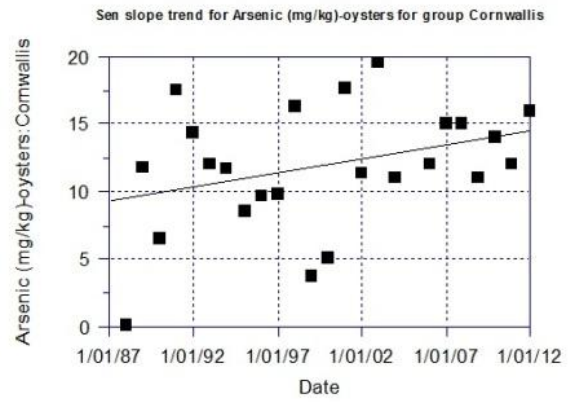
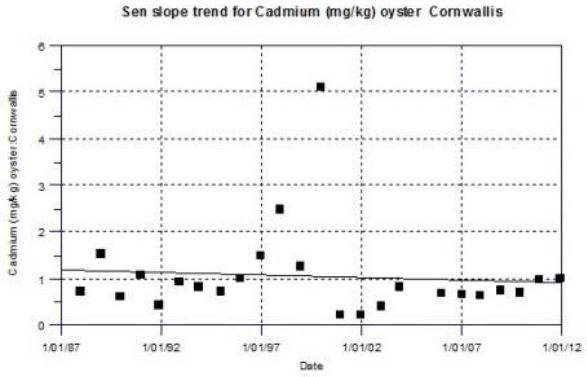


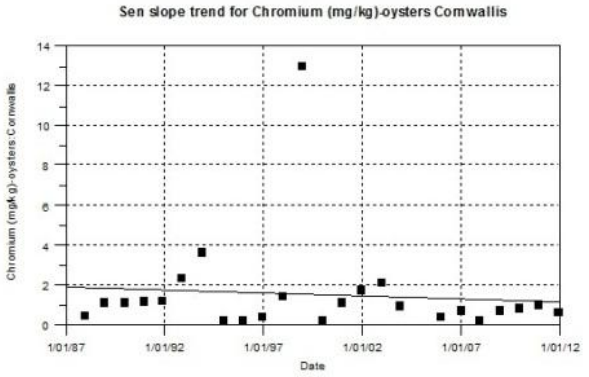
Figure Appendix 3. Scatter plots of the relationships between organic contaminants in oysters (grey) and mussels (blue-green).

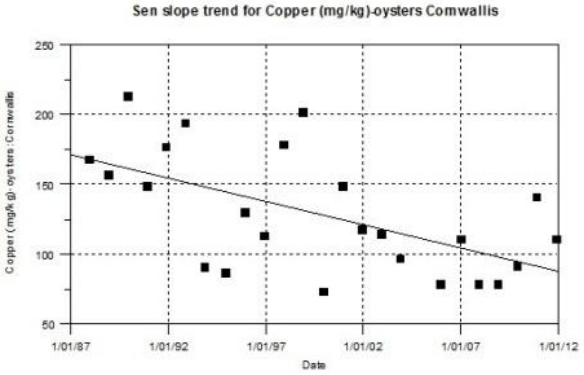
Note: Named variable at left of each row of scatter plots is y-axis. Named variable at bottom of each column of scatter plots is x-axis. Correlation coefficients are presented in lower left side of matrix. Font size for correlation coefficient indicates strength of relationship. Organic suites as lipid normalised dry weight.

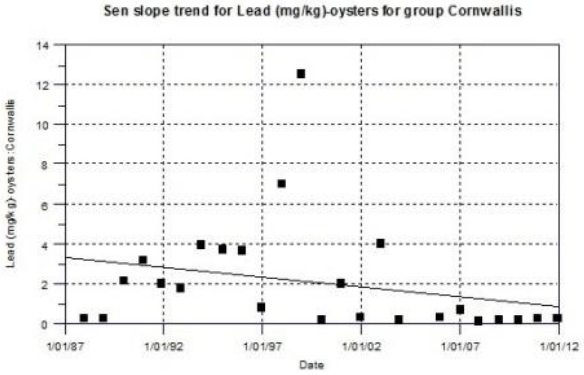
Appendix E Contaminant trends in Oysters from the SCMP

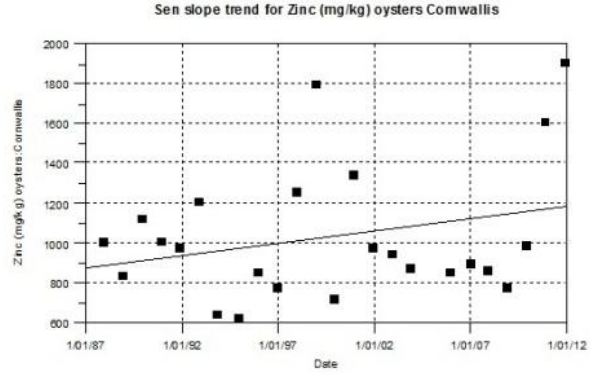

Sen slope trend for Arsenic (mg/kg)-oysters for group Cornwallis
Arsenic (mg/kg)-oysters:Cornwallis
20
15
10
5
0
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12
Date

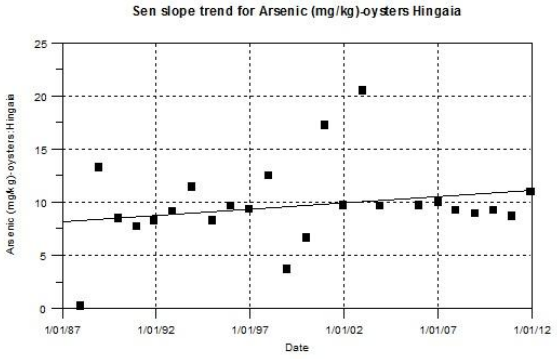

Sen slope trend for Cadmium (mg/kg) oyster Cornwallis
Cadmium (mg/kg) oyster:Cornwallis
6
5
4
3
2
1
0
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12
Date

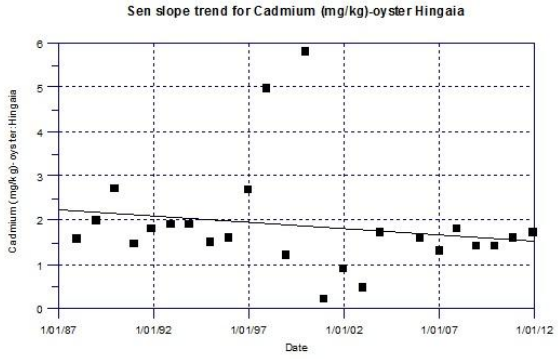

Sen slope trend for Chromium (mg/kg)-oysters Cornwallis
Chromium (mg/kg)-oysters:Cornwallis
14
12
10
8
6
4
2
0
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12
Date

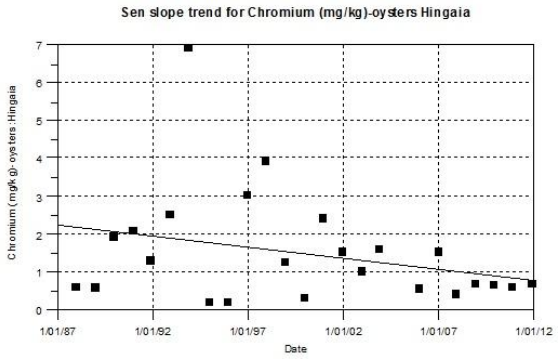

Sen slope trend for Copper (mg/kg)-oysters Cornwallis
Copper (mg/kg)-oysters:Cornwallis
250
200
150
100
50
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12
Date

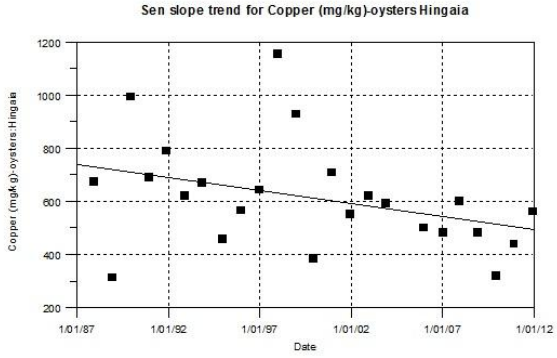

Sen slope trend for Lead (mg/kg)-oysters for group Cornwallis
Lead (mg/kg) oysters:Cornwallis
14
12
10
8
6
4
2
0
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12
Date

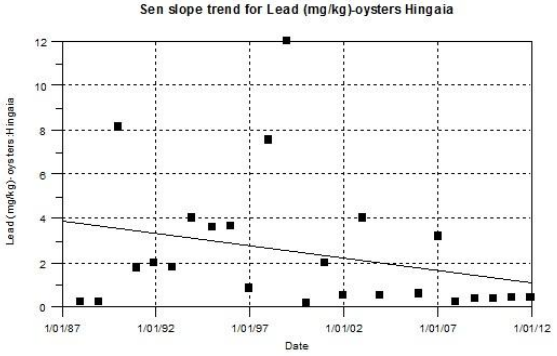

Sen slope trend for Zinc (mg/kg) oysters Cornwallis
Zinc (mg/kg) oysters:Cornwallis
2000
1800
1600
1400
1200
1000
800
600
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12
Date

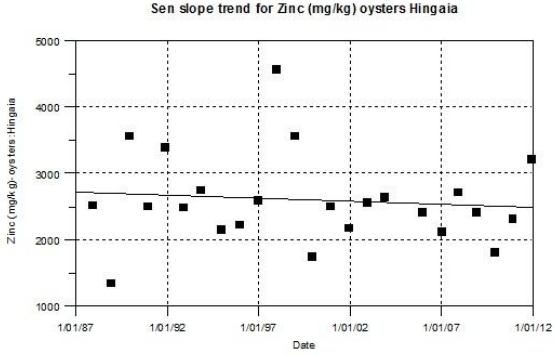

Sen slope trend for Arsenic (mg/kg)-oysters Hingaia
Arsenic (mg/kg)-oysters Hingaia
Date
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12

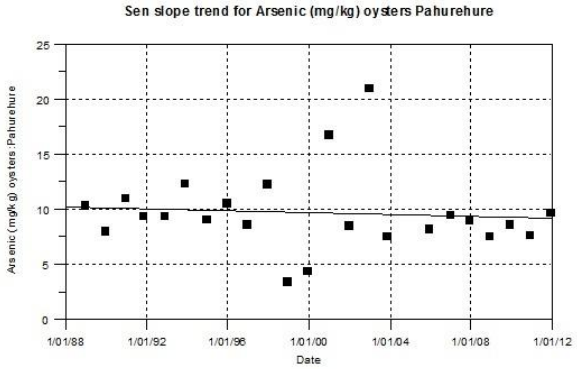

Sen slope trend for Cadmium (mg/kg)-oyster Hingaia
Cadmium (mg/kg)-oyster Hingaia
Date
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12

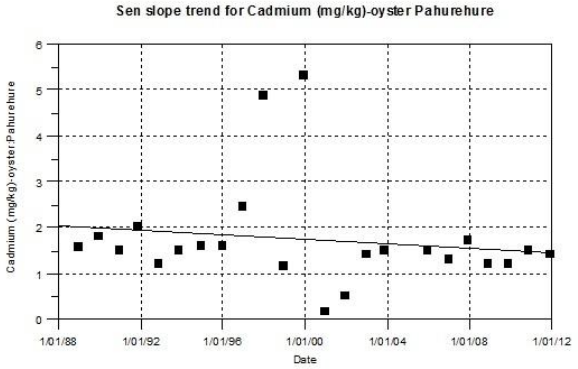

Sen slope trend for Chromium (mg/kg)-oysters Hingaia
Chromium (mg/kg)-oysters Hingaia
Date
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12

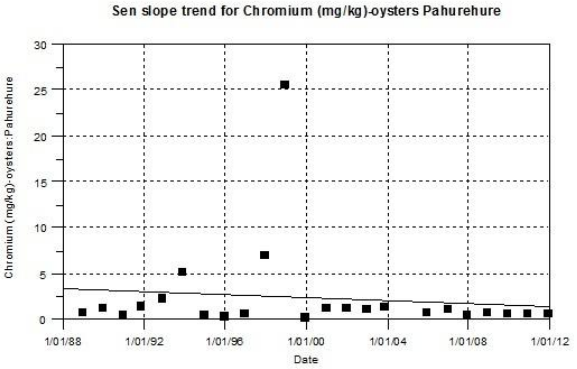

Sen slope trend for Copper (mg/kg)-oysters Hingaia
Copper (mg/kg)-oysters Hingaia
Date
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12

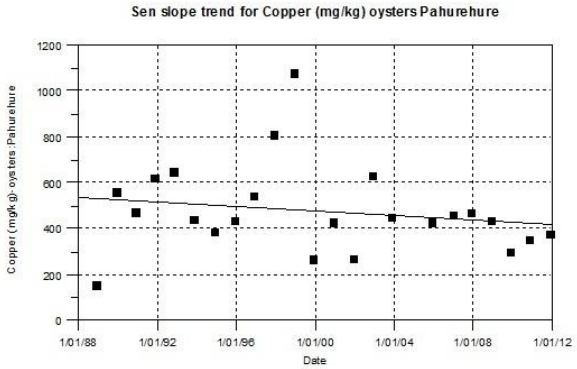

Sen slope trend for Lead (mg/kg)-oysters Hingaia
Lead (mg/kg)-oysters Hingaia
Date
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12

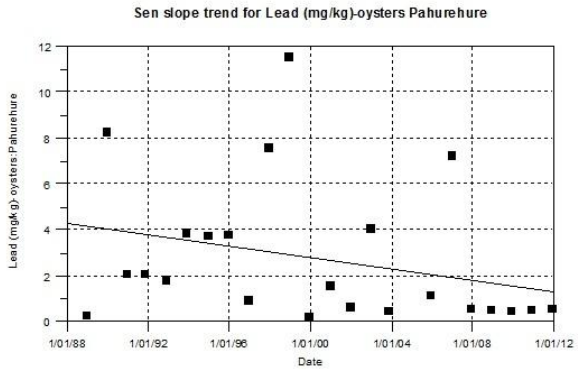

Sen slope trend for Zinc (mg/kg) oysters Hingaia
Zinc (mg/kg)-oysters Hingaia
Date
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12

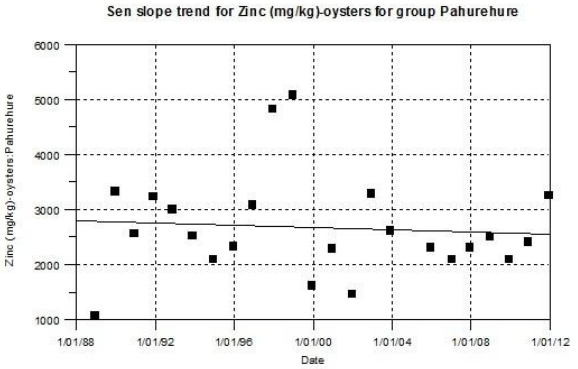

Sen slope trend for Arsenic (mg/kg) oysters Pahurehure
Arsenic (mg/kg) oysters Pahurehure
25
20
15
10
5
0
1/01/88
1/01/92
1/01/96
1/01/00
1/01/04
1/01/08
1/01/12
Date


Sen slope trend for Cadmium (mg/kg)-oyster Pahurehure
Cadmium (mg/kg)-oyster Pahurehure
6
5
4
3
2
1
0
1/01/88
1/01/92
1/01/96
1/01/00
1/01/04
1/01/08
1/01/12
Date


Sen slope trend for Chromium (mg/kg)-oysters Pahurehure
Chromium (mg/kg)-oysters Pahurehure
30
25
20
15
10
5
0
1/01/88
1/01/92
1/01/96
1/01/00
1/01/04
1/01/08
1/01/12
Date


Sen slope trend for Copper (mg/kg) oysters Pahurehure
Copper (mg/kg) oysters Pahurehure
1200
1000
800
600
400
200
0
1/01/88
1/01/92
1/01/96
1/01/00
1/01/04
1/01/08
1/01/12
Date


Sen slope trend for Lead (mg/kg)-oysters Pahurehure
Lead (mg/kg) oysters Pahurehure
12
10
8
6
4
2
0
1/01/88
1/01/92
1/01/96
1/01/00
1/01/04
1/01/08
1/01/12
Date


Sen slope trend for Zinc (mg/kg)-oysters for group Pahurehure
Zinc (mg/kg)-oysters Pahurehure
6000
5000
4000
3000
2000
1000
1/01/88
1/01/92
1/01/96
1/01/00
1/01/04
1/01/08
1/01/12
Date

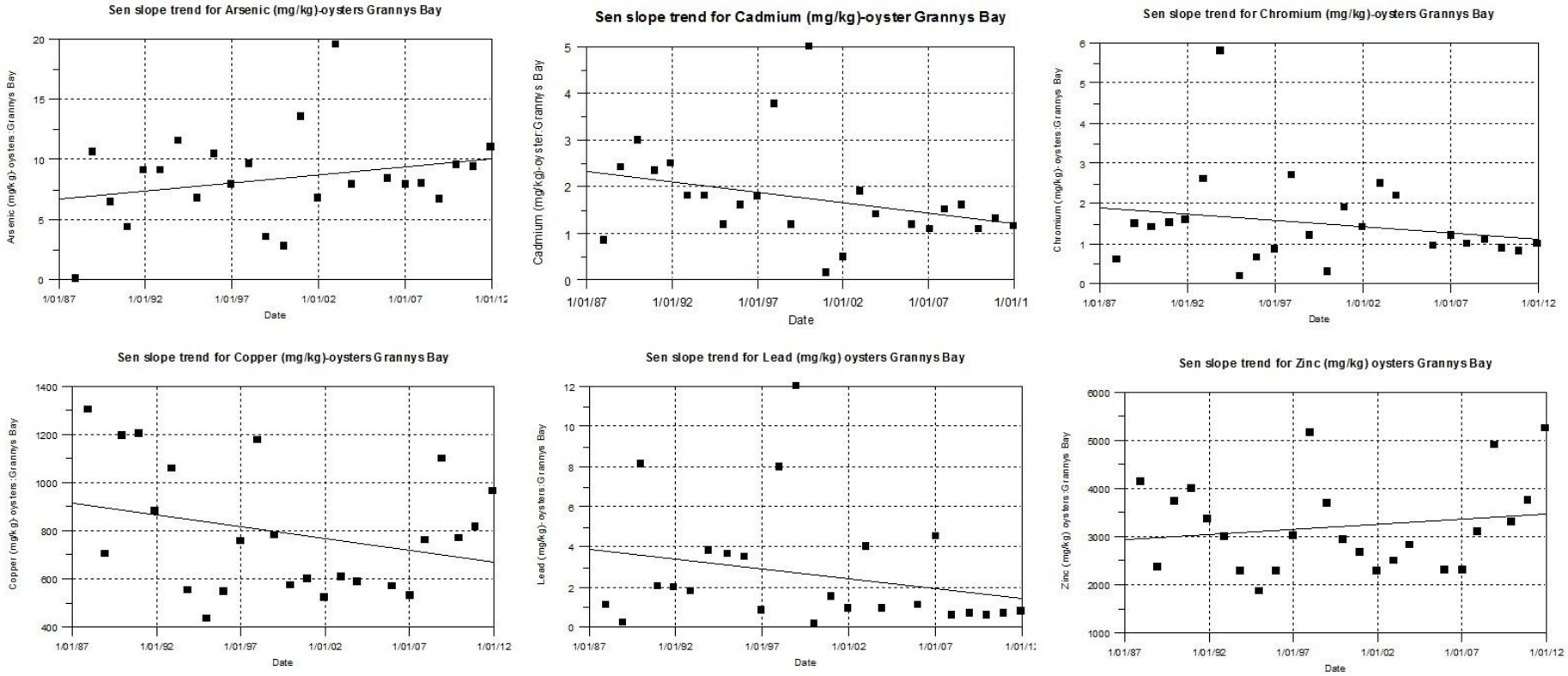
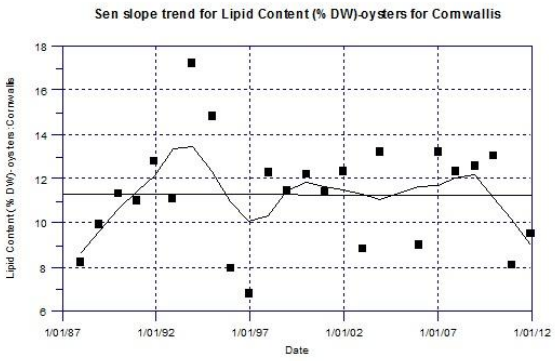
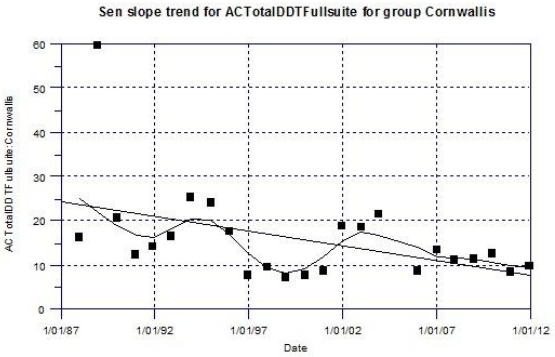
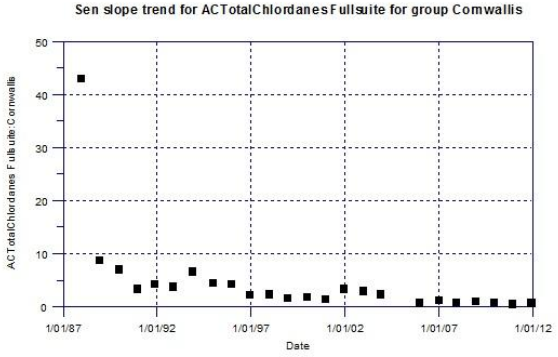
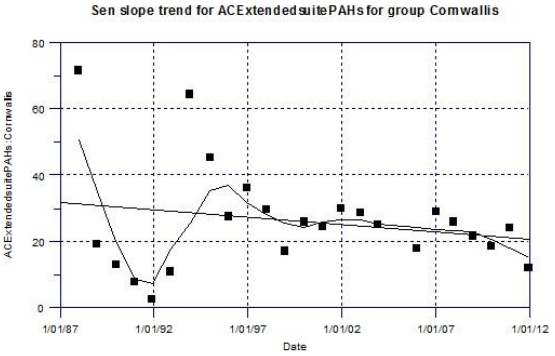


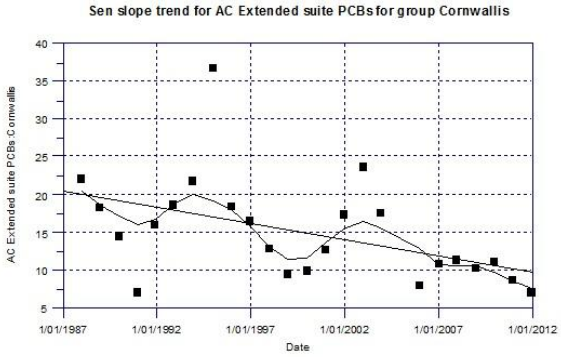
Figure Appendix 4. Heavy metal trends in oysters (1987-2011) from the SCMP. Contaminant trends are clockwise from top left: arsenic; cadmium; chromium; zinc; lead; copper.

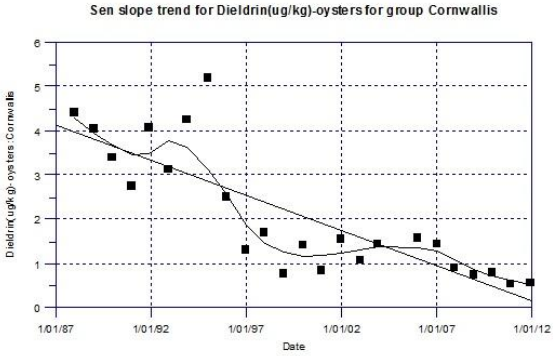

Sen slope trend for Lipid Content (% DW)-oysters for Cornwallis
Lipid Content (% DW)-oysters:Cornwallis
Date
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12

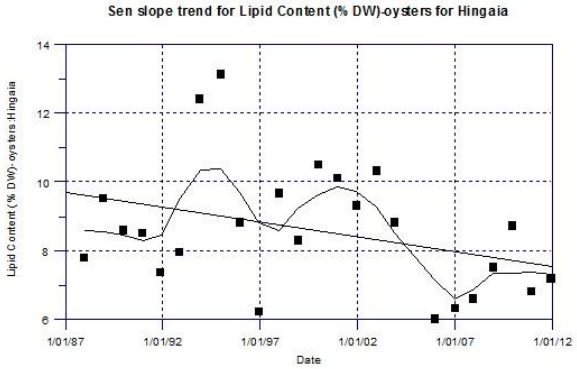

Sen slope trend for ACTotalDDTFullsuite for group Cornwallis
ACTotalDDTFullsuite:Cornwallis
Date
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12

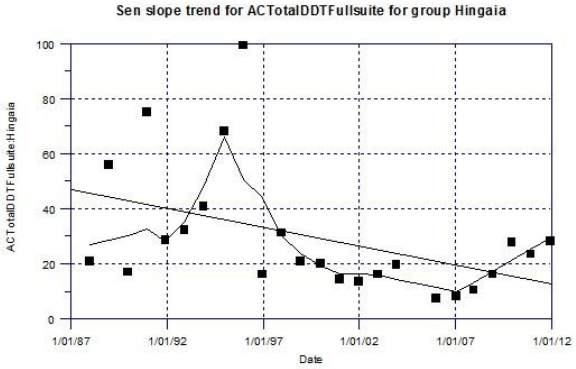

Sen slope trend for ACTotalChlordanesFullsuite for group Cornwallis
ACTotalChlordanes Fullsuite:Cornwallis
Date
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12

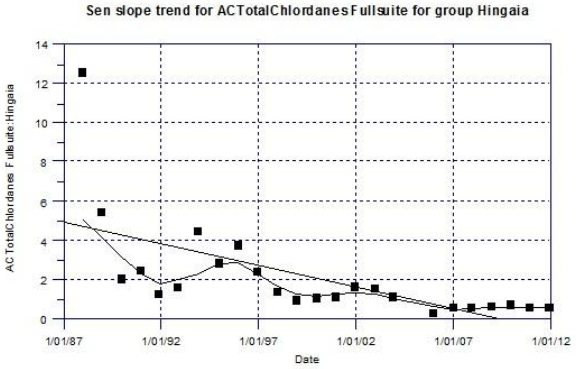

Sen slope trend for ACExtendedsuitePAHs for group Cornwallis
ACExtendedsuitePAHs:Cornwallis
Date
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12

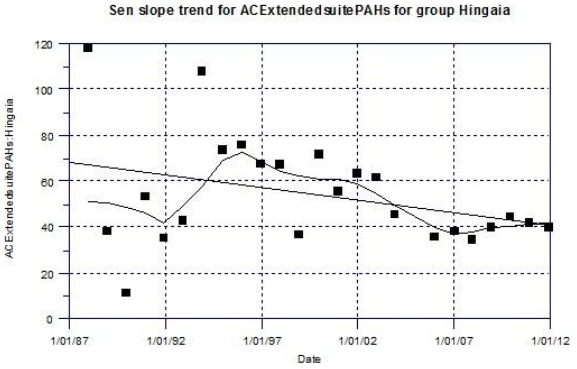

Sen slope trend for AC Extended suite PCBs for group Cornwallis
AC Extended suite PCBs:Cornwallis
Date
1/01/1987
1/01/1992
1/01/1997
1/01/2002
1/01/2007
1/01/2012

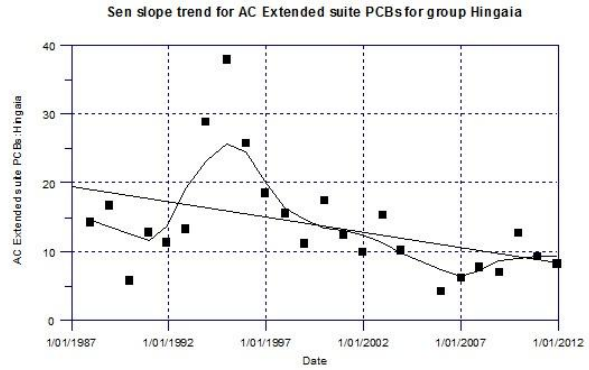

Sen slope trend for Dieldrin(ug/kg)-oysters for group Cornwallis
Dieldrin(ug/kg)-oysters:Cornwallis
Date
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12

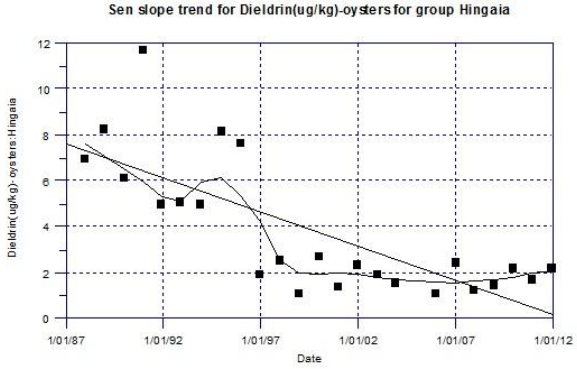

Sen slope trend for Lipid Content (% DW)-oysters for Hingaia
Lipid Content (% DW)- oysters:Hingaia
Date
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12

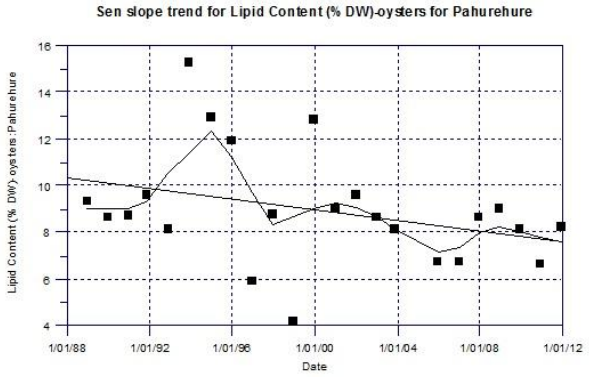

Sen slope trend for ACTotalDDTFullsuite for group Hingaia
ACTotalDDTFullsuite:Hingaia
Date
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12

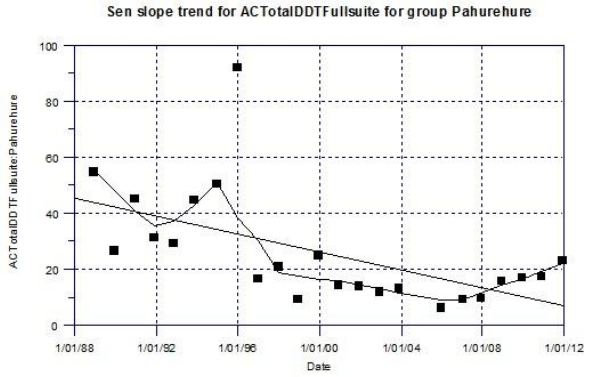

Sen slope trend for ACTotalChlordanes Fullsuite for group Hingaia
ACTotalChlordanes Fullsuite:Hingaia
Date
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12

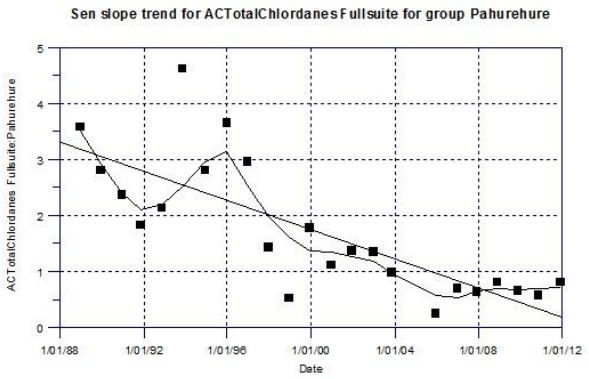

Sen slope trend for ACExtendedsuitePAHs for group Hingaia
ACExtendedsuitePAHs:Hingaia
Date
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12

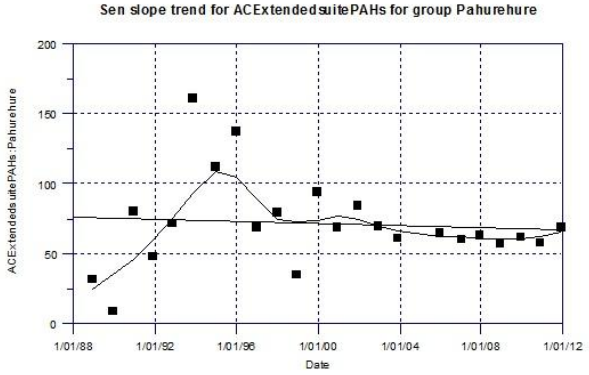

Sen slope trend for AC Extended suite PCBs for group Hingaia
AC Extended suite PCBs:Hingaia
Date
1/01/1987
1/01/1992
1/01/1997
1/01/2002
1/01/2007
1/01/2012

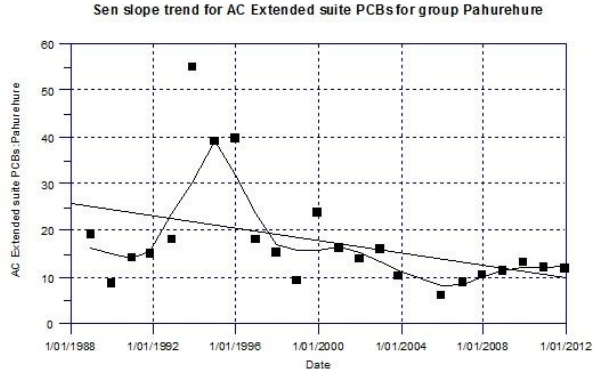

Sen slope trend for Dieldrin(ug/kg)-oysters for group Hingaia
Dieldrin(ug/kg)- oysters:Hingaia
Date
1/01/87
1/01/92
1/01/97
1/01/02
1/01/07
1/01/12

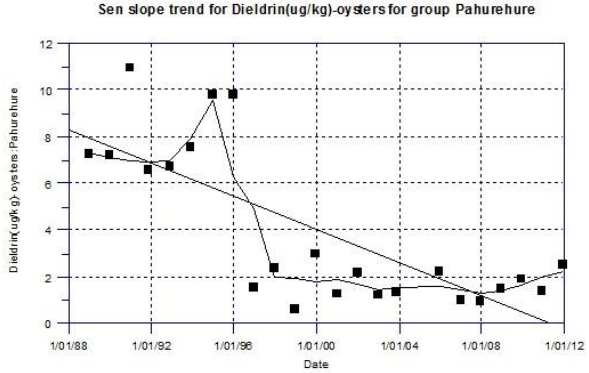

Sen slope trend for Lipid Content (% DW)-oysters for Pahurehure
Lipid Content (% DW)-oysters:Pahurehure
Date
1/01/88
1/01/92
1/01/96
1/01/00
1/01/04
1/01/08
1/01/12


Sen slope trend for ACTotalDDTFullsuite for group Pahurehure
ACTotalDDTFullsuite:Pahurehure
Date
1/01/88
1/01/92
1/01/96
1/01/00
1/01/04
1/01/08
1/01/12


Sen slope trend for ACTotalChlordanes Fullsuite for group Pahurehure
ACTotalChlordanes Fullsuite:Pahurehure
Date
1/01/88
1/01/92
1/01/96
1/01/00
1/01/04
1/01/08
1/01/12


Sen slope trend for ACExtendedsuitePAHs for group Pahurehure
ACExtendedsuitePAHs:Pahurehure
Date
1/01/88
1/01/92
1/01/96
1/01/00
1/01/04
1/01/08
1/01/12


Sen slope trend for AC Extended suite PCBs for group Pahurehure
AC Extended suite PCBs:Pahurehure
Date
1/01/1988
1/01/1992
1/01/1996
1/01/2000
1/01/2004
1/01/2008
1/01/2012


Sen slope trend for Dieldrin(ug/kg)-oysters for group Pahurehure
Dieldrin(ug/kg)-oysters:Pahurehure
Date
1/01/88
1/01/92
1/01/96
1/01/00
1/01/04
1/01/08
1/01/12

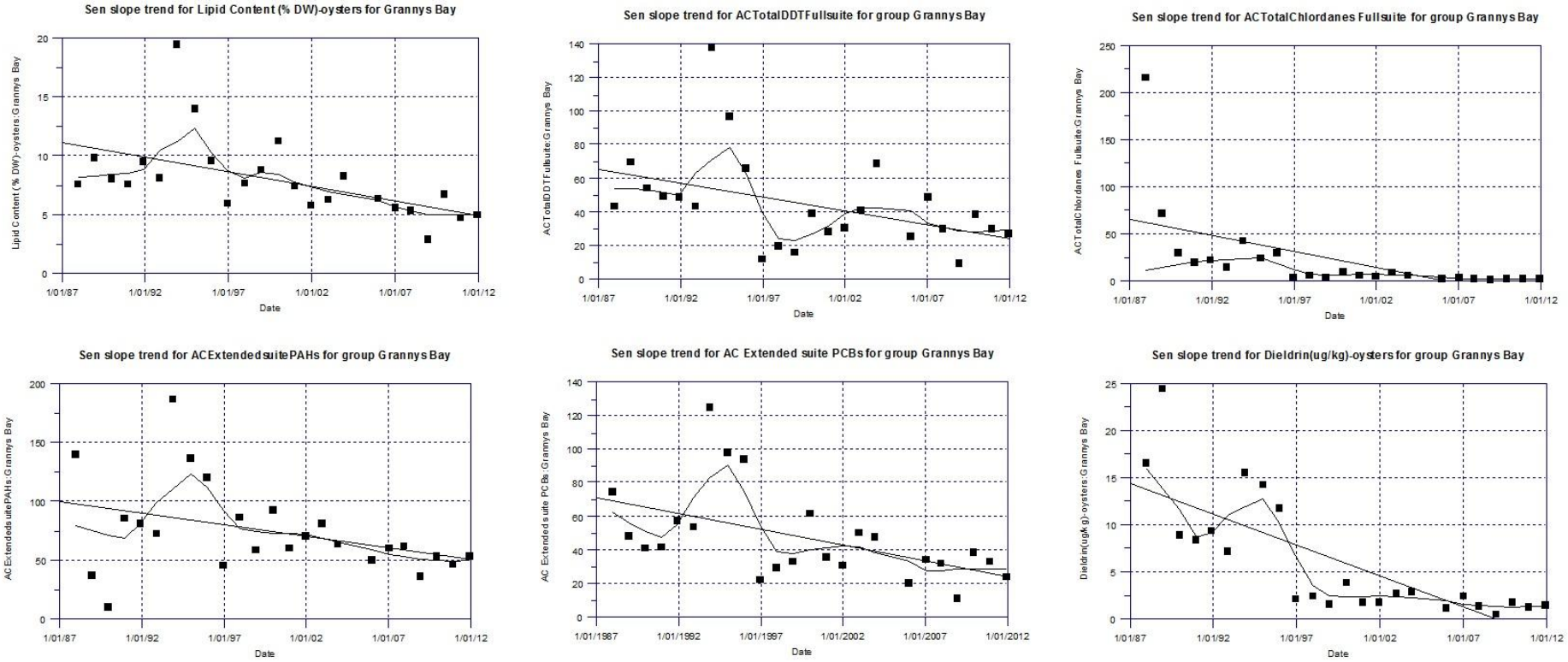
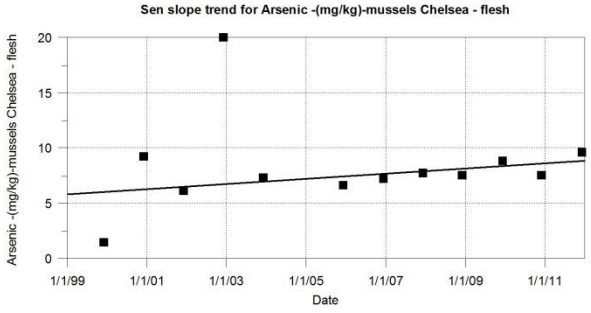
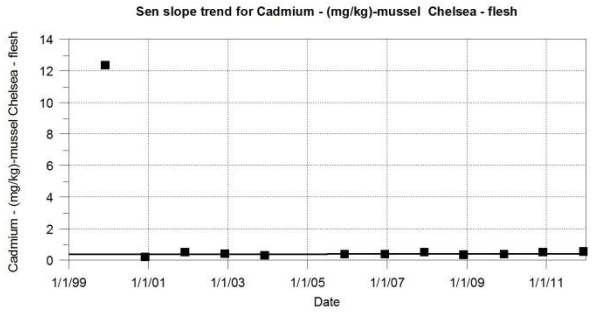
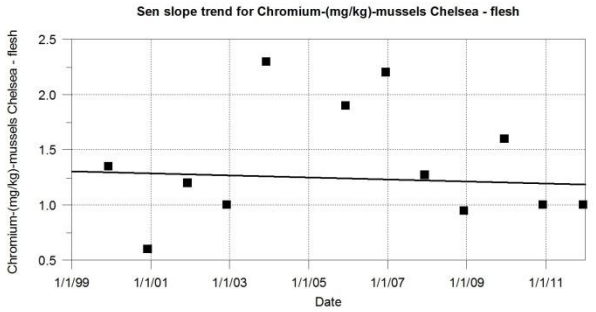


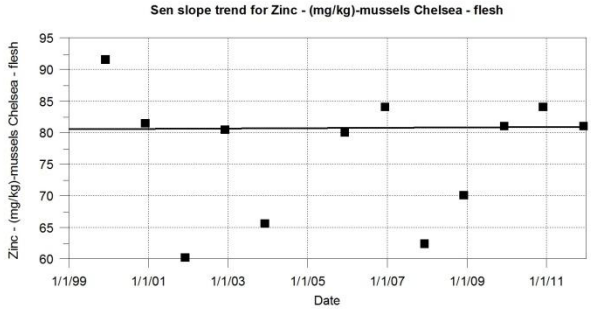
Figure Appendix 5. Lipid content and organic contaminant trends in oysters (1987-2011) from the SCMP. Trends are clockwise from top left: %lipid; DDT; Chlordanes; Dieldrin; PCBs; PAHs. All organics suites are extended suites.

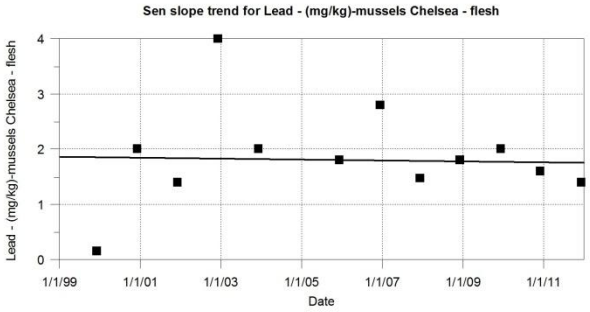
Appendix F Contaminant trends in Mussels from the SCMP

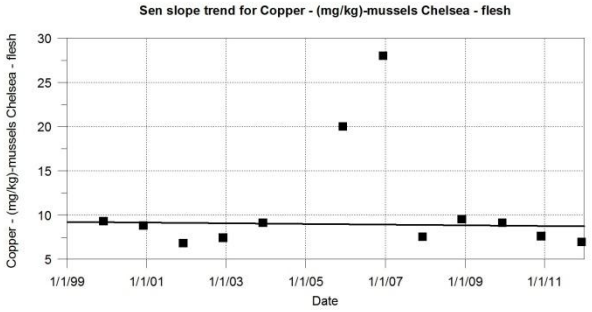

Sen slope trend for Arsenic -(mg/kg)-mussels Chelsea - flesh
Arsenic -(mg/kg)-mussels Chelsea - flesh
20
15
10
5
0
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

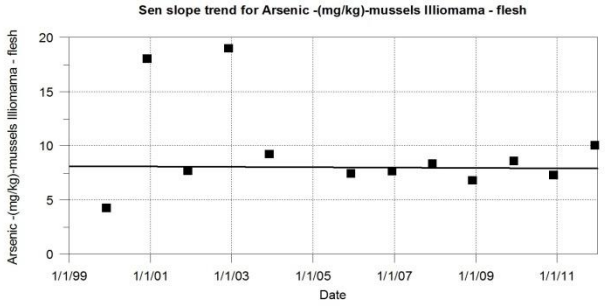

Sen slope trend for Cadmium - (mg/kg)-mussel Chelsea - flesh
Cadmium - (mg/kg)-mussel Chelsea - flesh
14
12
10
8
6
4
2
0
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

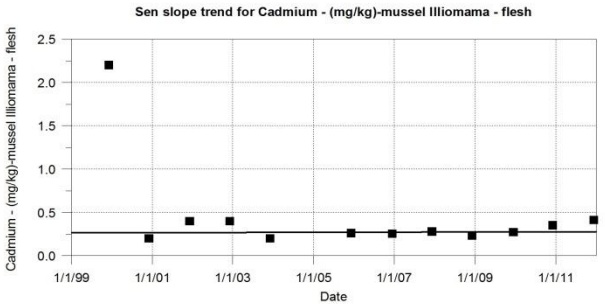

Sen slope trend for Chromium-(mg/kg)-mussels Chelsea - flesh
Chromium-(mg/kg)-mussels Chelsea - flesh
2.5
2.0
1.5
1.0
0.5
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

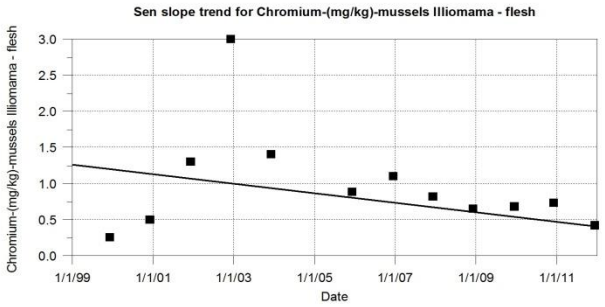

Sen slope trend for Zinc - (mg/kg)-mussels Chelsea - flesh
Zinc - (mg/kg)-mussels Chelsea - flesh
95
90
85
80
75
70
65
60
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

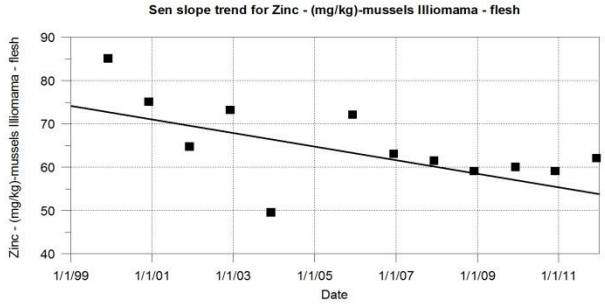

Sen slope trend for Lead - (mg/kg)-mussels Chelsea - flesh
Lead - (mg/kg)-mussels Chelsea - flesh
4
3
2
1
0
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

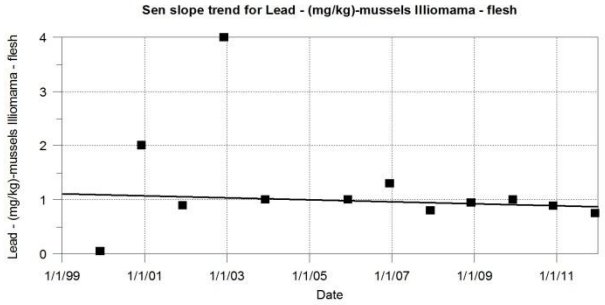

Sen slope trend for Copper - (mg/kg)-mussels Chelsea - flesh
Copper - (mg/kg)-mussels Chelsea - flesh
30
25
20
15
10
5
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

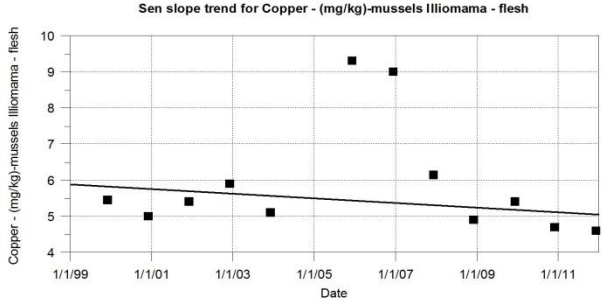

Sen slope trend for Arsenic -(mg/kg)-mussels Illiomama - flesh
Arsenic -(mg/kg)-mussels Illiomama - flesh
20
15
10
5
0
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

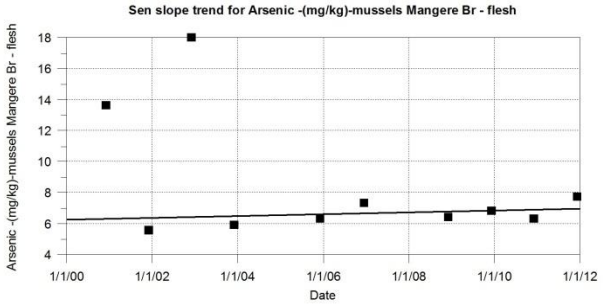

Sen slope trend for Cadmium - (mg/kg)-mussel Illiomama - flesh
Cadmium - (mg/kg)-mussel Illiomama - flesh
2.5
2.0
1.5
1.0
0.5
0.0
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

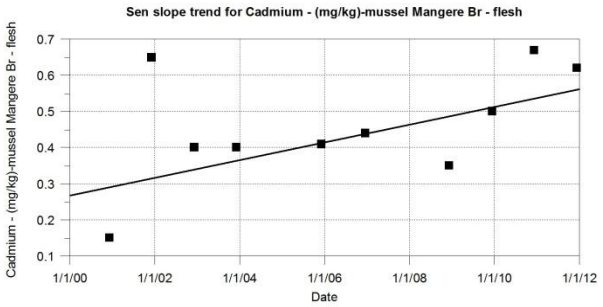

Sen slope trend for Chromium-(mg/kg)-mussels Illiomama - flesh
Chromium-(mg/kg)-mussels Illiomama - flesh
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

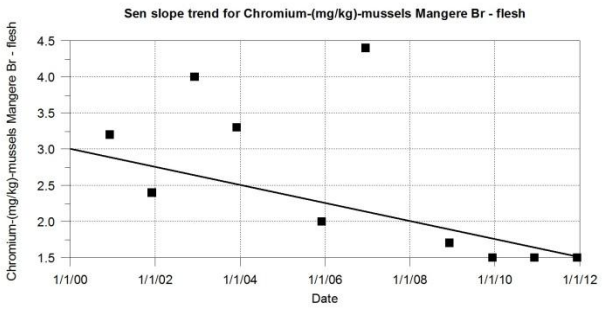

Sen slope trend for Zinc - (mg/kg)-mussels Illiomama - flesh
Zinc - (mg/kg)-mussels Illiomama - flesh
90
80
70
60
50
40
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

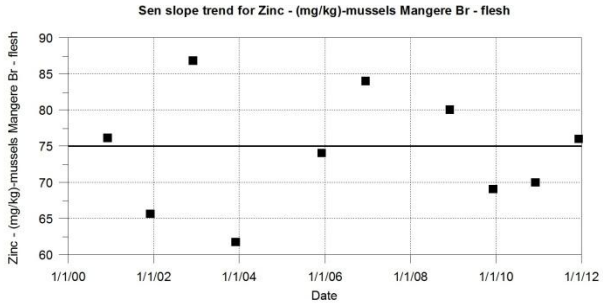

Sen slope trend for Lead - (mg/kg)-mussels Illiomama - flesh
Lead - (mg/kg)-mussels Illiomama - flesh
4
3
2
1
0
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

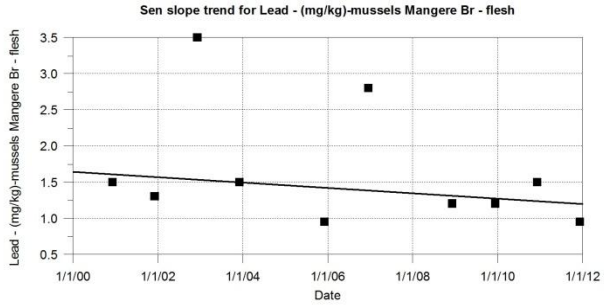

Sen slope trend for Copper - (mg/kg)-mussels Illiomama - flesh
Copper - (mg/kg)-mussels Illiomama - flesh
10
9
8
7
6
5
4
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

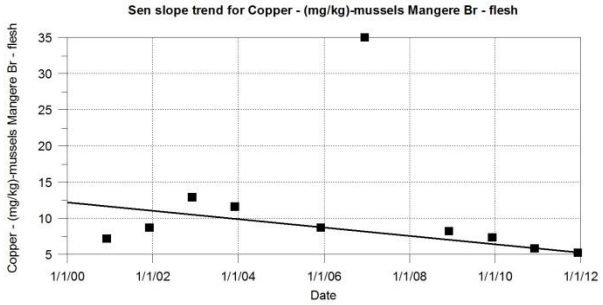

Sen slope trend for Arsenic -(mg/kg)-mussels Mangere Br - flesh
Arsenic -(mg/kg)-mussels Mangere Br - flesh
18
16
14
12
10
8
6
4
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
Date

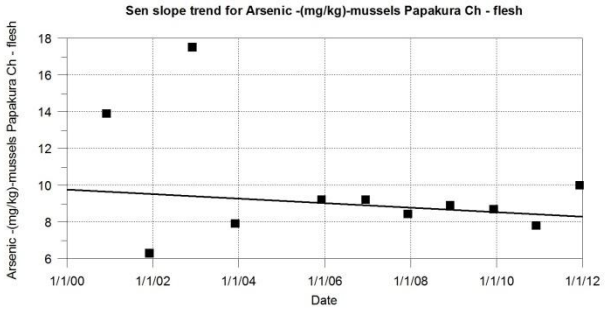

Sen slope trend for Cadmium - (mg/kg)-mussel Mangere Br - flesh
Cadmium - (mg/kg)-mussel Mangere Br - flesh
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
Date

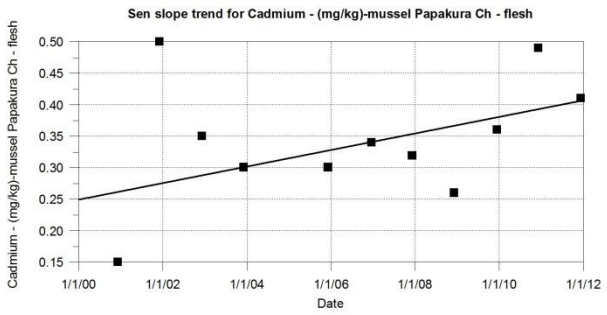

Sen slope trend for Chromium-(mg/kg)-mussels Mangere Br - flesh
Chromium-(mg/kg)-mussels Mangere Br - flesh
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
Date

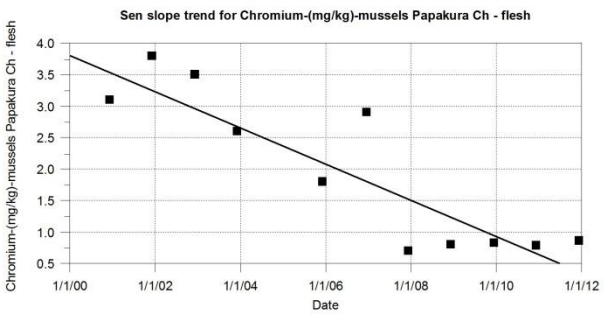

Sen slope trend for Zinc - (mg/kg)-mussels Mangere Br - flesh
Zinc - (mg/kg)-mussels Mangere Br - flesh
90
85
80
75
70
65
60
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
Date

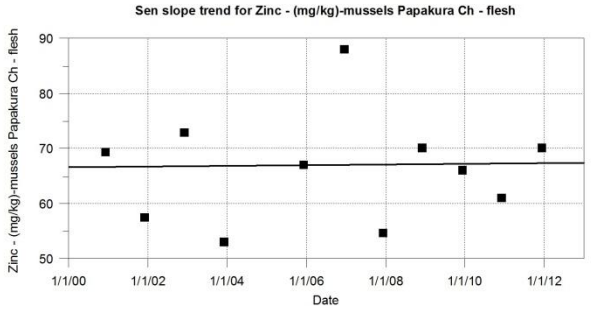

Sen slope trend for Lead - (mg/kg)-mussels Mangere Br - flesh
Lead - (mg/kg)-mussels Mangere Br - flesh
3.5
3.0
2.5
2.0
1.5
1.0
0.5
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
Date

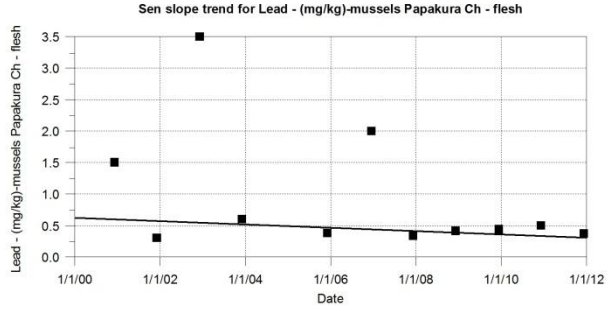

Sen slope trend for Copper - (mg/kg)-mussels Mangere Br - flesh
Copper - (mg/kg)-mussels Mangere Br - flesh
35
30
25
20
15
10
5
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
Date

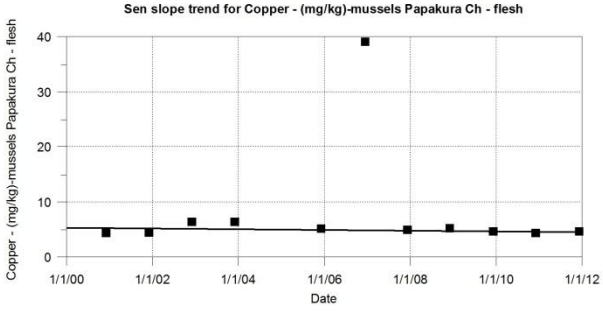

Sen slope trend for Arsenic -(mg/kg)-mussels Papakura Ch - flesh
Arsenic -(mg/kg)-mussels Papakura Ch - flesh
18
16
14
12
10
8
6
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
Date

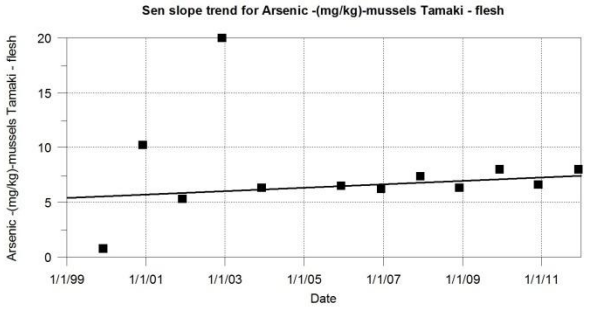

Sen slope trend for Cadmium - (mg/kg)-mussel Papakura Ch - flesh
Cadmium - (mg/kg)-mussel Papakura Ch - flesh
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
Date

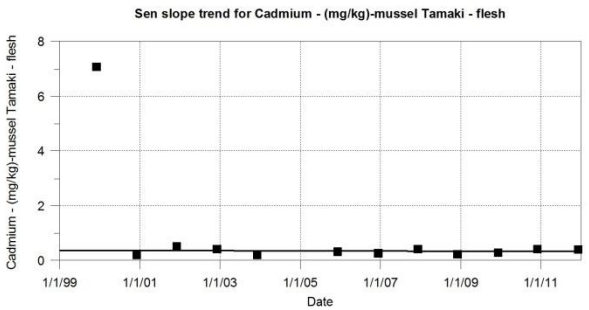

Sen slope trend for Chromium-(mg/kg)-mussels Papakura Ch - flesh
Chromium-(mg/kg)-mussels Papakura Ch - flesh
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
Date

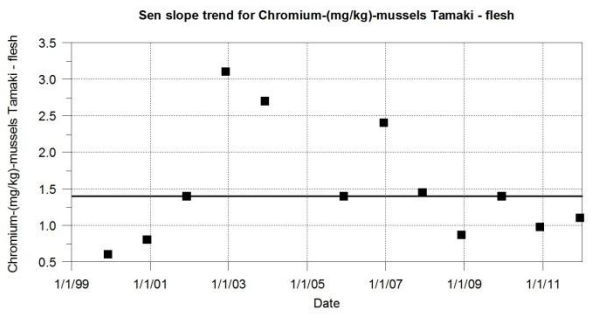

Sen slope trend for Zinc - (mg/kg)-mussels Papakura Ch - flesh
Zinc - (mg/kg)-mussels Papakura Ch - flesh
90
80
70
60
50
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
Date

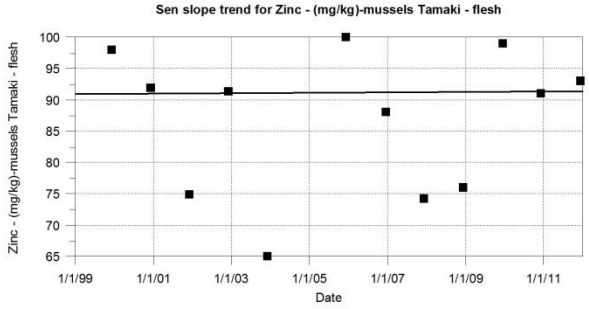

Sen slope trend for Lead - (mg/kg)-mussels Papakura Ch - flesh
Lead - (mg/kg)-mussels Papakura Ch - flesh
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
Date

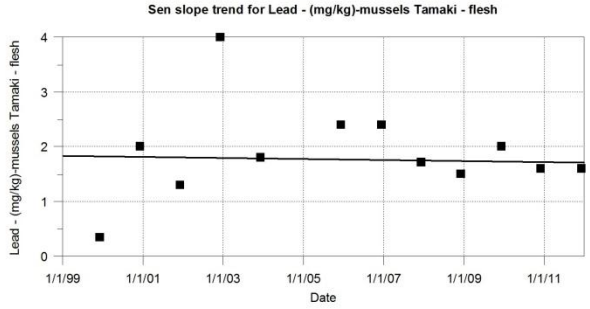

Sen slope trend for Copper - (mg/kg)-mussels Papakura Ch - flesh
Copper - (mg/kg)-mussels Papakura Ch - flesh
40
30
20
10
0
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
Date

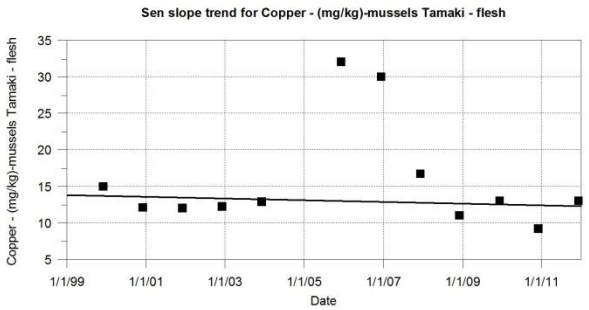

Sen slope trend for Arsenic -(mg/kg)-mussels Tamaki - flesh
Arsenic -(mg/kg)-mussels Tamaki - flesh
20
15
10
5
0
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

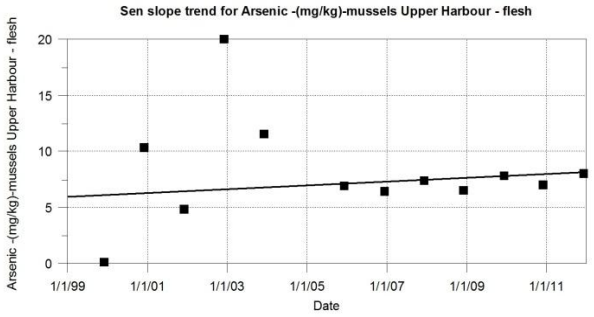

Sen slope trend for Cadmium - (mg/kg)-mussel Tamaki - flesh
Cadmium - (mg/kg)-mussel Tamaki - flesh
8
6
4
2
0
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

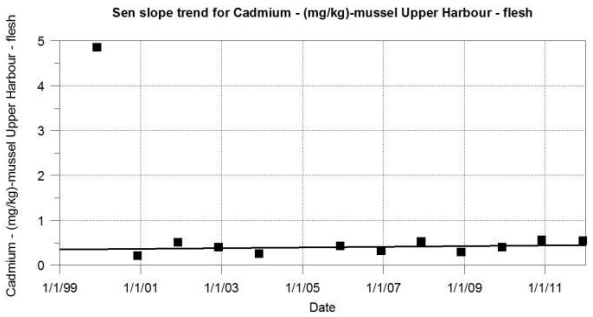

Sen slope trend for Chromium-(mg/kg)-mussels Tamaki - flesh
Chromium-(mg/kg)-mussels Tamaki - flesh
3.5
3.0
2.5
2.0
1.5
1.0
0.5
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

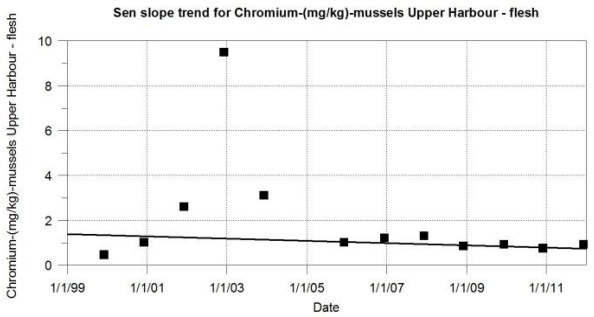

Sen slope trend for Zinc - (mg/kg)-mussels Tamaki - flesh
Zinc - (mg/kg)-mussels Tamaki - flesh
100
95
90
85
80
75
70
65
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

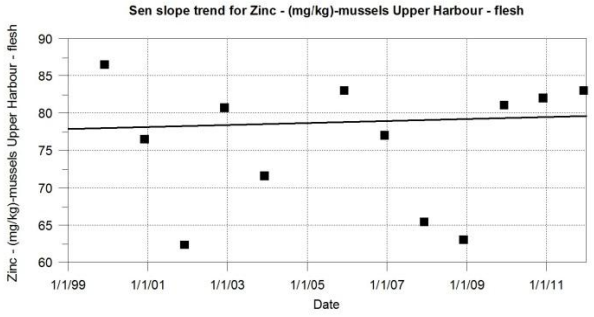

Sen slope trend for Lead - (mg/kg)-mussels Tamaki - flesh
Lead - (mg/kg)-mussels Tamaki - flesh
4
3
2
1
0
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

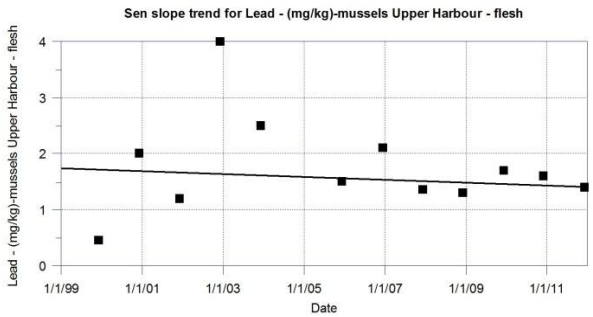

Sen slope trend for Copper - (mg/kg)-mussels Tamaki - flesh
Copper - (mg/kg)-mussels Tamaki - flesh
35
30
25
20
15
10
5
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

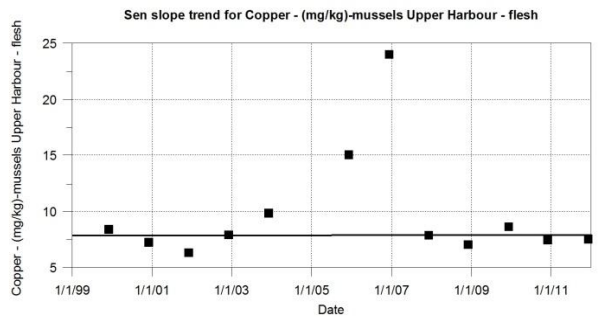

Sen slope trend for Arsenic -(mg/kg)-mussels Upper Harbour - flesh
Arsenic -(mg/kg)-mussels Upper Harbour - flesh
20
15
10
5
0
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date


Sen slope trend for Cadmium - (mg/kg)-mussel Upper Harbour - flesh
Cadmium - (mg/kg)-mussel Upper Harbour - flesh
5
4
3
2
1
0
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date


Sen slope trend for Chromium-(mg/kg)-mussels Upper Harbour - flesh
Chromium-(mg/kg)-mussels Upper Harbour - flesh
10
8
6
4
2
0
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date


Sen slope trend for Zinc - (mg/kg)-mussels Upper Harbour - flesh
Zinc - (mg/kg)-mussels Upper Harbour - flesh
90
85
80
75
70
65
60
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date


Sen slope trend for Lead - (mg/kg)-mussels Upper Harbour - flesh
Lead - (mg/kg)-mussels Upper Harbour - flesh
4
3
2
1
0
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date


Sen slope trend for Copper - (mg/kg)-mussels Upper Harbour - flesh
Copper - (mg/kg)-mussels Upper Harbour - flesh
25
20
15
10
5
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

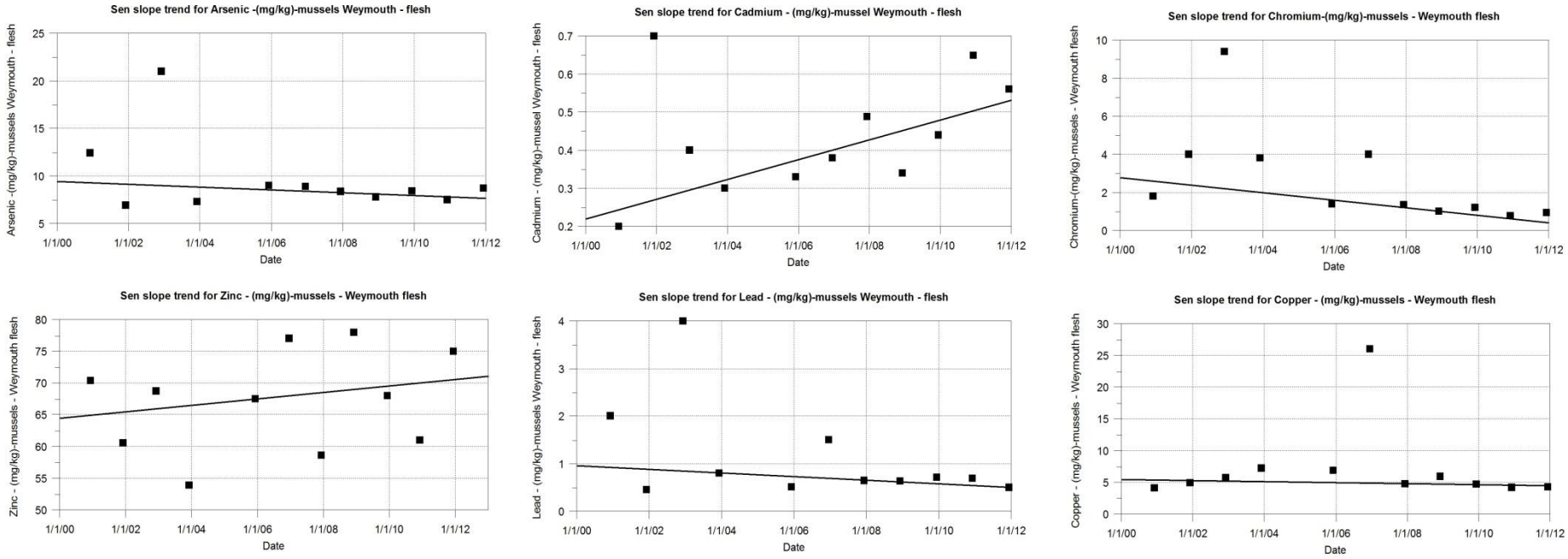
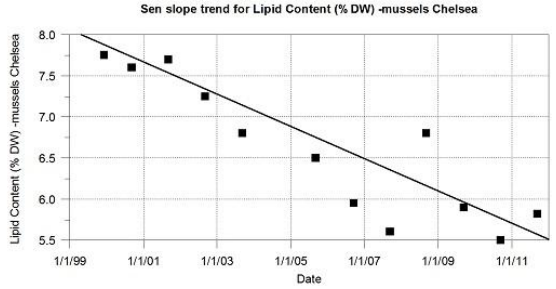
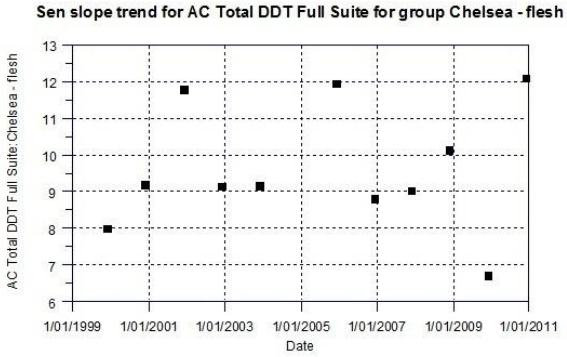
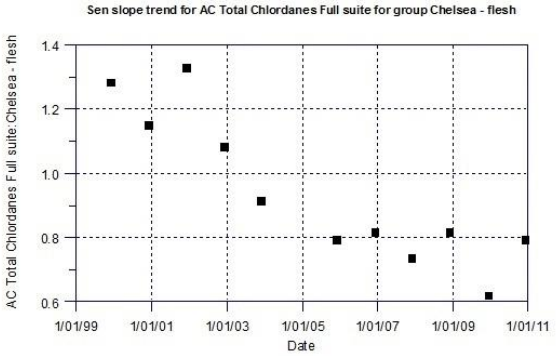
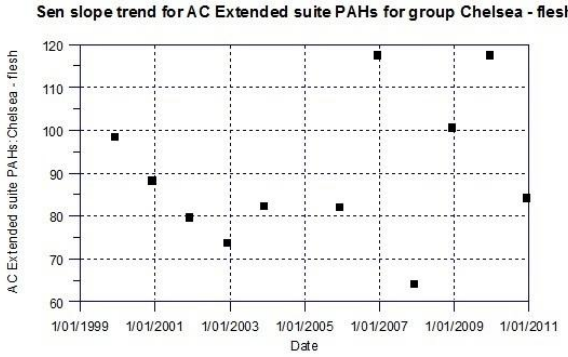


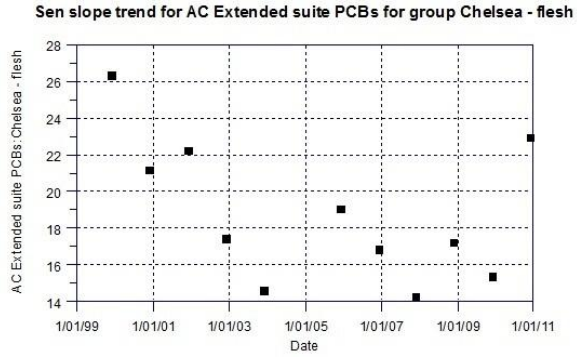
Figure Appendix 6. Heavy metal trends in mussels (1999-2011) from the SCMP. Contaminant trends are clockwise from top left: arsenic; cadmium; chromium; copper; lead; zinc. Note: Weymouth, Papakura Channel and Mangere trends were from 2000-2011.

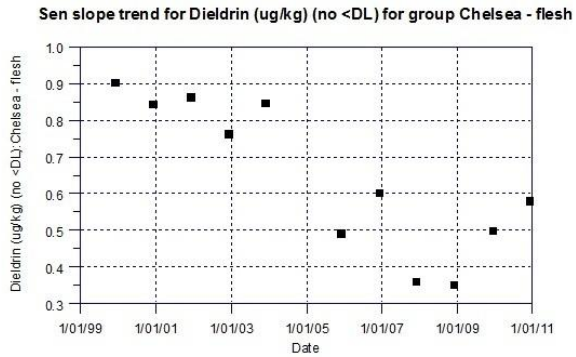

Sen slope trend for Lipid Content (% DW) -mussels Chelsea
Lipid Content (% DW) -mussels Chelsea
8.0
7.5
7.0
6.5
6.0
5.5
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

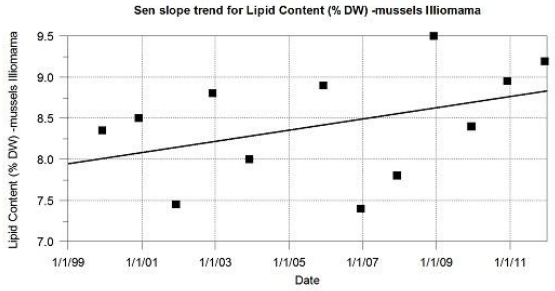

Sen slope trend for AC Total DDT Full Suite for group Chelsea - flesh
AC Total DDT Full Suite:Chelsea - flesh
13
12
11
10
9
8
7
6
1/01/1999
1/01/2001
1/01/2003
1/01/2005
1/01/2007
1/01/2009
1/01/2011
Date

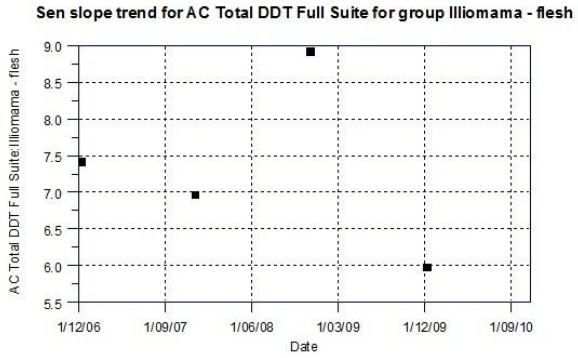

Sen slope trend for AC Total Chlordanes Full suite for group Chelsea - flesh
AC Total Chlordanes Full suite:Chelsea - flesh
1.4
1.2
1.0
0.8
0.6
1/01/99
1/01/01
1/01/03
1/01/05
1/01/07
1/01/09
1/01/11
Date

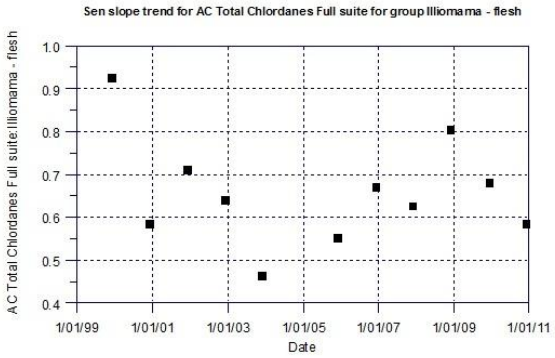

Sen slope trend for AC Extended suite PAHs for group Chelsea - flesh
AC Extended suite PAHs:Chelsea - flesh
120
110
100
90
80
70
60
1/01/1999
1/01/2001
1/01/2003
1/01/2005
1/01/2007
1/01/2009
1/01/2011
Date

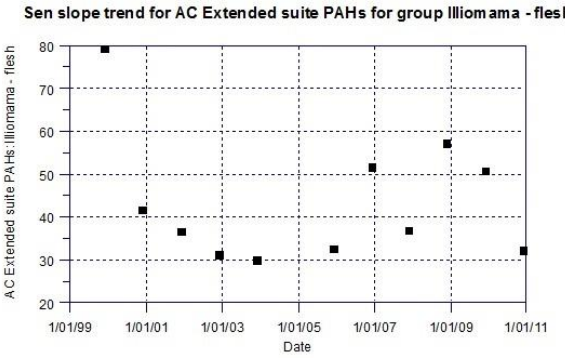

Sen slope trend for AC Extended suite PCBs for group Chelsea - flesh
AC Extended suite PCBs:Chelsea - flesh
28
26
24
22
20
18
16
14
1/01/99
1/01/01
1/01/03
1/01/05
1/01/07
1/01/09
1/01/11
Date

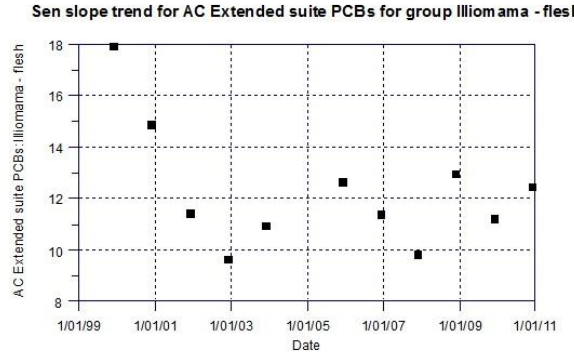

Sen slope trend for Dieldrin (ug/kg) (no <DL) for group Chelsea - flesh
Dieldrin (ug/kg) (no <DL):Chelsea - flesh
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
1/01/99
1/01/01
1/01/03
1/01/05
1/01/07
1/01/09
1/01/11
Date

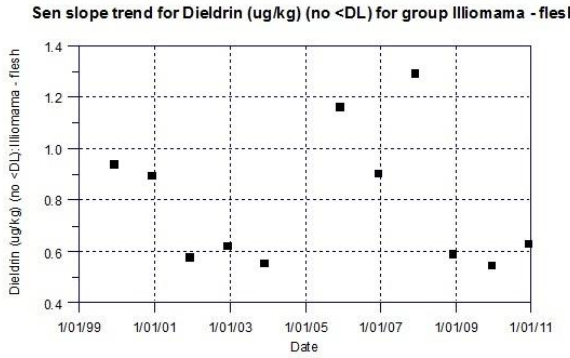

Sen slope trend for Lipid Content (% DW) -mussels Illiomama
Lipid Content (% DW) -mussels Illiomama
9.5
9.0
8.5
8.0
7.5
7.0
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

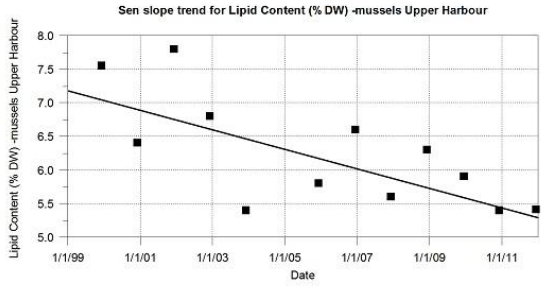

Sen slope trend for AC Total DDT Full Suite for group Illiomama - flesh
AC Total DDT Full Suite:Illiomama - flesh
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
1/12/06
1/09/07
1/06/08
1/03/09
1/12/09
1/09/10
Date

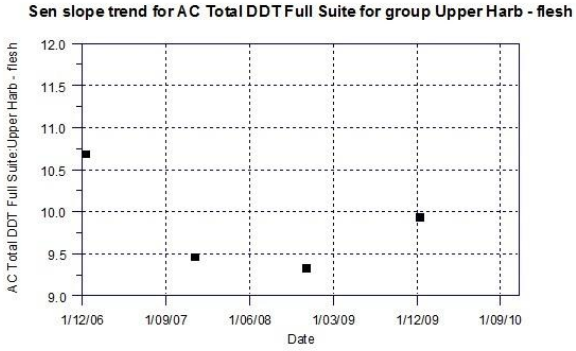

Sen slope trend for AC Total Chlordanes Full suite for group Illiomama - flesh
AC Total Chlordanes Full suite:Illiomama - flesh
1.0
0.9
0.8
0.7
0.6
0.5
0.4
1/01/99
1/01/01
1/01/03
1/01/05
1/01/07
1/01/09
1/01/11
Date

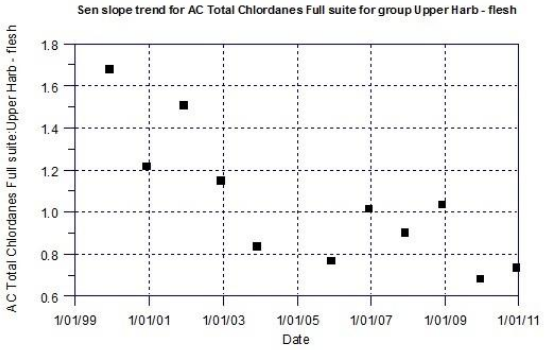

Sen slope trend for AC Extended suite PAHs for group Illiomama - flesh
AC Extended suite PAHs:Illiomama - flesh
80
70
60
50
40
30
20
1/01/99
1/01/01
1/01/03
1/01/05
1/01/07
1/01/09
1/01/11
Date

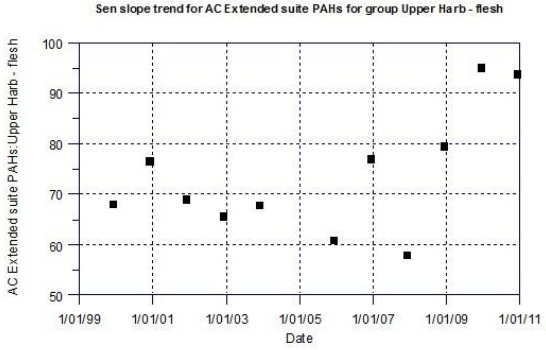

Sen slope trend for AC Extended suite PCBs for group Illiomama - flesh
AC Extended suite PCBs:Illiomama - flesh
18
16
14
12
10
8
1/01/99
1/01/01
1/01/03
1/01/05
1/01/07
1/01/09
1/01/11
Date

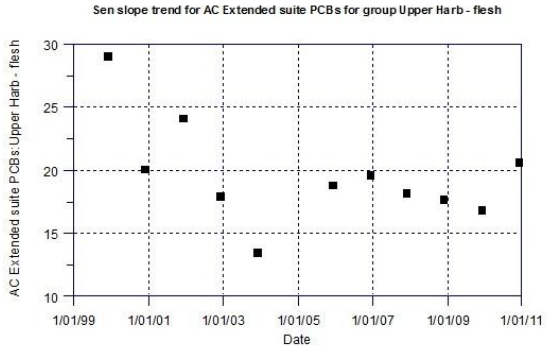

Sen slope trend for Dieldrin (ug/kg) (no <DL) for group Illiomama - flesh
Dieldrin (ug/kg) (no <DL):Illiomama - flesh
1.4
1.2
1.0
0.8
0.6
0.4
1/01/99
1/01/01
1/01/03
1/01/05
1/01/07
1/01/09
1/01/11
Date

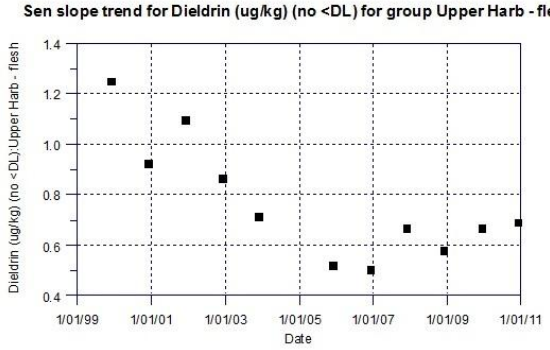

Sen slope trend for Lipid Content (% DW) -mussels Upper Harbour
Lipid Content (% DW) -mussels Upper Harbour
8.0
7.5
7.0
6.5
6.0
5.5
5.0
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

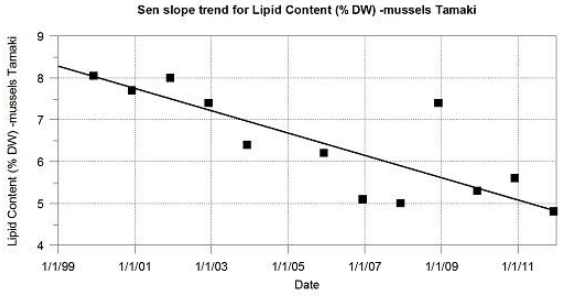

Sen slope trend for AC Total DDT Full Suite for group Upper Harb - flesh
AC Total DDT Full Suite:Upper Harb - flesh
12.0
11.5
11.0
10.5
10.0
9.5
9.0
1/12/06
1/09/07
1/06/08
1/03/09
1/12/09
1/09/10
Date

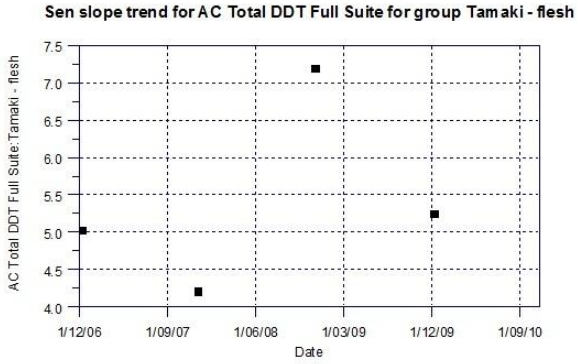

Sen slope trend for AC Total Chlordanes Full suite for group Upper Harb - flesh
AC Total Chlordanes Full suite:Upper Harb - flesh
1.8
1.6
1.4
1.2
1.0
0.8
0.6
1/01/99
1/01/01
1/01/03
1/01/05
1/01/07
1/01/09
1/01/11
Date

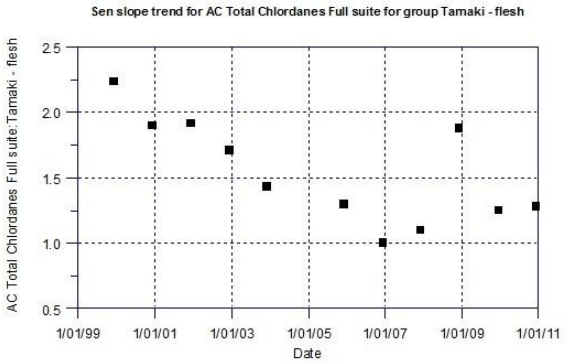

Sen slope trend for AC Extended suite PAHs for group Upper Harb - flesh
AC Extended suite PAHs:Upper Harb - flesh
100
90
80
70
60
50
1/01/99
1/01/01
1/01/03
1/01/05
1/01/07
1/01/09
1/01/11
Date

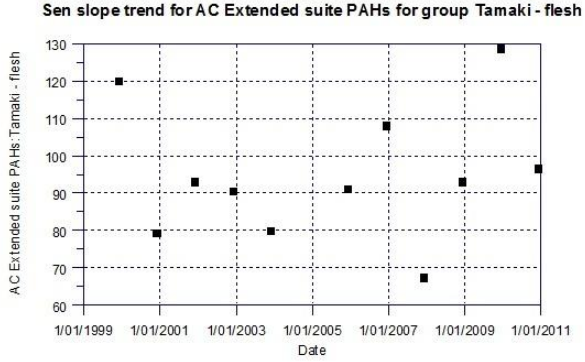

Sen slope trend for AC Extended suite PCBs for group Upper Harb - flesh
AC Extended suite PCBs:Upper Harb - flesh
30
25
20
15
10
1/01/99
1/01/01
1/01/03
1/01/05
1/01/07
1/01/09
1/01/11
Date

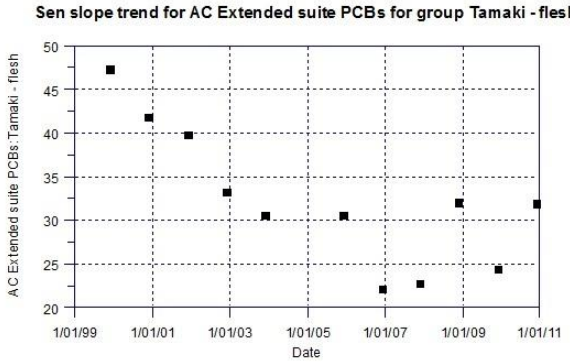

Sen slope trend for Dieldrin (ug/kg) (no <DL) for group Upper Harb - flesh
Dieldrin (ug/kg) (no <DL):Upper Harb - flesh
1.4
1.2
1.0
0.8
0.6
0.4
1/01/99
1/01/01
1/01/03
1/01/05
1/01/07
1/01/09
1/01/11
Date

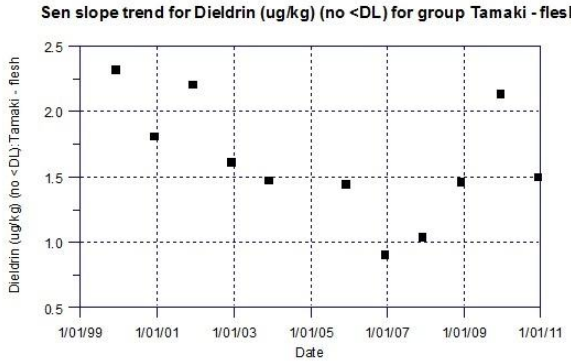

Sen slope trend for Lipid Content (% DW) -mussels Tamaki
Lipid Content (% DW) -mussels Tamaki
9
8
7
6
5
4
1/1/99
1/1/01
1/1/03
1/1/05
1/1/07
1/1/09
1/1/11
Date

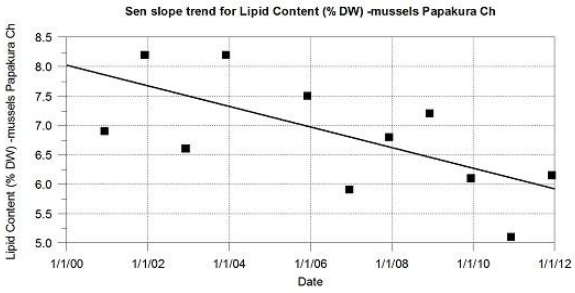

Sen slope trend for AC Total DDT Full Suite for group Tamaki - flesh
AC Total DDT Full Suite:Tamaki - flesh
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
1/12/06
1/09/07
1/06/08
1/03/09
1/12/09
1/09/10
Date

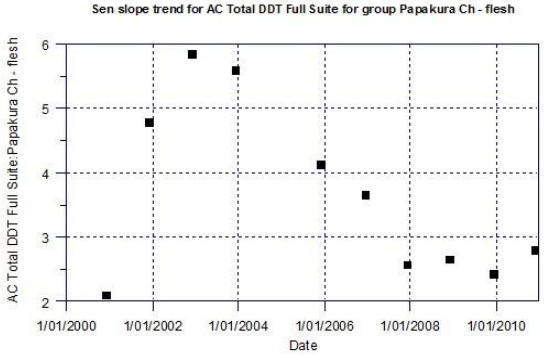

Sen slope trend for AC Total Chlordanes Full suite for group Tamaki - flesh
AC Total Chlordanes Full suite:Tamaki - flesh
2.5
2.0
1.5
1.0
0.5
1/01/99
1/01/01
1/01/03
1/01/05
1/01/07
1/01/09
1/01/11
Date

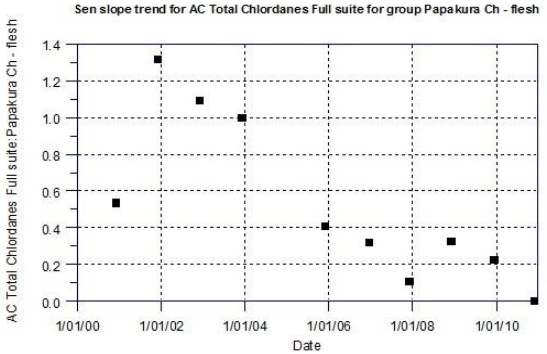

Sen slope trend for AC Extended suite PAHs for group Tamaki - flesh
AC Extended suite PAHs:Tamaki - flesh
130
120
110
100
90
80
70
60
1/01/1999
1/01/2001
1/01/2003
1/01/2005
1/01/2007
1/01/2009
1/01/2011
Date

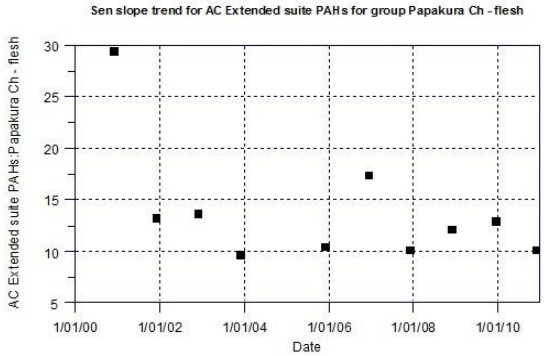

Sen slope trend for AC Extended suite PCBs for group Tamaki - flesh
AC Extended suite PCBs:Tamaki - flesh
50
45
40
35
30
25
20
1/01/99
1/01/01
1/01/03
1/01/05
1/01/07
1/01/09
1/01/11
Date

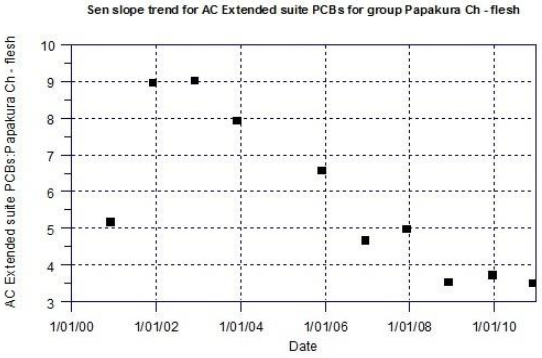

Sen slope trend for Dieldrin (ug/kg) (no <DL) for group Tamaki - flesh
Dieldrin (ug/kg) (no <DL):Tamaki - flesh
2.5
2.0
1.5
1.0
0.5
1/01/99
1/01/01
1/01/03
1/01/05
1/01/07
1/01/09
1/01/11
Date

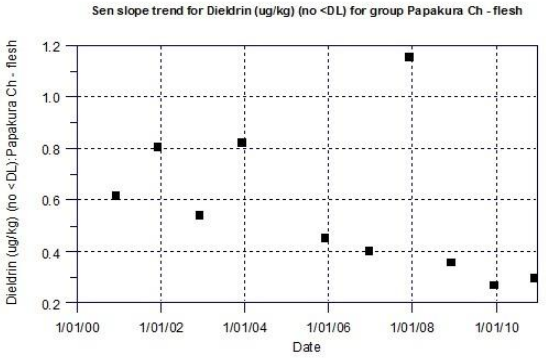

Sen slope trend for Lipid Content (% DW) -mussels Papakura Ch
Lipid Content (% DW) -mussels Papakura Ch
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
Date

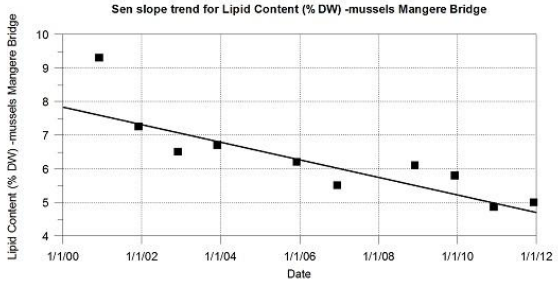

Sen slope trend for AC Total DDT Full Suite for group Papakura Ch - flesh
AC Total DDT Full Suite:Papakura Ch - flesh
6
5
4
3
2
1/01/2000
1/01/2002
1/01/2004
1/01/2006
1/01/2008
1/01/2010
Date

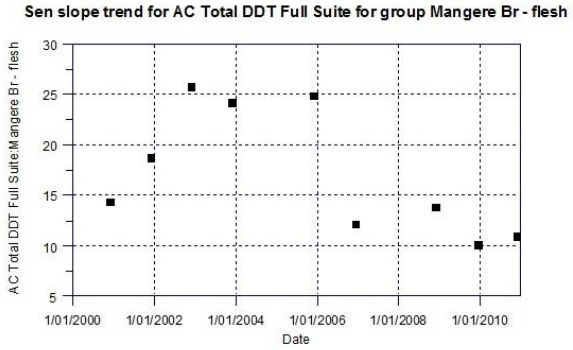

Sen slope trend for AC Total Chlordanes Full suite for group Papakura Ch - flesh
AC Total Chlordanes Full suite:Papakura Ch - flesh
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1/01/00
1/01/02
1/01/04
1/01/06
1/01/08
1/01/10
Date

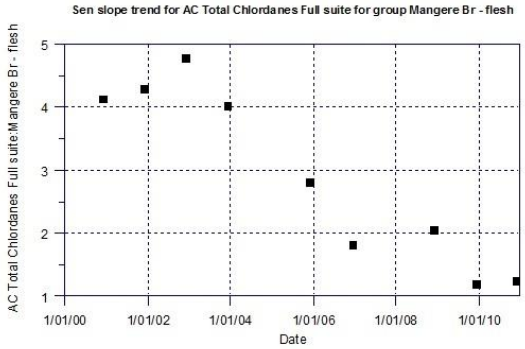

Sen slope trend for AC Extended suite PAHs for group Papakura Ch - flesh
AC Extended suite PAHs:Papakura Ch - flesh
30
25
20
15
10
5
1/01/00
1/01/02
1/01/04
1/01/06
1/01/08
1/01/10
Date

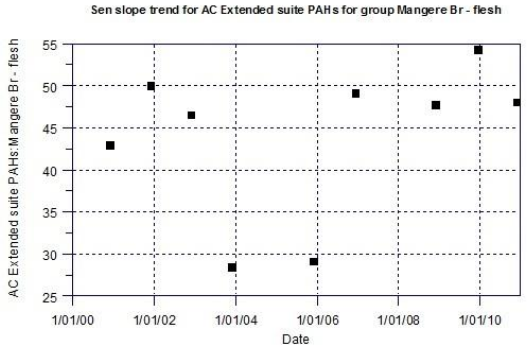

Sen slope trend for AC Extended suite PCBs for group Papakura Ch - flesh
AC Extended suite PCBs:Papakura Ch - flesh
10
9
8
7
6
5
4
3
1/01/00
1/01/02
1/01/04
1/01/06
1/01/08
1/01/10
Date

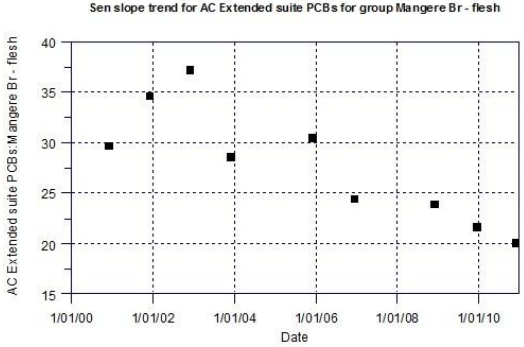

Sen slope trend for Dieldrin (ug/kg) (no <DL) for group Papakura Ch - flesh
Dieldrin (ug/kg) (no <DL):Papakura Ch - flesh
1.2
1.0
0.8
0.6
0.4
0.2
1/01/00
1/01/02
1/01/04
1/01/06
1/01/08
1/01/10
Date

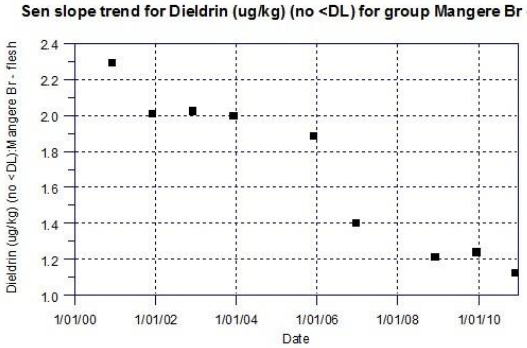

Sen slope trend for Lipid Content (% DW) -mussels Mangere Bridge
Lipid Content (% DW) -mussels Mangere Bridge
10
9
8
7
6
5
4
1/1/00
1/1/02
1/1/04
1/1/06
1/1/08
1/1/10
1/1/12
Date


Sen slope trend for AC Total DDT Full Suite for group Mangere Br - flesh
AC Total DDT Full Suite:Mangere Br - flesh
30
25
20
15
10
5
1/01/2000
1/01/2002
1/01/2004
1/01/2006
1/01/2008
1/01/2010
Date


Sen slope trend for AC Total Chlordanes Full suite for group Mangere Br - flesh
AC Total Chlordanes Full suite:Mangere Br - flesh
5
4
3
2
1
1/01/00
1/01/02
1/01/04
1/01/06
1/01/08
1/01/10
Date


Sen slope trend for AC Extended suite PAHs for group Mangere Br - flesh
AC Extended suite PAHs:Mangere Br - flesh
55
50
45
40
35
30
25
1/01/00
1/01/02
1/01/04
1/01/06
1/01/08
1/01/10
Date


Sen slope trend for AC Extended suite PCBs for group Mangere Br - flesh
AC Extended suite PCBs:Mangere Br - flesh
40
35
30
25
20
15
1/01/00
1/01/02
1/01/04
1/01/06
1/01/08
1/01/10
Date


Sen slope trend for Dieldrin (ug/kg) (no <DL) for group Mangere Br - flesh
Dieldrin (ug/kg) (no <DL):Mangere Br - flesh
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
1/01/00
1/01/02
1/01/04
1/01/06
1/01/08
1/01/10
Date

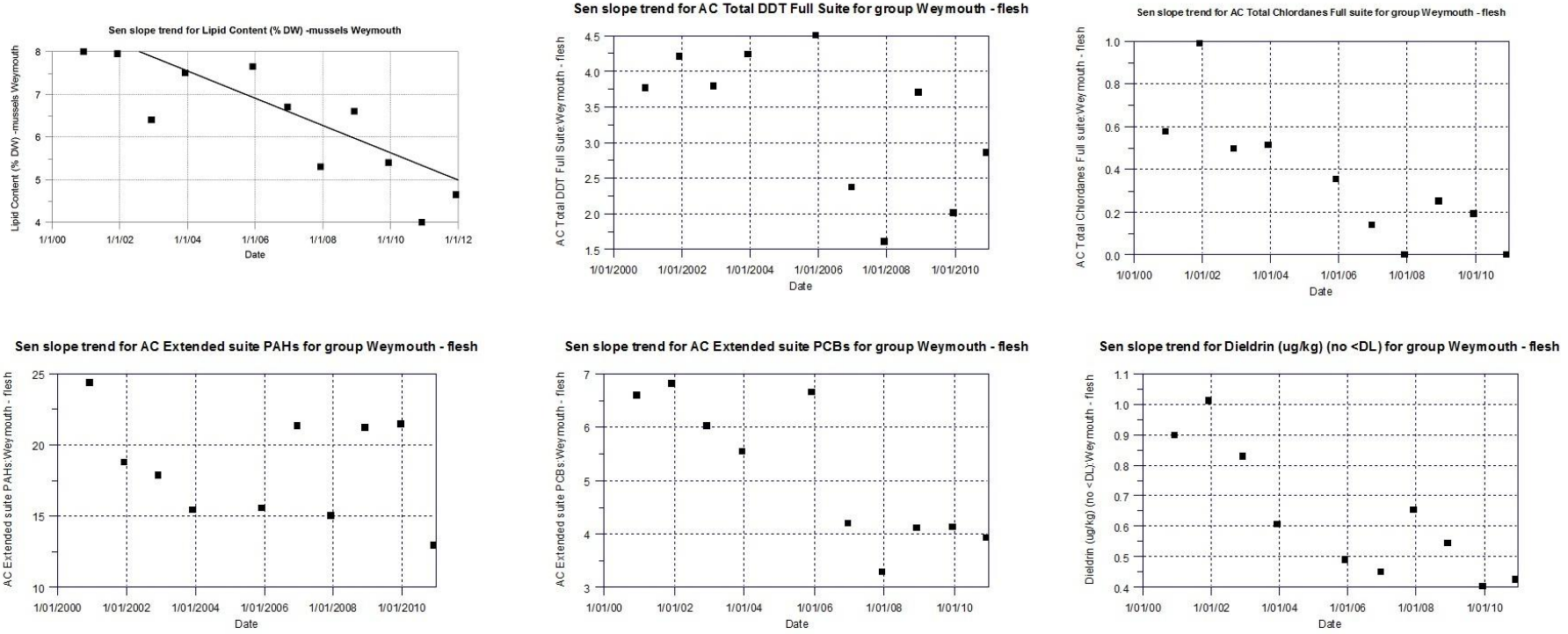


Figure Appendix 7. Lipid content and organic contaminant trends for mussels (1999-2011) from the SCMP. Trends are clockwise from top left: %lipid; DDT; Chlordanes; Dieldrin; PCBs; PAHs. All organics suites are extended suites. Note: Weymouth, Papakura Channel and Mangere trends were from 2000-2011.

Appendix G Box Plot comparisons of oyster and mussel contaminant concentrations in the Manukau Harbour

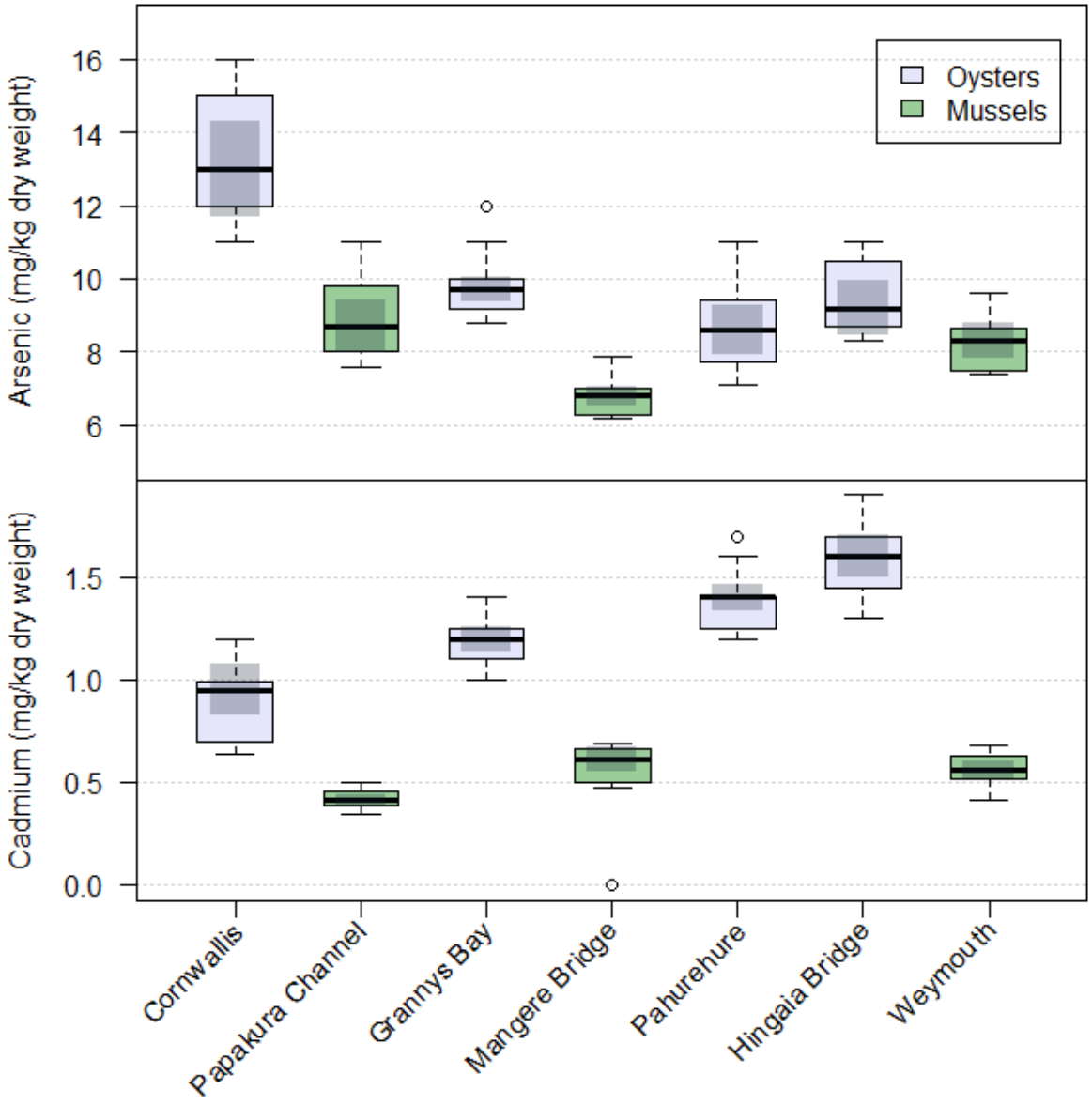


Figure Appendix 8. Arsenic and cadmium in oysters and mussels at sites in the Manukau Harbour. Shaded boxes overlaid on box plots indicate the confidence interval about the median.

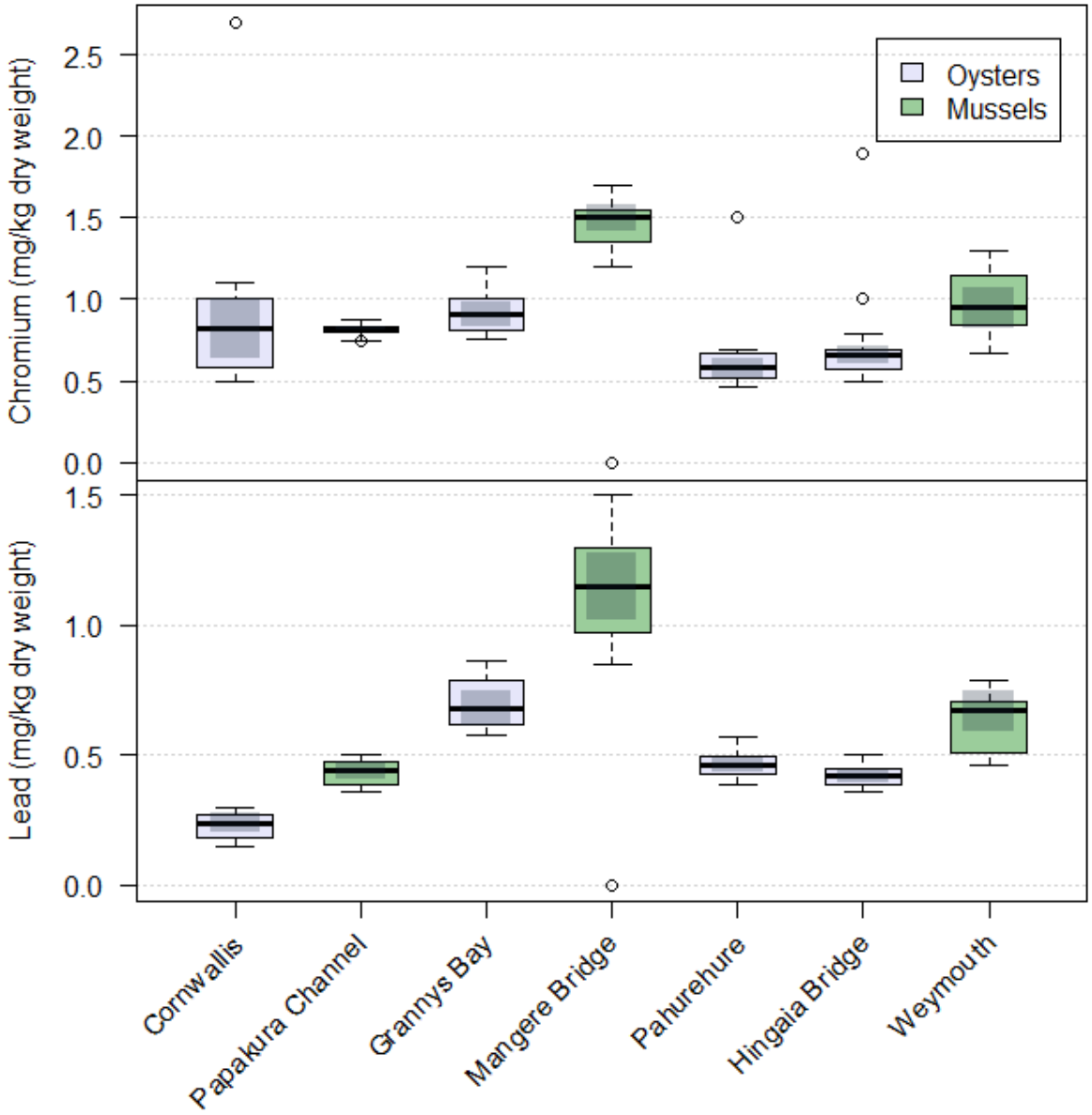


Figure Appendix 9. Chromium and lead in oysters and mussels at sites in the Manukau Harbour. Shaded boxes overlaid on box plots indicate the confidence interval about the median.

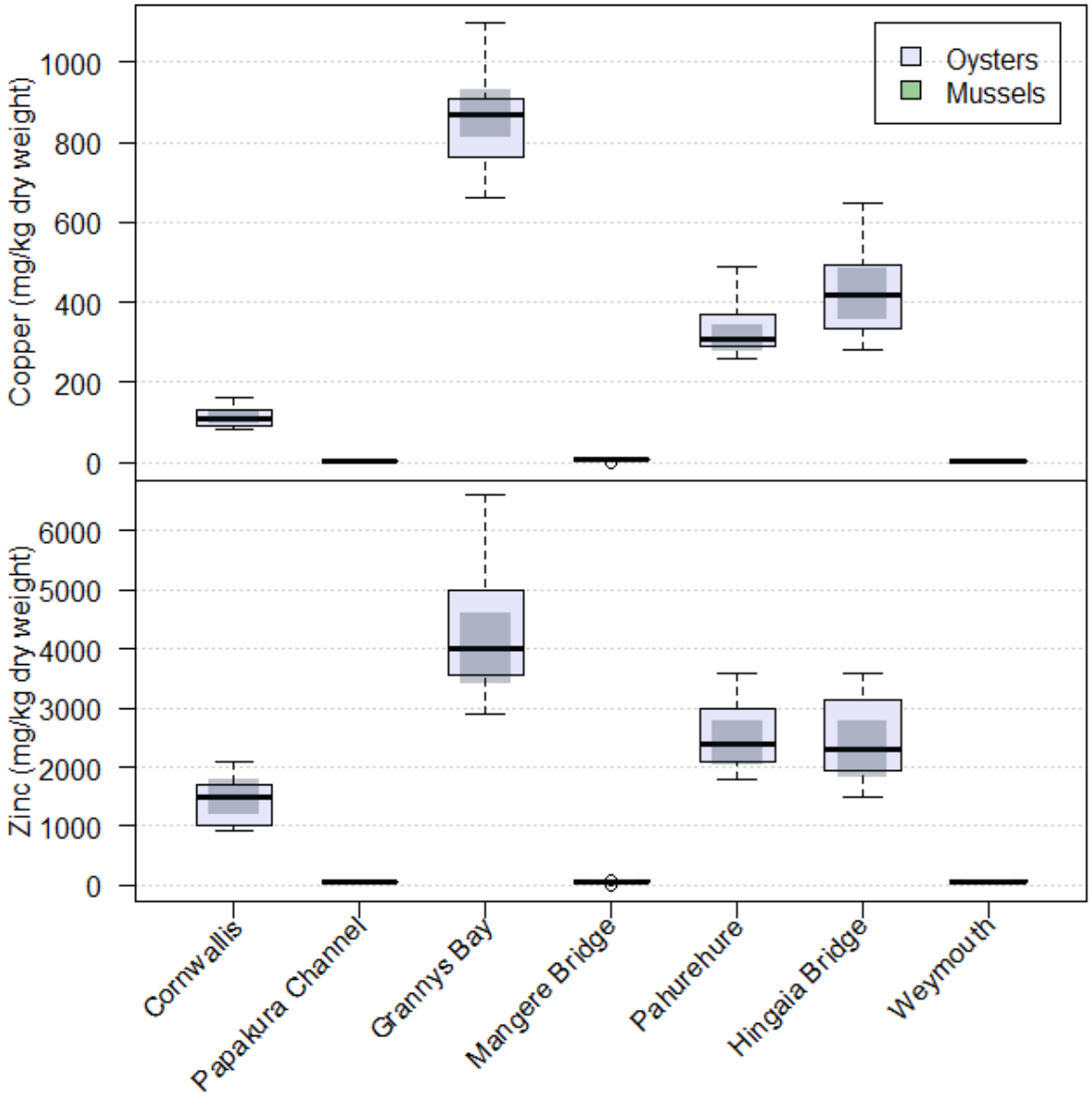


Figure Appendix 10. Copper and zinc in oysters and mussels at sites in the Manukau Harbour. Shaded boxes overlaid on box plots indicate the confidence interval about the median.

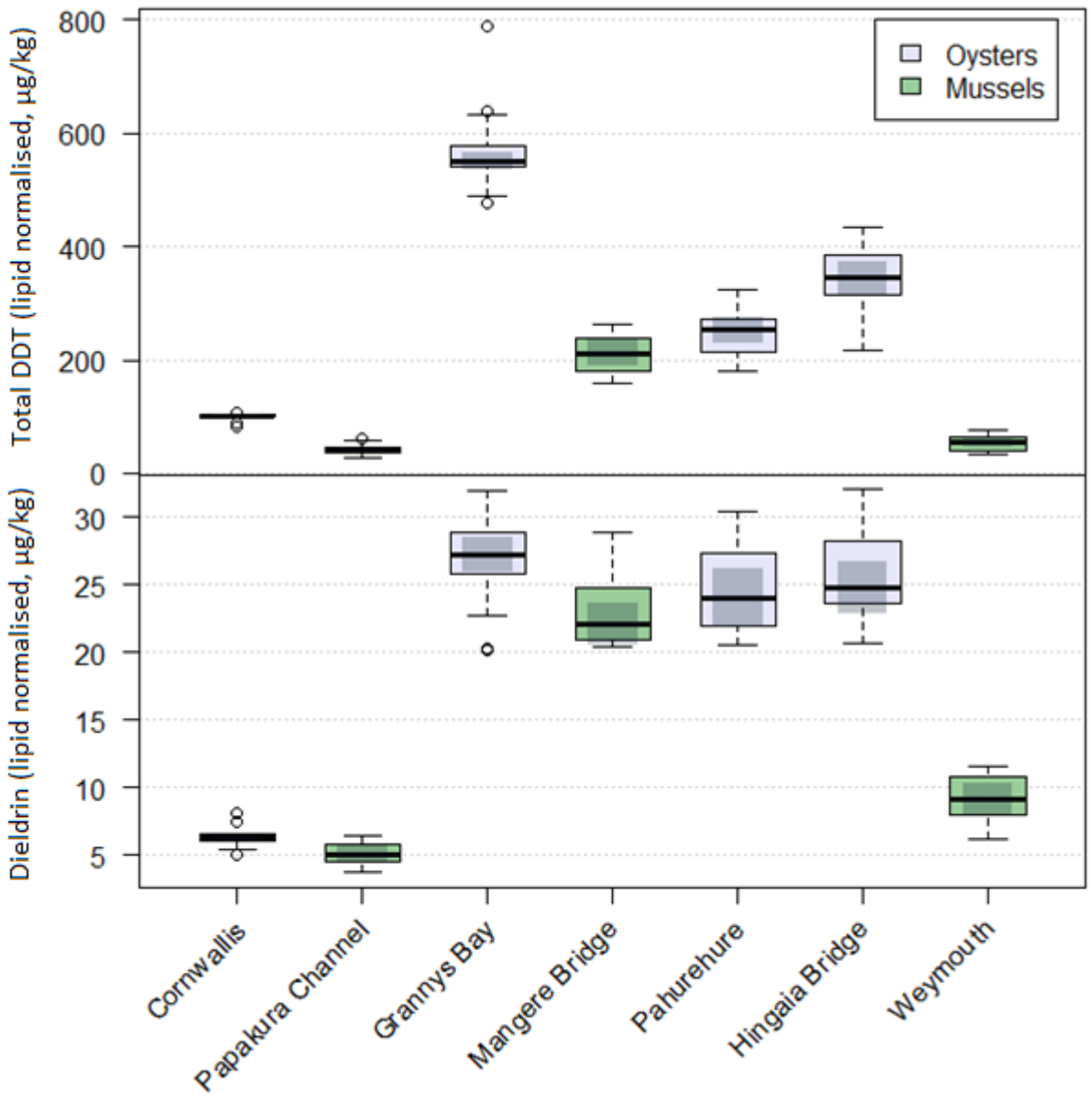


Figure Appendix 11. Lipid normalized Total DDT and dieldrin in oysters and mussels at sites in the Manukau Harbour. Shaded boxes overlaid on box plots indicate the confidence interval about the median.

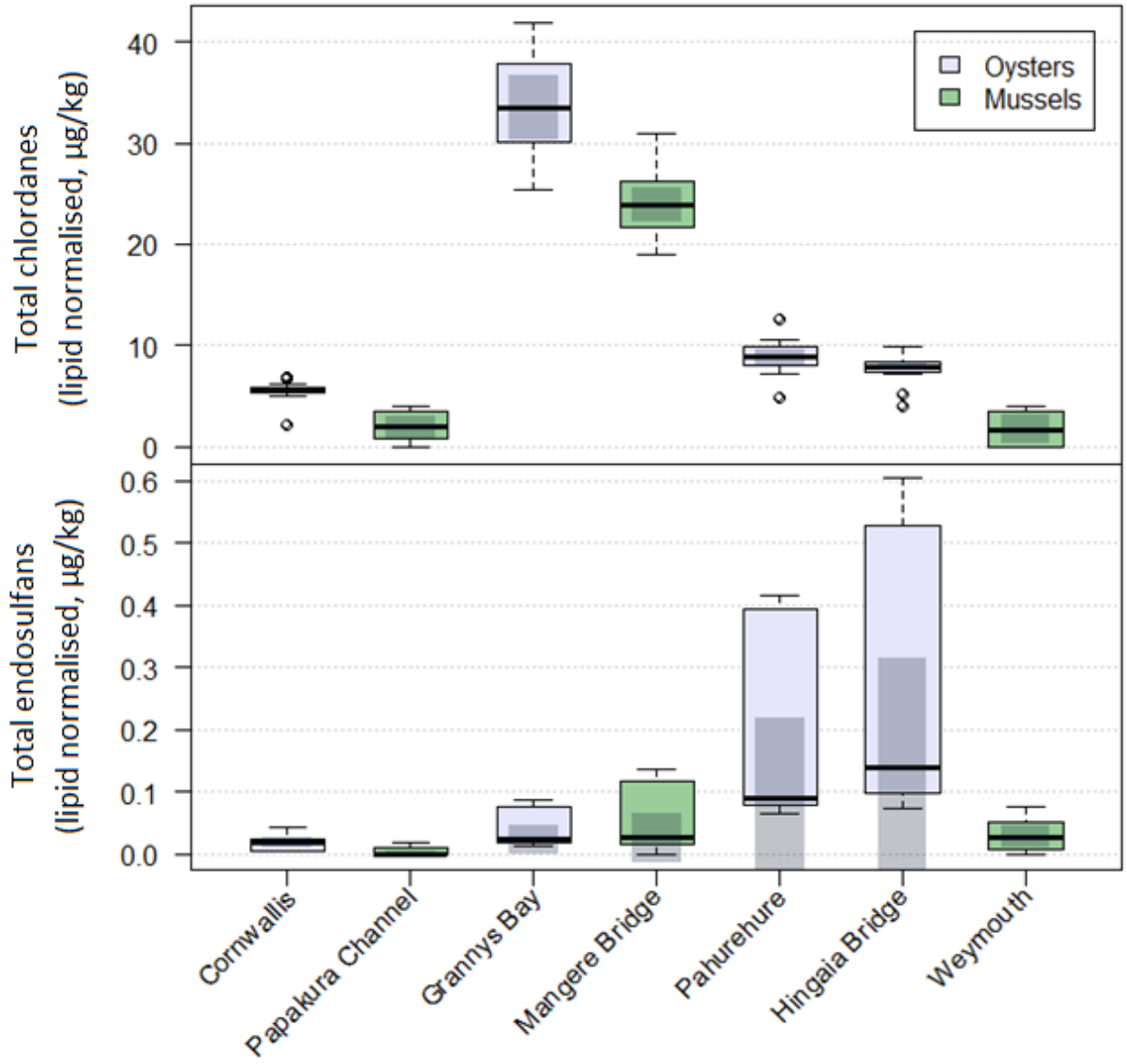


Figure Appendix 12. Lipid normalized Total chlordanes and total endosulfans in oysters and mussels at sites in the Manukau Harbour. Shaded boxes overlaid on box plots indicate the confidence interval about the median.

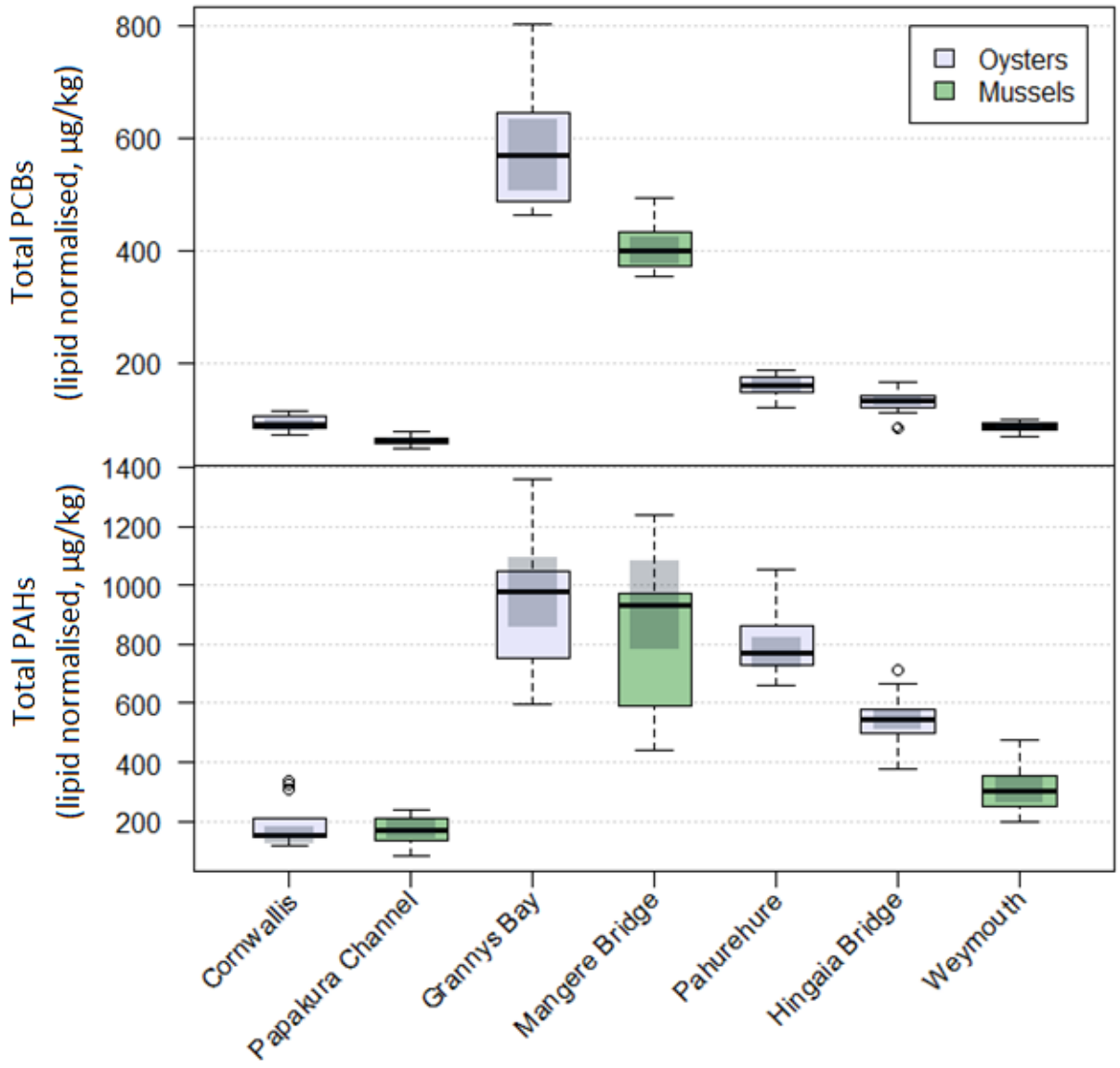


Figure Appendix 13. Lipid normalized Total PCBs and total PAHs in oysters and mussels at sites in the Manukau Harbour. Shaded boxes overlaid on box plots indicate the confidence interval about the media.

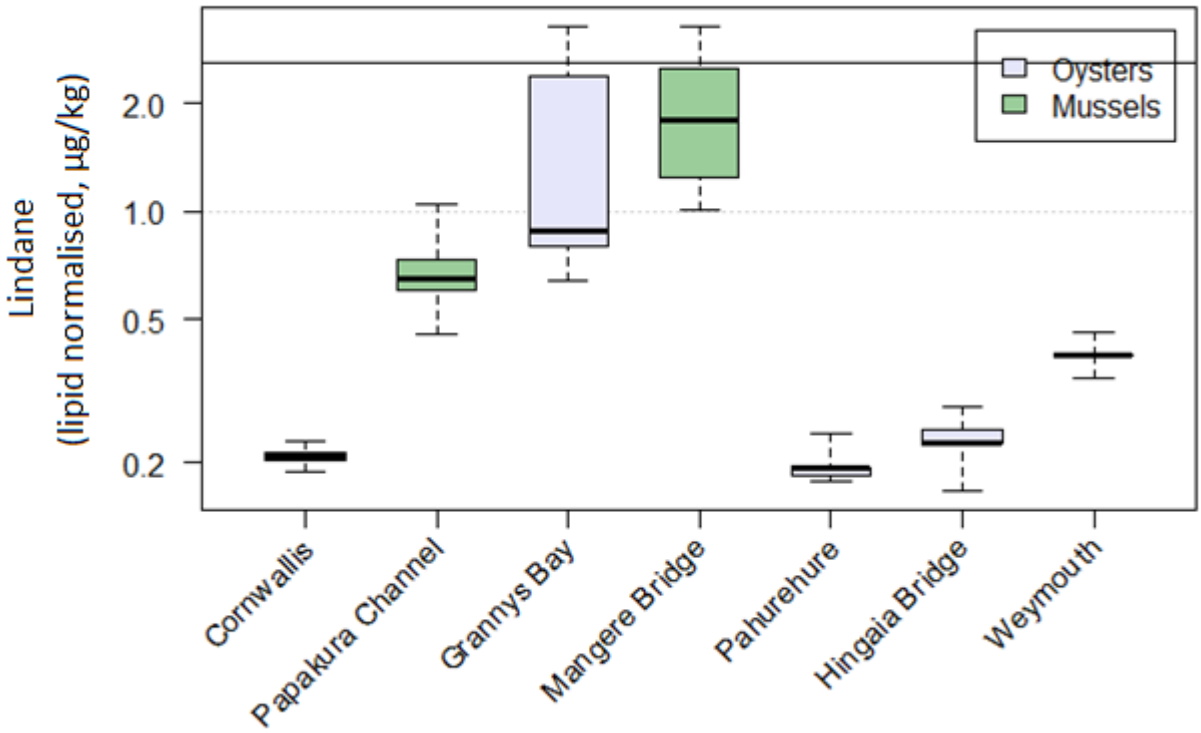


Figure Appendix 14. Lindane in oysters and mussels at sites in the Manukau Harbour.

Appendix H Correlation of climate variables with shellfish PC1 score and condition

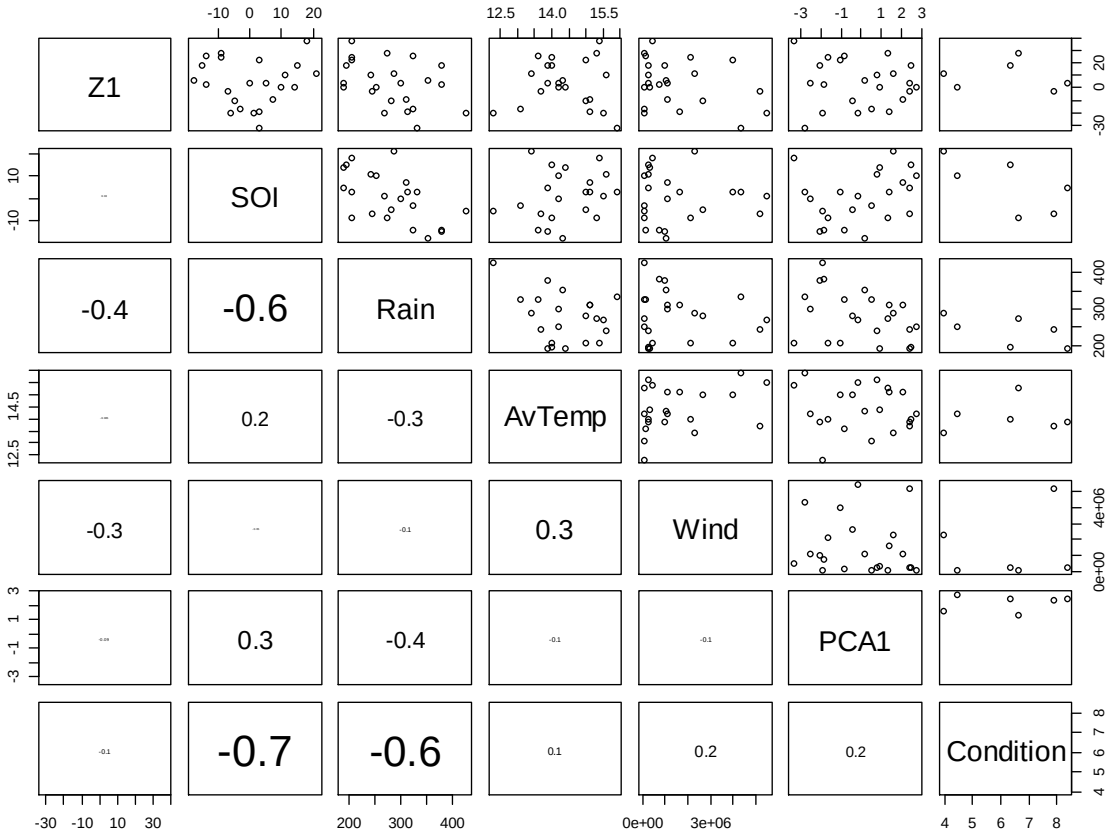


Figure Appendix 15. Correlation of climate variables with oyster PC1 score and condition index at Cornwallis oyster site.

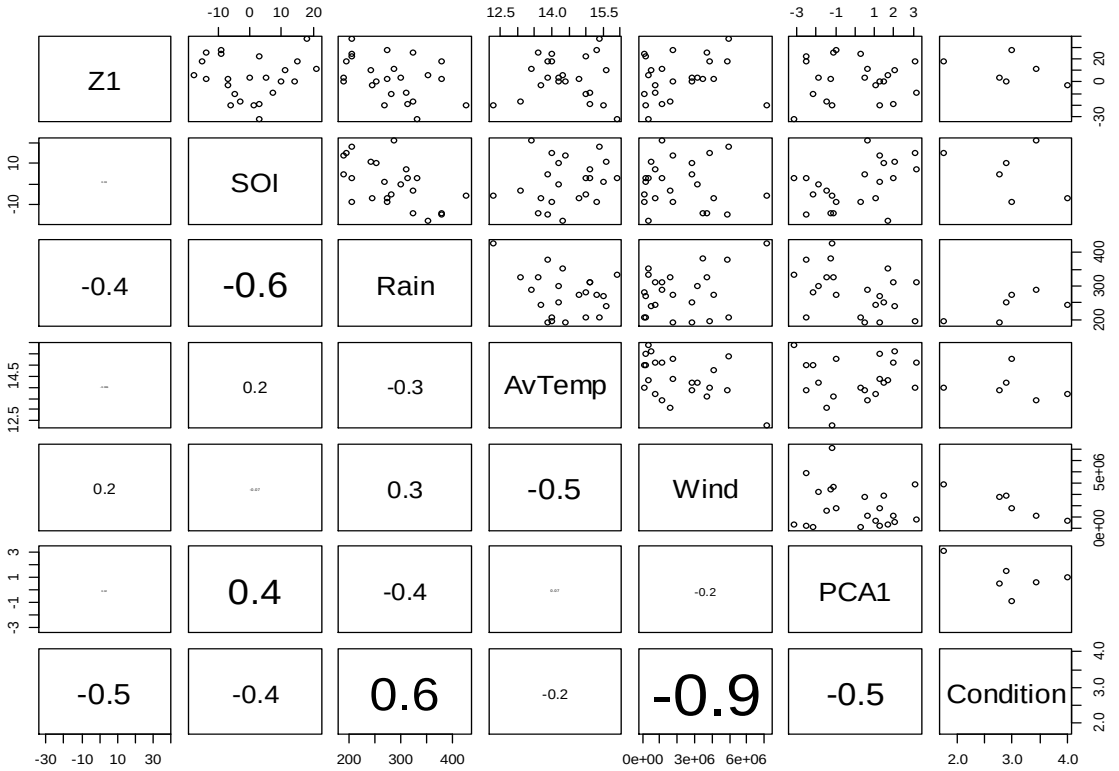


Figure Appendix 16. Correlation of climate variables with oyster PC1 score and condition index at Grannys Bay oyster site.

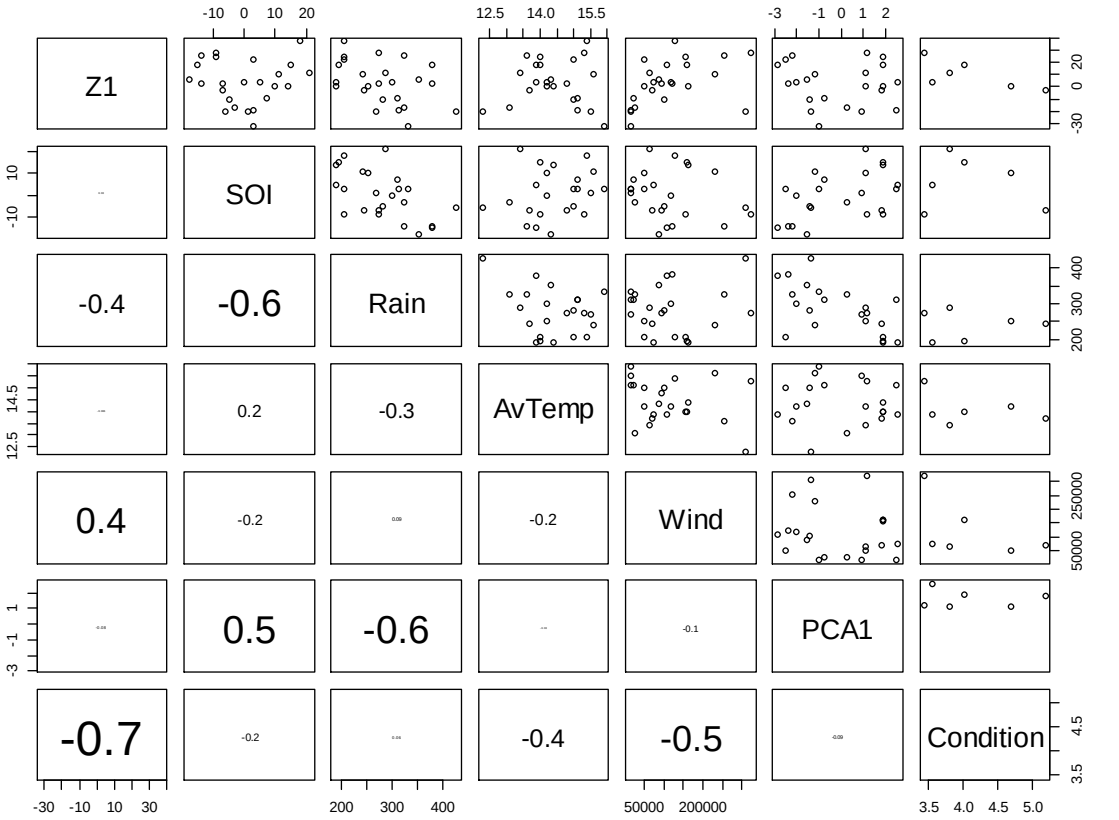


Figure Appendix 17. Correlation of climate variables with oyster PC1 score and condition at Pahurehure oyster site.

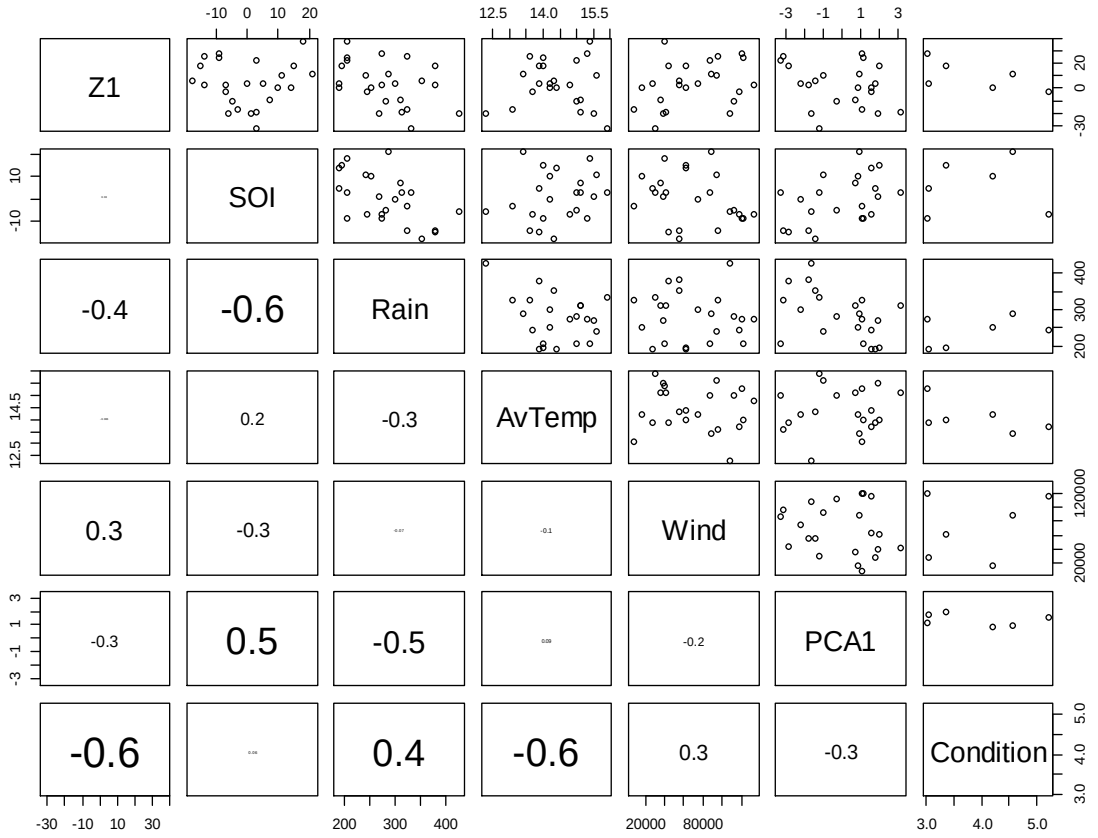


Figure Appendix 18. Correlation of climate variables with oyster PC1 score and condition at Hingaia oyster site.

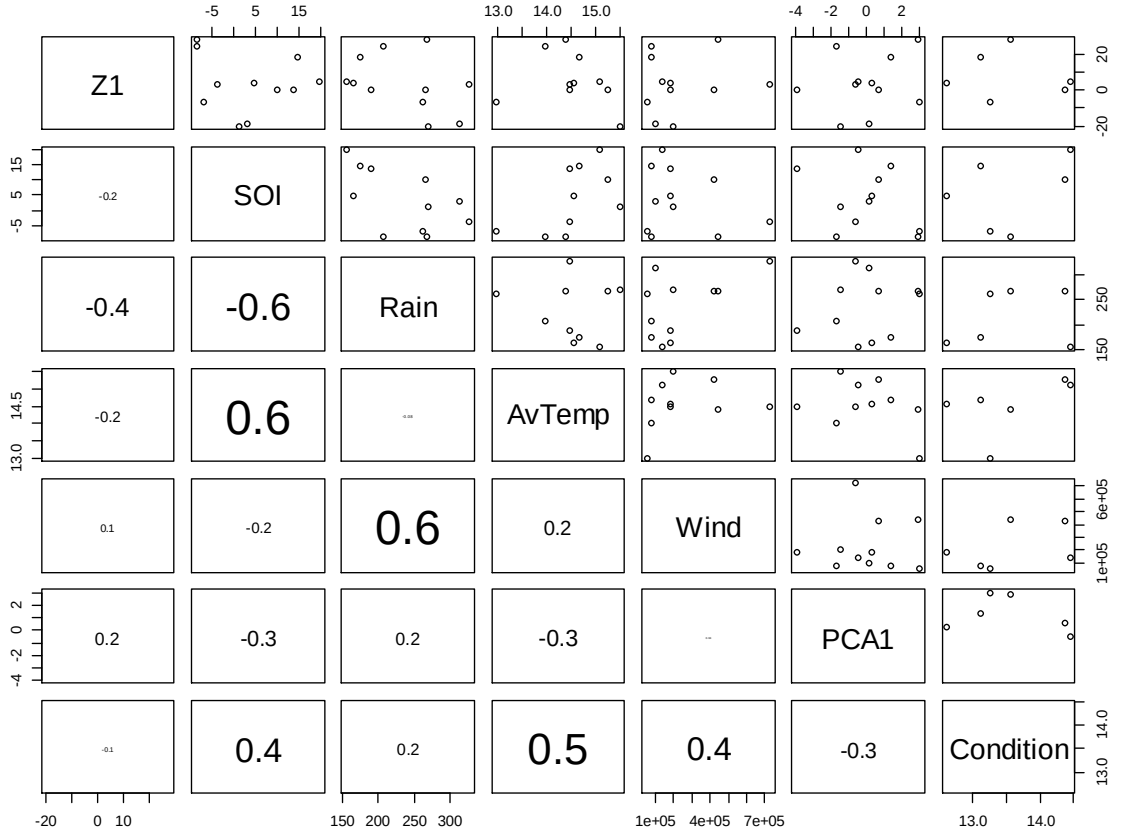


Figure Appendix 19. Correlation of climate variables with mussel PC1 score and condition index at Chelsea mussel site.

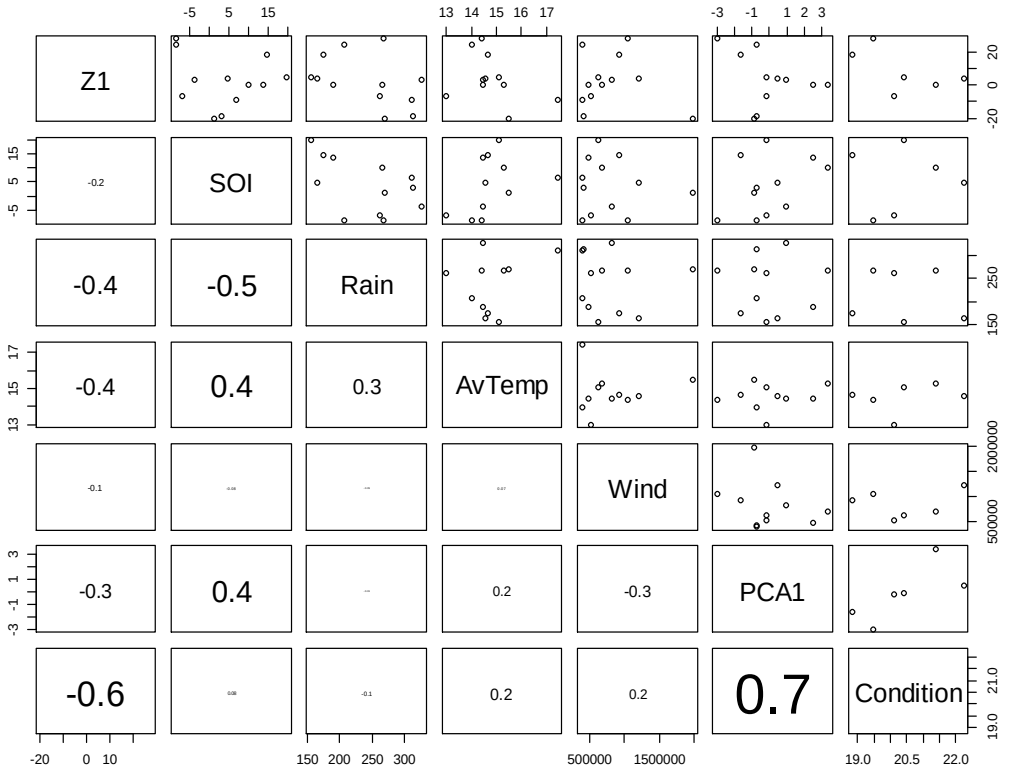


Figure Appendix 20. Correlation of climate variables with mussel PC1 score and condition index at Illiomama mussel site.

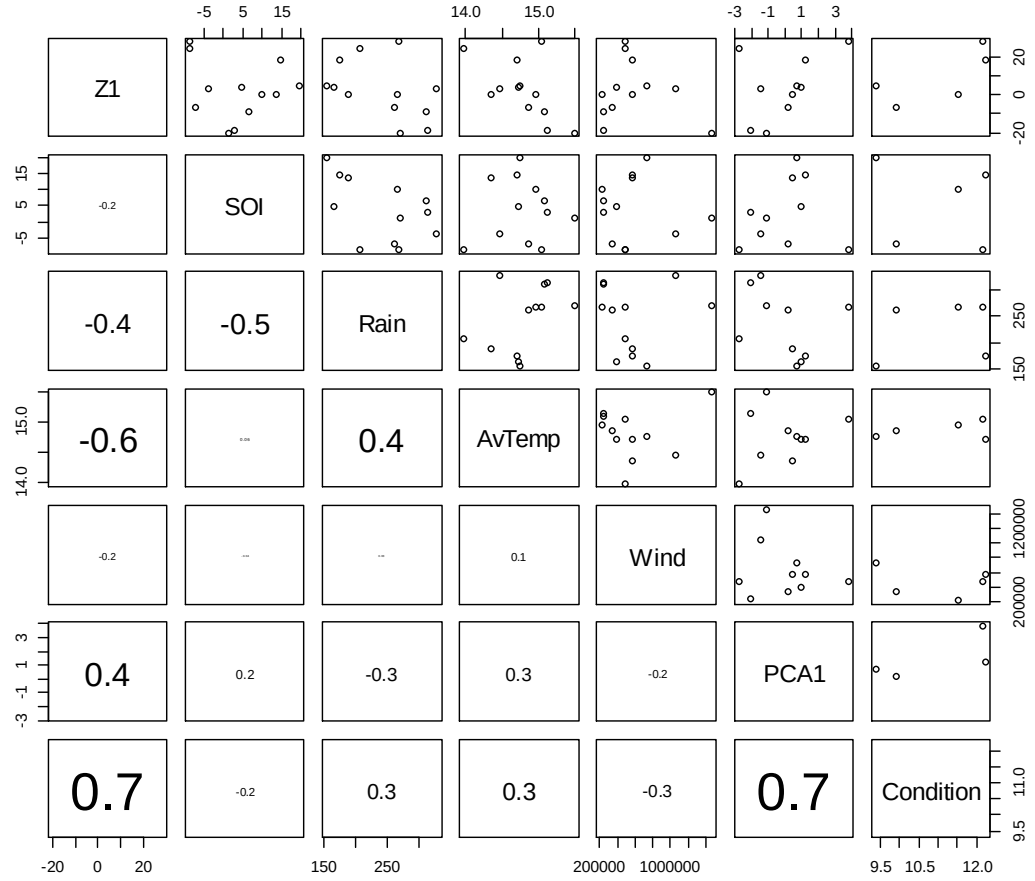


Figure Appendix 21. Correlation of climate variables with mussel PC1 score and condition index at Mangere Bridge mussel site.

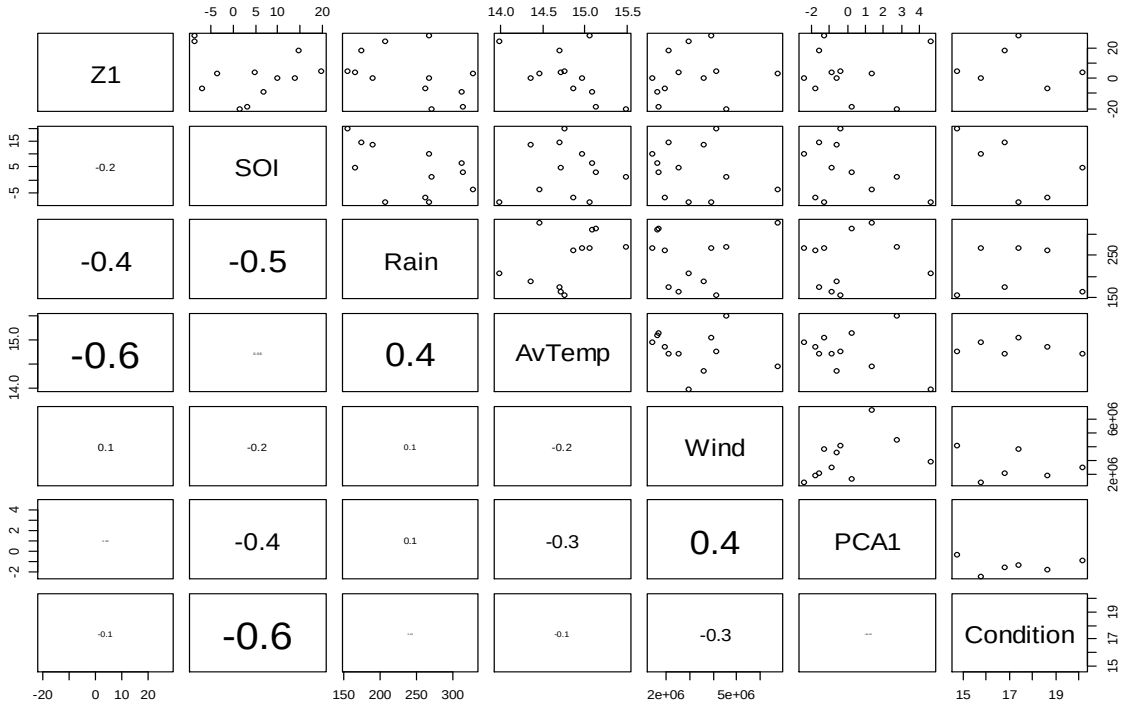


Figure Appendix 22. Correlation of climate variables with mussel PC1 score and condition index at Papakura Channel mussel site.

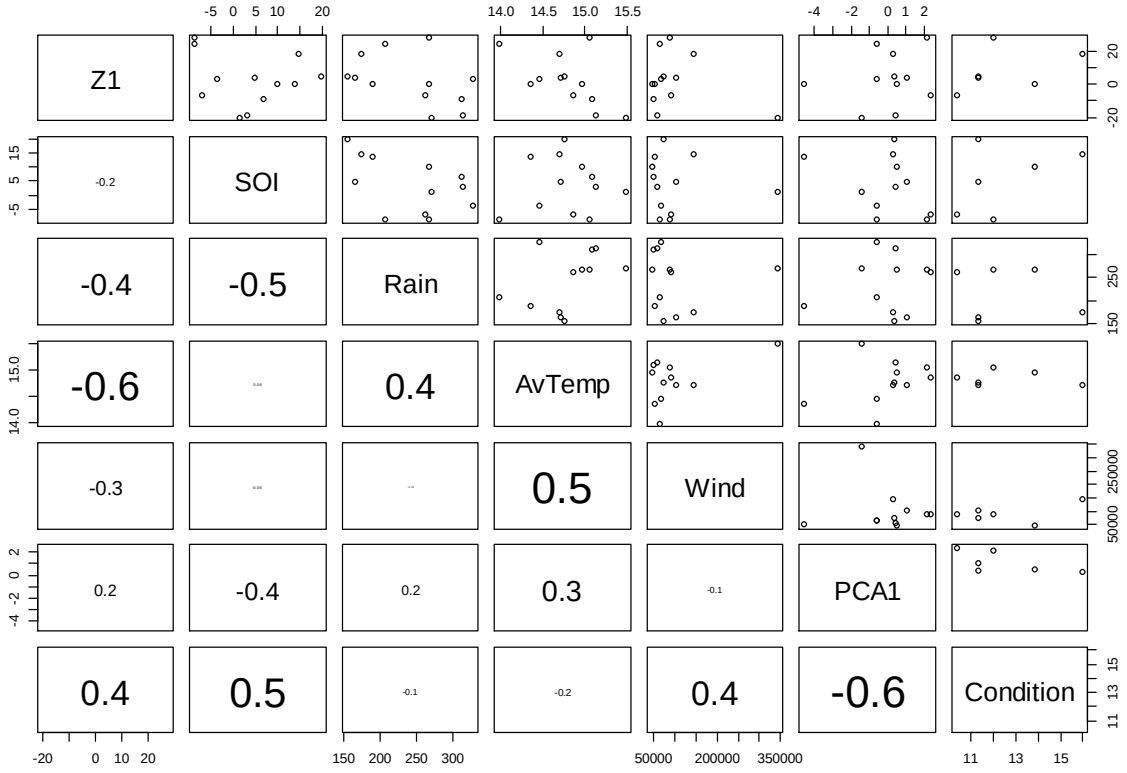


Figure Appendix 23. Correlation of climate variables with mussel PC1 score and condition index at Tamaki mussel site.

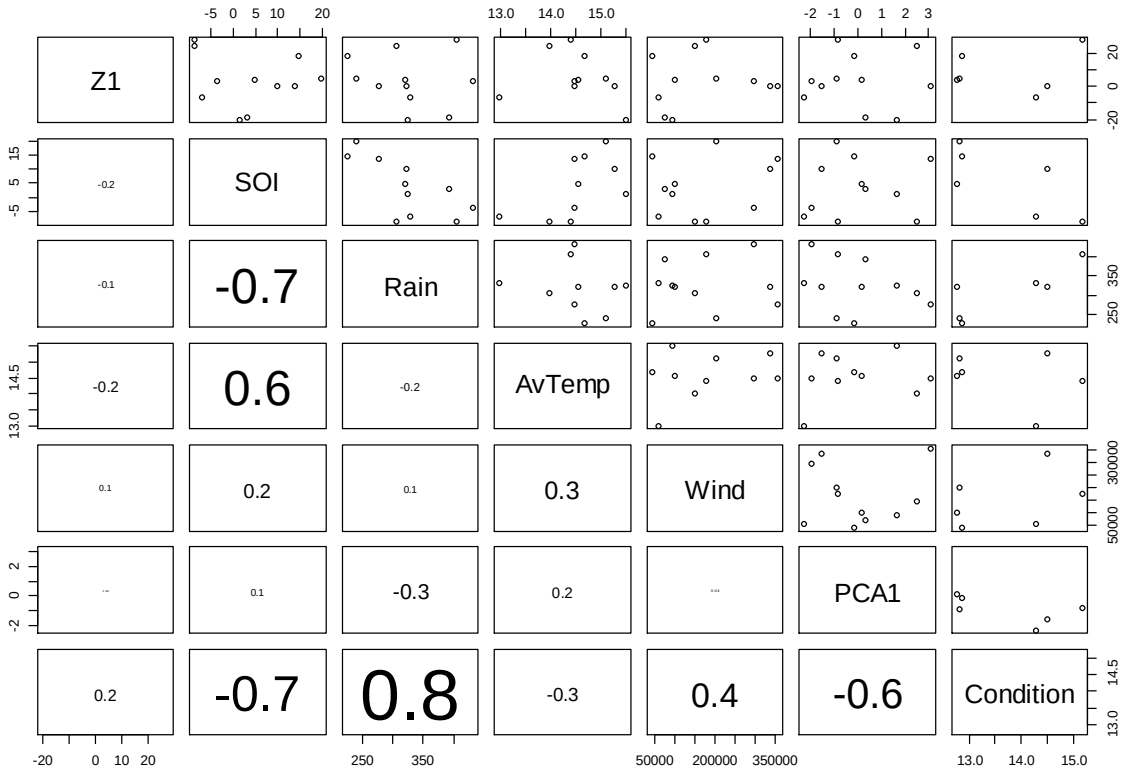


Figure Appendix 24. Correlation of climate variables with mussel PC1 score and condition index at Upper Harbour mussel site.

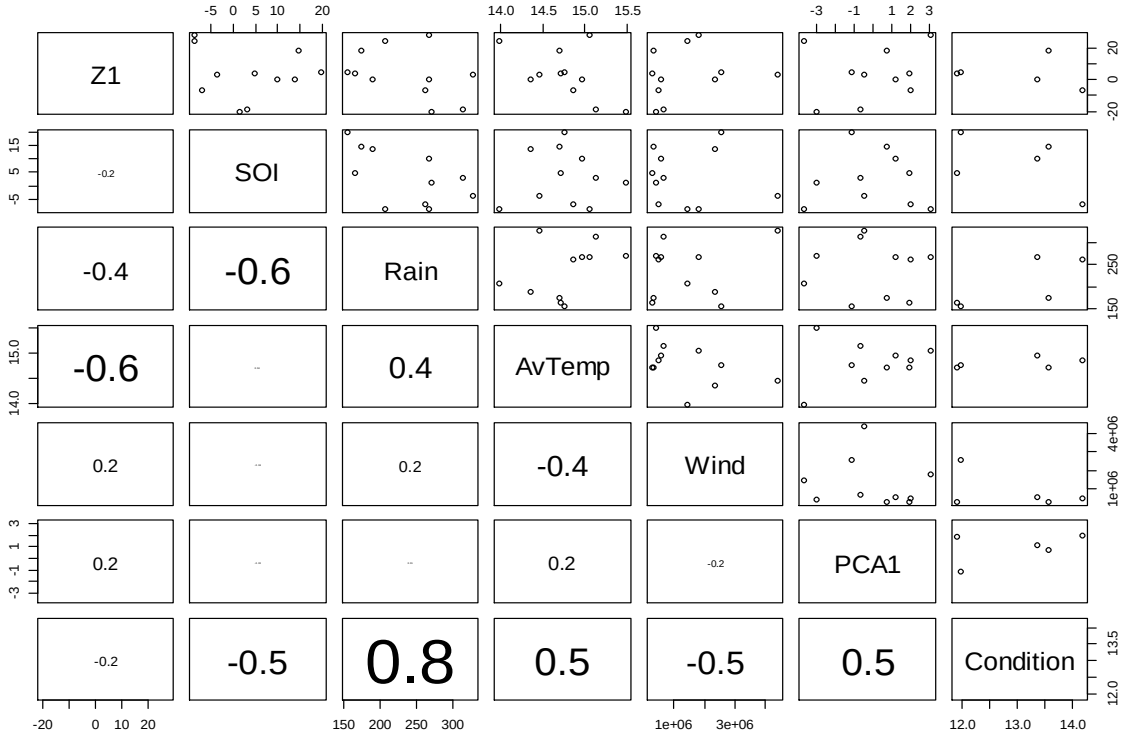


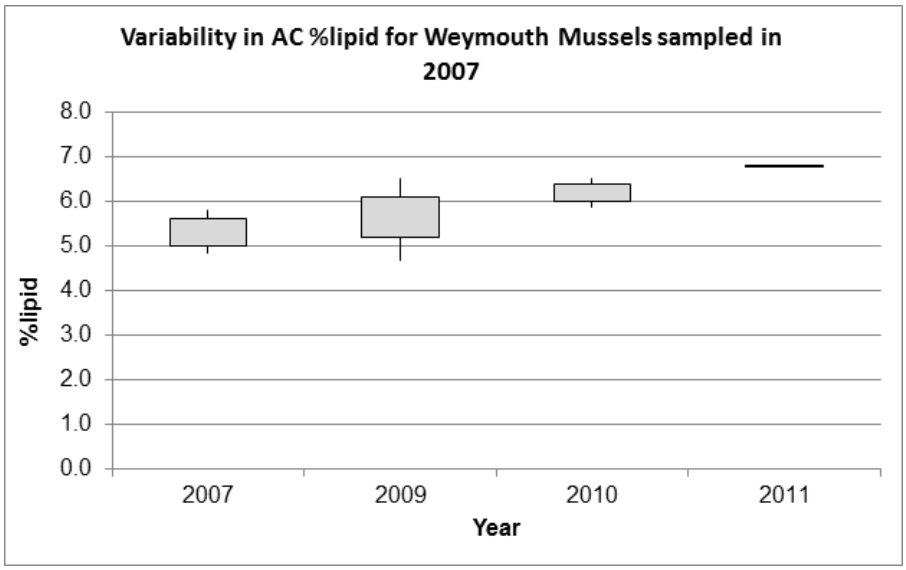
Figure Appendix 25. Correlation of climate variables with mussel PC1 score and condition index at Weymouth mussel site.

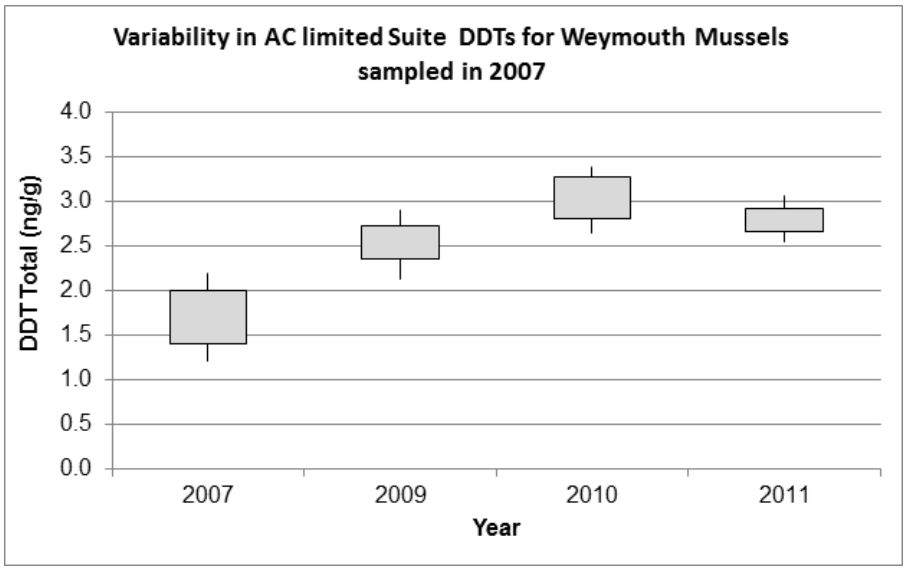
Appendix I Plots of Organic Contaminant QA Data

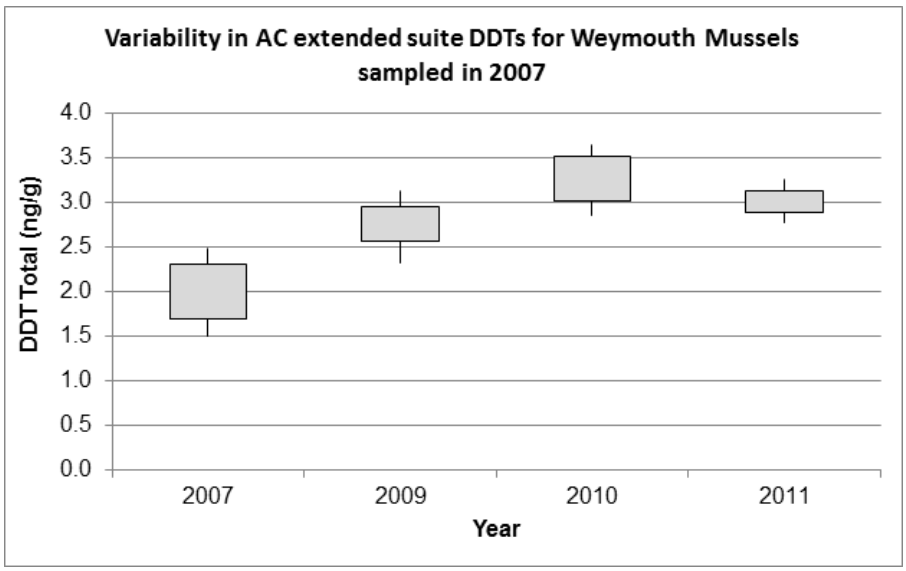
Overview

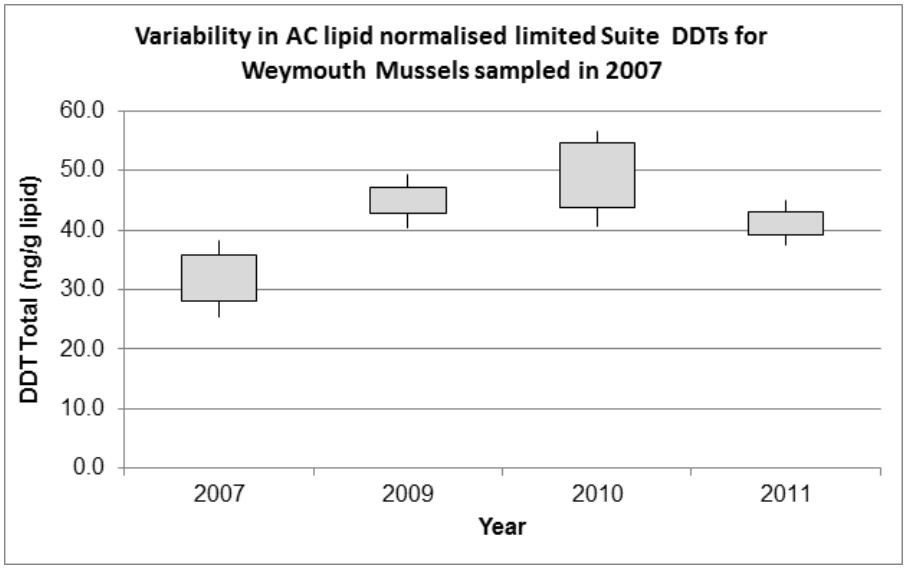
The plots provided show the maximum and minimum (box) and variance (whiskers) ± 2 standard deviations about the mean (95% confidence interval) for each set of data. Plots are based upon dry weight AC limited suites and extended suites (DL), lipid-normalised AC limited suites and extended suites (DL) for each organic contaminant group, i.e., %lipid, PAHs, PCBs, DDTs, chlordanes, dieldrin and hexachlorobenzene (HCB) for the period 2007, 2009, 2010 and 2011 for Weymouth bulk mussel tissue sampled in 2007. The suites are described in detail below.

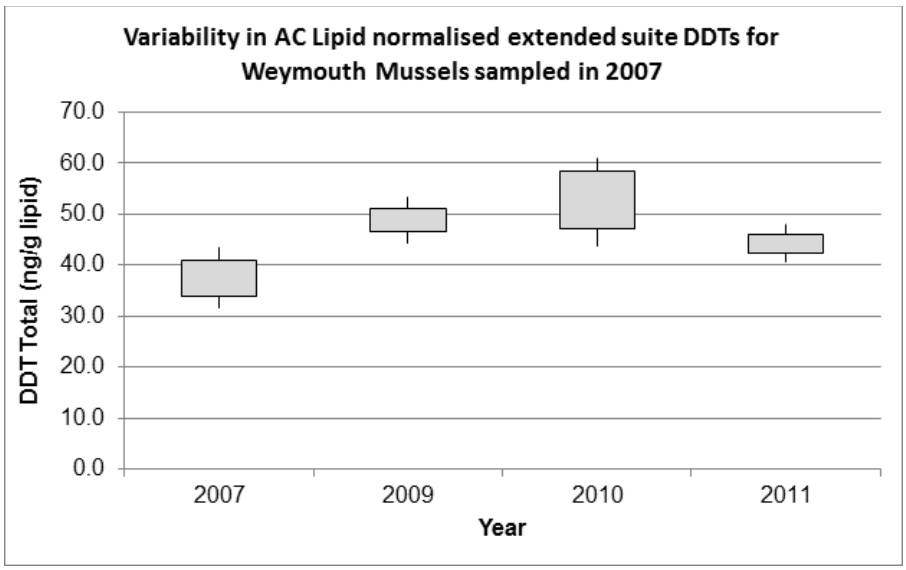
The plots provide a quick visual comparison of data sets and provide an indication of the variance in the data sets.

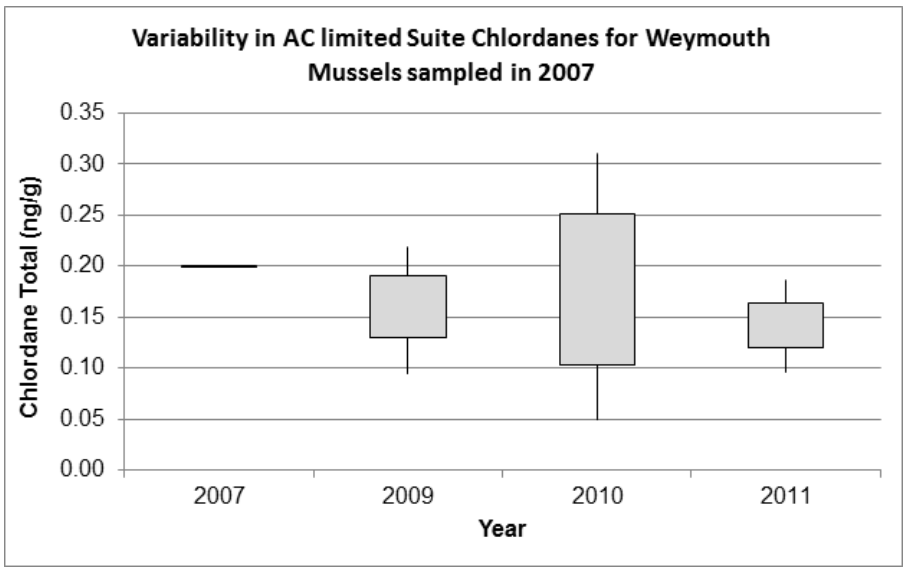


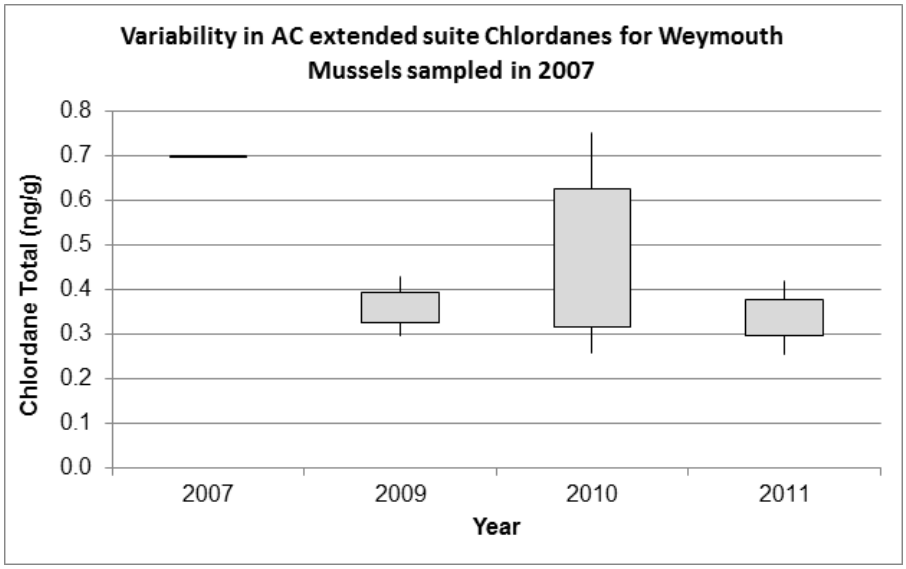


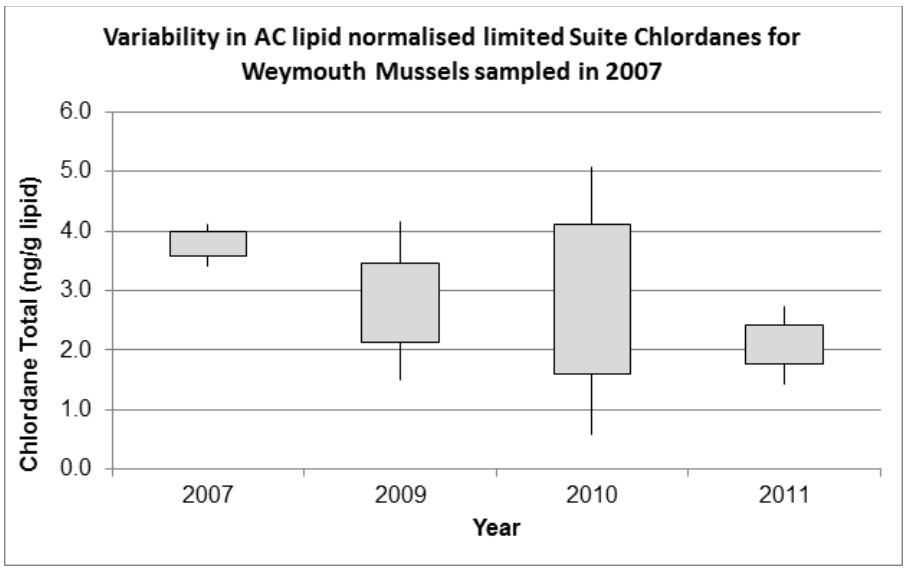

Variability in AC extended suite DDTs for Weymouth Mussels sampled in 2007
DDT Total (ng/g)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2007
2009
2010
2011
Year

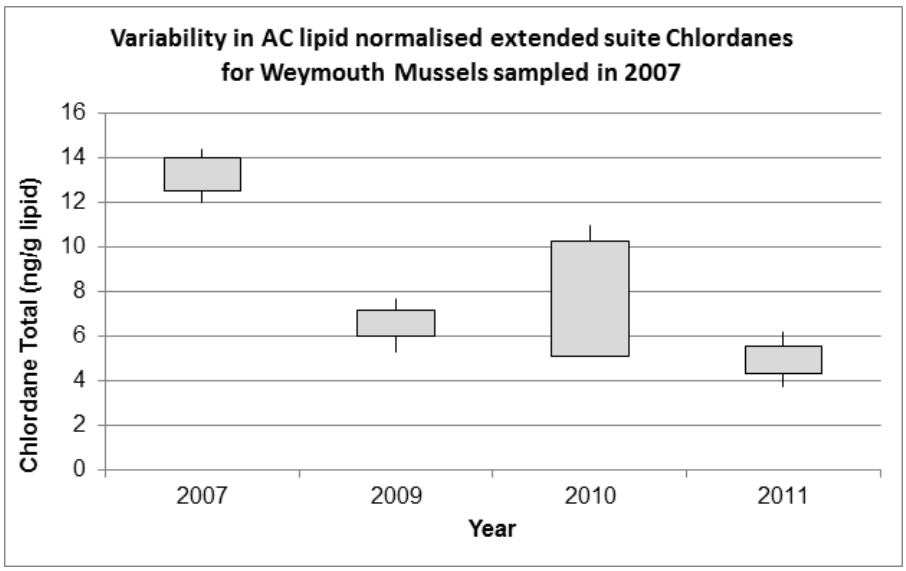

Variability in AC lipid normalised limited Suite DDTs for Weymouth Mussels sampled in 2007
DDT Total (ng/g lipid)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
2007
2009
2010
2011
Year

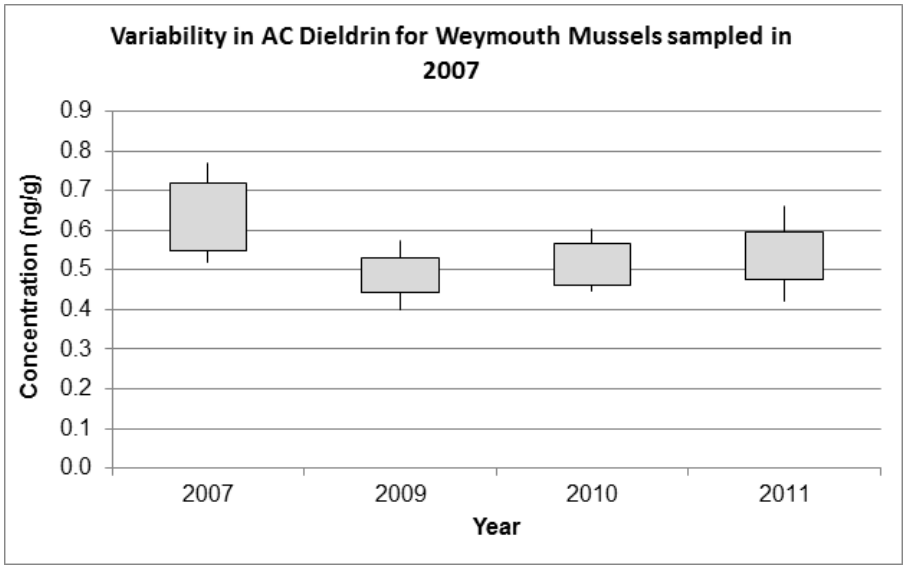

Variability in AC Lipid normalised extended suite DDTs for Weymouth Mussels sampled in 2007
DDT Total (ng/g lipid)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
2007
2009
2010
2011
Year

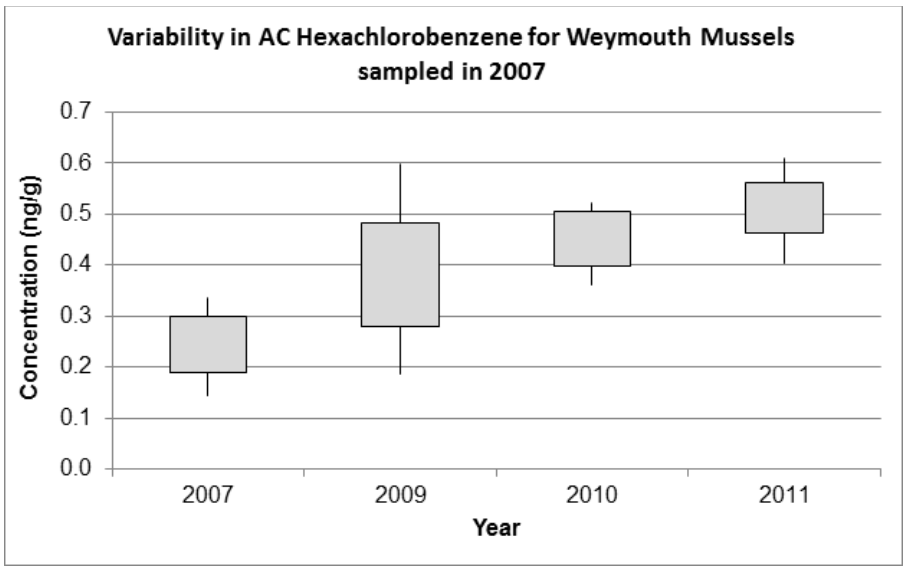

Variability in AC limited Suite Chlordanes for Weymouth Mussels sampled in 2007
Chlordane Total (ng/g)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
2007
2009
2010
2011
Year

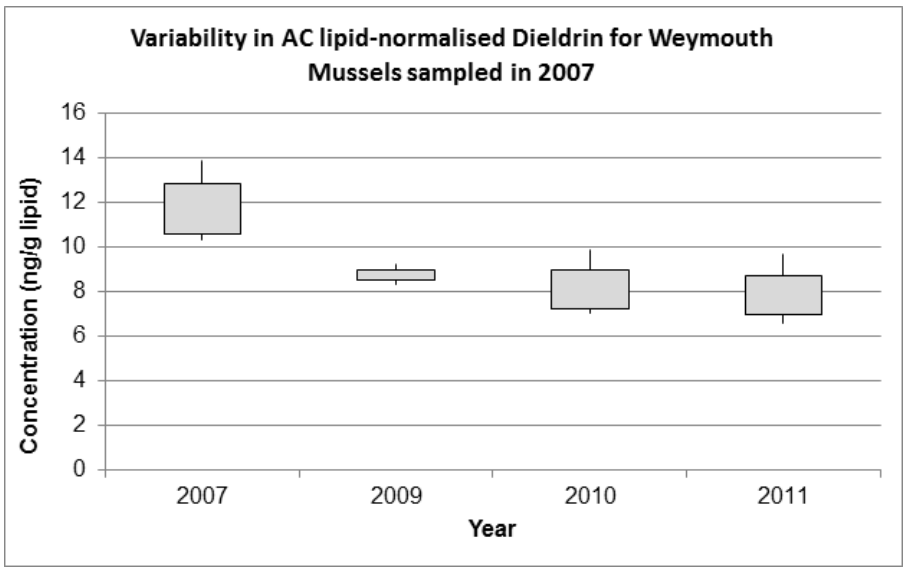

Variability in AC extended suite Chlordanes for Weymouth Mussels sampled in 2007
Chlordane Total (ng/g)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2007
2009
2010
2011
Year

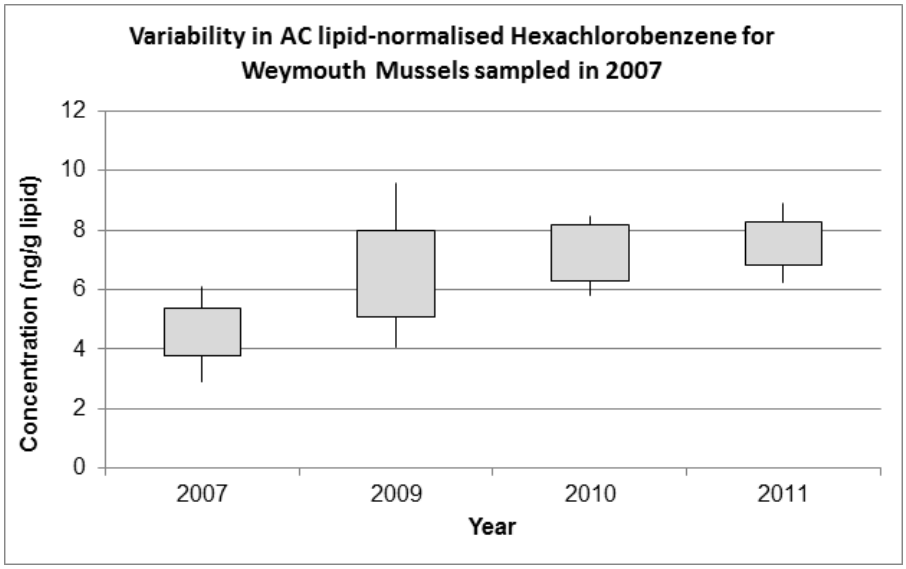

Variability in AC lipid normalised limited Suite Chlordanes for Weymouth Mussels sampled in 2007
Chlordane Total (ng/g lipid)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
2007
2009
2010
2011
Year

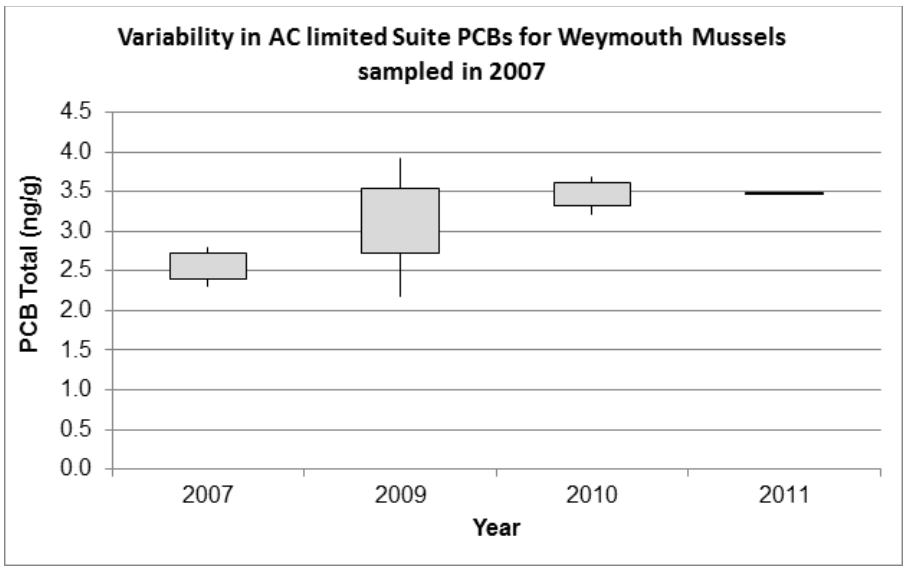

Variability in AC lipid normalised extended suite Chlordanes for Weymouth Mussels sampled in 2007
Chlordane Total (ng/g lipid)
16
14
12
10
8
6
4
2
0
2007
2009
2010
2011
Year

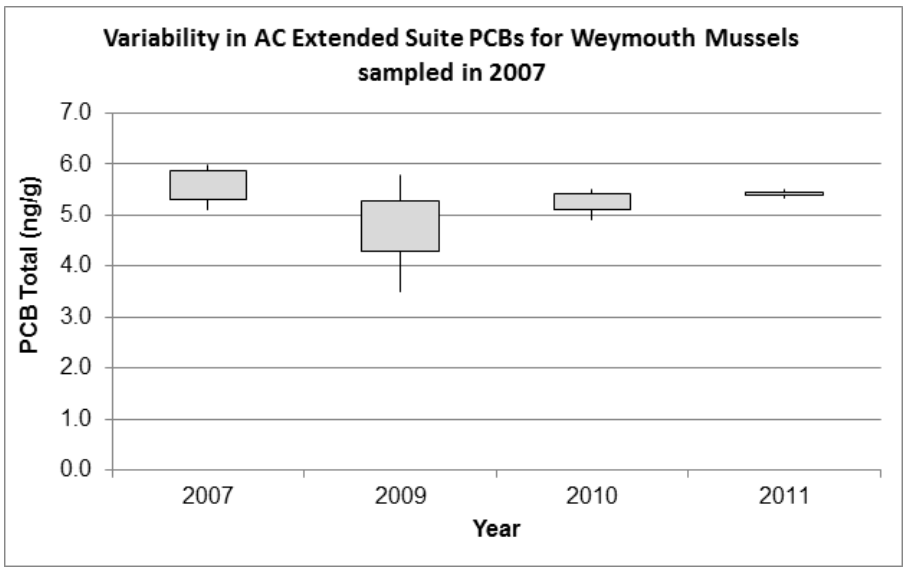

Variability in AC Dieldrin for Weymouth Mussels sampled in 2007
Concentration (ng/g)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2007
2009
2010
2011
Year

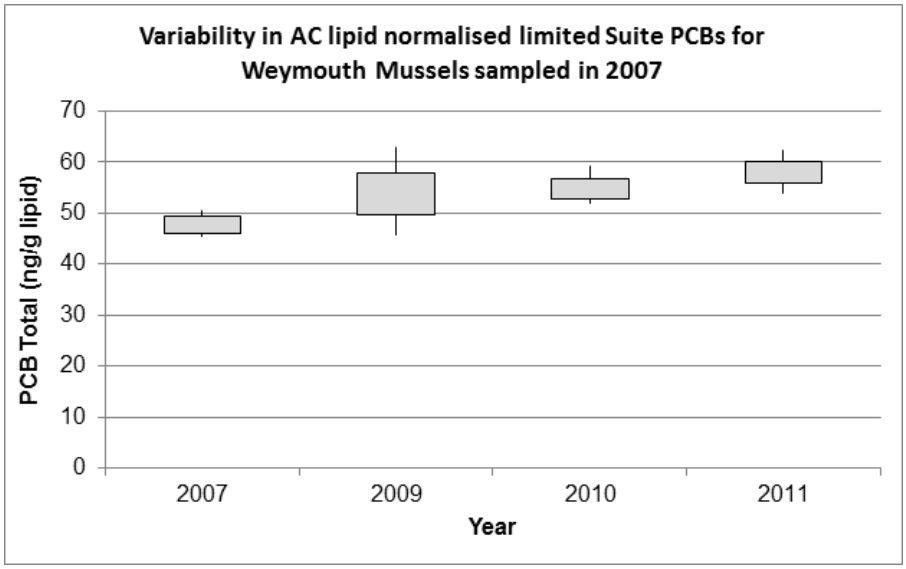

Variability in AC Hexachlorobenzene for Weymouth Mussels sampled in 2007
Concentration (ng/g)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2007
2009
2010
2011
Year

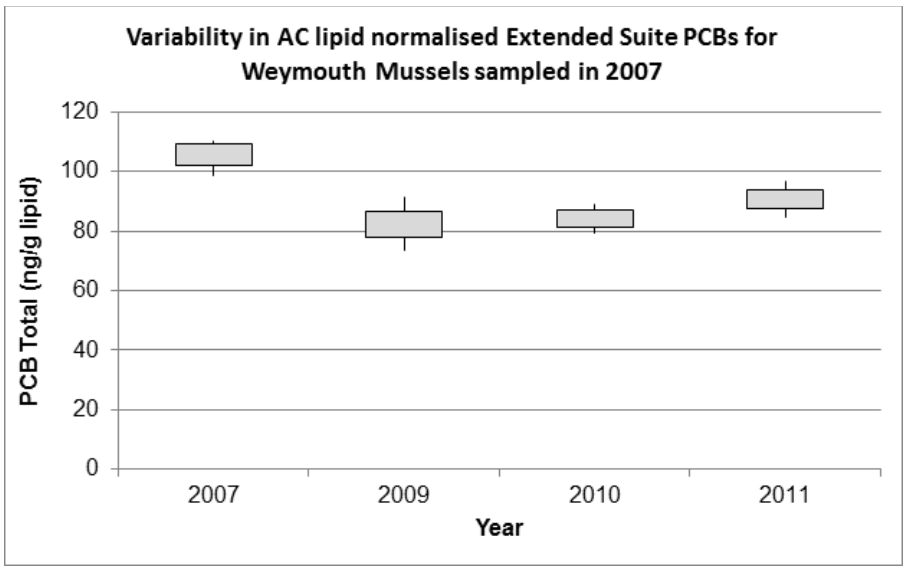

Variability in AC lipid-normalised Dieldrin for Weymouth Mussels sampled in 2007
Concentration (ng/g lipid)
16
14
12
10
8
6
4
2
0
2007
2009
2010
2011
Year

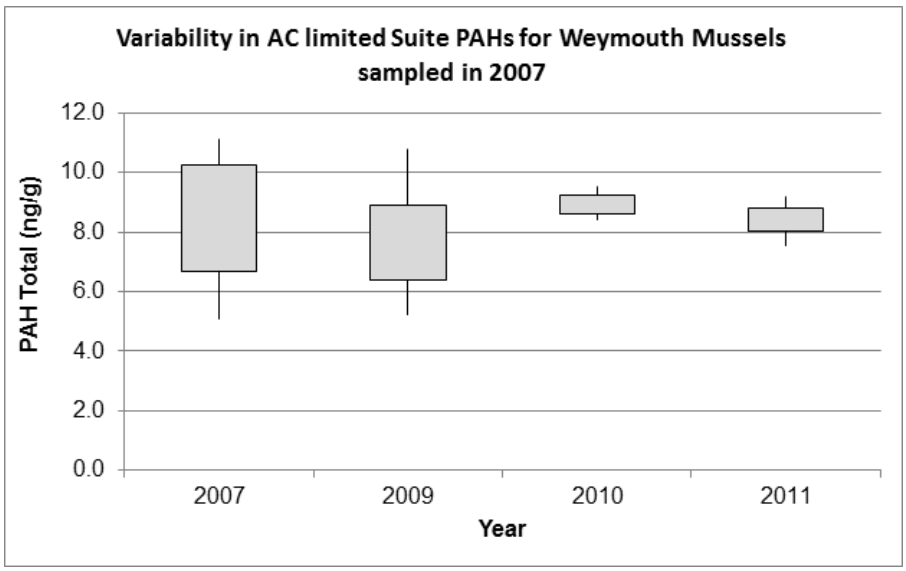

Variability in AC lipid-normalised Hexachlorobenzene for Weymouth Mussels sampled in 2007
Concentration (ng/g lipid)
12
10
8
6
4
2
0
2007
2009
2010
2011
Year

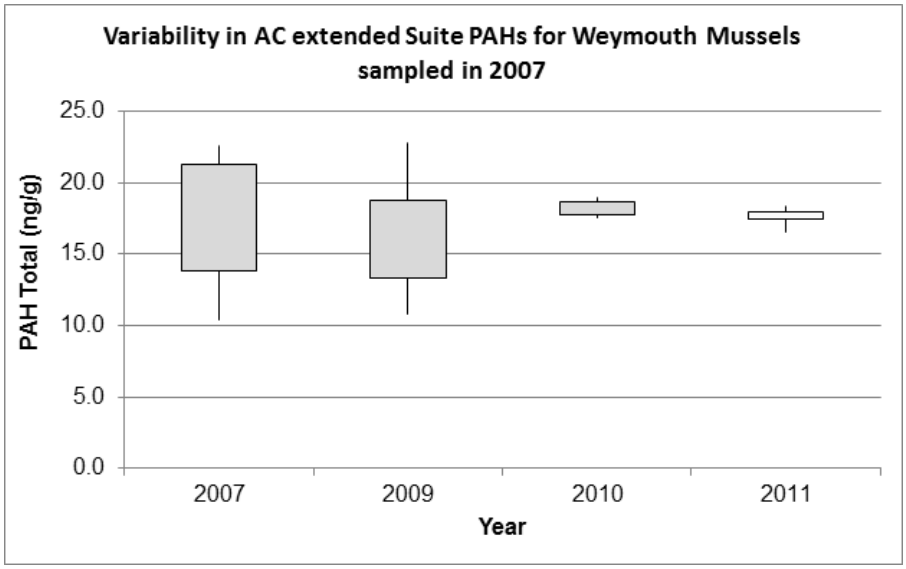

Variability in AC limited Suite PCBs for Weymouth Mussels sampled in 2007
PCB Total (ng/g)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2007
2009
2010
2011
Year

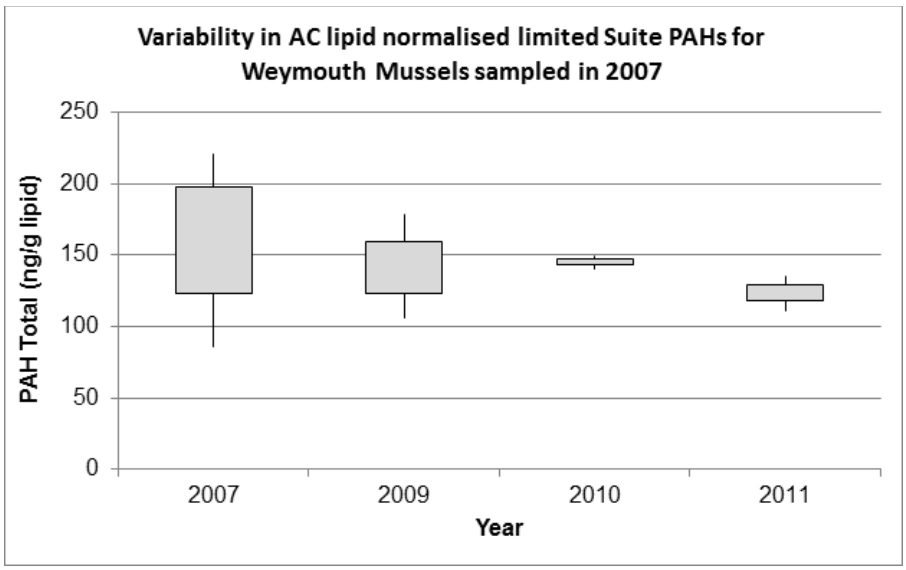

Variability in AC Extended Suite PCBs for Weymouth Mussels sampled in 2007
PCB Total (ng/g)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
2007
2009
2010
2011
Year

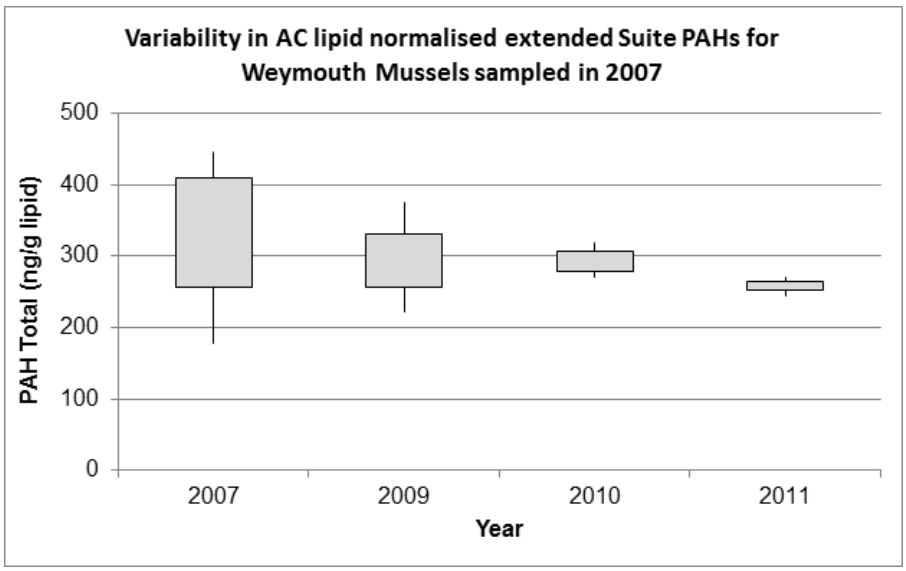

Variability in AC lipid normalised limited Suite PCBs for Weymouth Mussels sampled in 2007
PCB Total (ng/g lipid)
70
60
50
40
30
20
10
0
2007
2009
2010
2011
Year


Variability in AC lipid normalised Extended Suite PCBs for Weymouth Mussels sampled in 2007
PCB Total (ng/g lipid)
120
100
80
60
40
20
0
2007
2009
2010
2011
Year


Variability in AC limited Suite PAHs for Weymouth Mussels sampled in 2007
PAH Total (ng/g)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
2007
2009
2010
2011
Year


Variability in AC extended Suite PAHs for Weymouth Mussels sampled in 2007
PAH Total (ng/g)
25.0
20.0
15.0
10.0
5.0
0.0
2007
2009
2010
2011
Year


Variability in AC lipid normalised limited Suite PAHs for Weymouth Mussels sampled in 2007
PAH Total (ng/g lipid)
250
200
150
100
50
0
2007
2009
2010
2011
Year


Variability in AC lipid normalised extended Suite PAHs for Weymouth Mussels sampled in 2007
PAH Total (ng/g lipid)
500
400
300
200
100
0
2007
2009
2010
2011
Year