WHAT HAVE WE LEARNT FROM 14 YEARS OF MARINE SEDIMENT CHEMISTRY MONITORING IN THE AUCKLAND REGION?

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ABSTRACT

In 1998, the Auckland Regional Council (now Auckland Council) initiated a sediment chemistry monitoring programme aimed at assessing the spatial distribution of, and temporal trends in, key chemical contaminants across the region's urban estuaries, harbours, and sheltered open coast. Over the subsequent 14 years important lessons have been learned concerning factors such as QA procedures and reporting, consistency of methods and the influence of analytical variability. As a result the programme has recently undergone significant review and restructure and improvements have been achieved including the consolidation of three originally separate programmes. Substantial data analysis has been carried out and results (including trends) will be presented for copper, lead, zinc and polycyclic aromatic hydrocarbons (PAHs). Of particular interest is that the early patterns of linear increases in zinc and copper (and decreases in lead) have not necessarily persisted, and recent data illustrate that changes over time are more complex and variable than might have been expected. Consideration of other potential sources of contaminants (such as marinas) and implications for the ecological health of the marine receiving environment will also be discussed.

KEYWORDS

Contaminants, metals, sediment, monitoring, trends, marine ecology, marinas

PRESENTER PROFILE

Marcus completed his Masters in marine biology at Auckland University in 2005 and has been working in the environmental science field at Auckland Council since. Marcus' current role focuses on monitoring and researching the source, fate and consequence of contaminants in the marine environment.

1 INTRODUCTION

Sediments accumulate many chemical contaminants originating from land-based activities, and sediment contamination therefore provides a useful marker of land use impacts on aquatic receiving environments and ecosystem health.

In 1998, the Auckland Regional Council (ARC) initiated a sediment contaminant monitoring programme aimed at assessing the spatial distribution and temporal trends in key chemical contaminants across the region's urban estuaries, harbours, and beaches. Key objectives of this "State of the Environment" (SoE) monitoring programme were to assess the effects of catchment land use, in particular urbanisation, on marine environmental quality, and the effectiveness of resource management initiatives and policies in mitigating adverse effects arising from land use activities.

Subsequently, two additional programmes have been used to acquire sediment contaminant data: the "Regional Discharges Project" (RDP), and the "Upper Waitemata Harbour Benthic Ecology Programme" (UWH).

Briefly, these complementary programmes were as follows:

1. State of the Environment (SoE) marine sediment monitoring programme, covered 27 sites, monitored every two years since 1998. This programme aimed to provide long-term information on contaminant status and trends across the region;

2. Regional Discharges Project (RDP), which monitored an additional 51 sites, at 2–5 yearly intervals (depending on their contamination status; see Kelly 2007). Monitoring in the RDP began in 2002, and was administered by the ARC on behalf of the region's Territorial Local Authorities (TLAs). This programme was aimed primarily at monitoring the effects of stormwater discharges, as part of the TLA stormwater network discharge consenting programme; and

3. The UWH programme, which has monitored 14 Upper Waitemata Harbour sites annually over a 4 year period (i.e. 5 samplings), from 2005–2009 (inclusive). This programme provides specific information on the effects of urban development on the Upper Waitemata Harbour;

The locations of the sites monitored in these programmes are shown in *Figure 2-1*

In order to achieve efficiencies, cost savings and standardization of methods for Auckland Council the contaminant monitoring components of the SoE, RDP, and UWH programmes have recently been combined into a single programme, the "Regional Sediment Chemistry Monitoring Programme" (RSCMP).

Information collected in the RSCMP is available for a wide range of end users and stakeholders. Uses of the monitoring data include:

- State of the Environment reporting;
- stormwater quality management;
- resource consenting;
- policy development, and
- public education.

The RSCMP data complement those obtained in other AC programmes (Coastal Water Quality, Shellfish Contaminants, and Benthic Ecology), which together aim to provide consistent, long-term information on the quality of Auckland's coastal environment. This enables AC's performance, in respect to its resource management responsibilities for protecting the coastal environment from the effects of land use activities and contaminant discharges, to be assessed.

This paper summarises a larger report (Mills et al., 2012) which brought together sediment contaminant monitoring data collected in the three former contaminant monitoring programmes and analysed them to evaluate:

- Chemical contaminant "status" in Auckland's estuaries and harbours – spatial patterns of sediment contamination, and the potential impacts of this contamination on benthic ecosystem health, as inferred from comparison of contaminant concentrations with sediment quality guidelines;
- Temporal trends in contaminant concentrations between 1998 and 2010 (inclusive), focusing on changes over time in the concentrations of key indicators of urban contamination – the heavy metals copper (Cu), lead (Pb), and zinc (Zn), and polycyclic aromatic hydrocarbons (PAH).
- How temporal trends compare with modelling predictions in areas where modelling has been conducted and output data made available.

This paper also includes consideration of other sources of contaminants (such as marinas) as outlined further in Gadd and Cameron (2012).

Limiting the accumulation of contaminants over time in the receiving environment has been a key goal for stormwater management in the Auckland region. Contaminant accumulation trends provide feedback on the effects of land use practices and the effectiveness of management policies relating to land use and stormwater discharges. They also enable us to predict what the future may hold, in particular for potential impacts on the health of aquatic ecosystems.

Obtaining a clear, reliable, picture of contaminant trends over time is therefore critical to effective on-going resource management. Evaluation of temporal trends in marine sediment contaminant concentrations is therefore a focus of this paper.

2 MONITORING PROGRAMME METHODS AND ANALYSIS APPROACH

2.1 SITES

The locations of the sites monitored in the three programmes outlined in the introduction are shown in *Figure 2-1*.

Monitoring sites are spread across the range of catchment land uses and histories. However, because a key focus of the RDP programme was to manage the impacts of urban stormwater, most of the sites from this programme are located in areas receiving runoff from predominately urban catchments. Predominantly rural catchment sites are less represented, but include several in the Upper Waitemata Harbour such as Brighams, Paremoremo, Rangitopuni, and Rarawaru Creeks. Reference sites (rural catchments having very little urban activity and catchment land cover dominated by regenerating bush and/or pasture) include Te Matuku Bay on Waiheke Island, and Big Muddy Creek in the outer reaches of the Manukau Harbour.

The sites are located in the intertidal zone, and cover a broad range of sediment textures. Many sites are soft and muddy with a significant proportion of silt and clay (particles <63 μm) and very fine sand (63–125 μm). The dominant representation by muddy sites reflects the accumulation of fine sediment in many estuarine locations as a consequence of historical land development. These muddy zones are more likely to trap and accumulate contaminants, and hence they are useful as sentinel sites for assessing the effects of runoff from upstream catchments.

Firmer, sandier textured sites include the East Coast beach sites (Browns Bay, Cheltenham, Long Bay beaches at the Awaruku and Vaughan's Stream mouths), Mill Bay and Blockhouse Bay (Manukau Harbour), outer zone (OZ) sites in the main body of the Waitemata Harbour (e.g. Henderson Entrance, Meola Outer, Hobsonville, Herald Island), some locations in Hobson Bay (e.g. Hobson Newmarket) and Te Matuku Bay (Waiheke Island).

Sampling in the UWH programme is undertaken using a different protocol (Lundquist et al. 2010). Briefly, this involves collection of at least three replicate cores (5 cm diameter, 0-2 cm depth) from three random locations within the site. This generates 3 replicate samples, each sample made up from at least 3 sub-samples.

Figure 2-1 Site locations for the sediment contaminant monitoring programmes

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Location of sediment sampling sites and associated programme

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2.2 SAMPLING

Sampling at both the former SoE and RDP programme sites is carried out using protocols detailed in the monitoring "blueprint" document, ARC Technical Publication 168 (TP168, ARC 2004). Briefly this involves taking 5 replicate sediment samples, usually from a 50 x 20 m plot marked out at each monitoring site. Each replicate is made up from 10 sub-samples taken at regular intervals (approximately every 2 metres) along two designated longitudinal transects within the sampling plot. The sampling depth is 0–2 cm.

Generally, three of the replicates are analysed for metals (Cu, Pb, and Zn) and polycyclic aromatic hydrocarbons (PAH), while a single composite is used for particle size analysis. The remaining two replicates are kept frozen in case unusual results require checking. A portion of each of three replicates is also retained for long-term archiving. The archived samples are freeze-dried, sieved (<0.5 mm), and stored in glass jars.

Sampling frequency is biannual (i.e. every 2 years) at former SoE programme sites, and 2–5 yearly for former RDP programme sites – more highly contaminated sites are monitored more frequently than cleaner sites. UWH programme sites have been sampled annually from 2005.

Sample collection in the former SoE programme was generally undertaken in August while sampling in the RDP programme (and for SoE sites since 2009) was conducted in October. Sampling in the UWH programme has been undertaken in November each year.

The timing of the chemical contaminant sampling is not considered critical, because concentrations are not expected to vary greatly over relatively short time intervals (e.g. weeks-to-months), and the focus of the monitoring is long-term trends (several years-to-decades). In addition, samples are taken from the top 2 cm of the sediment profile. This provides an integrated mixture of freshly deposited material and older sediment from deeper in the profile, the sediments being mixed by biological (bioturbation) and physical processes. This mixing is likely to "smooth" out short-term variations in contaminant levels in the samples taken for analysis.

2.3 CONSTITUENTS MEASURED

The chemical contaminants and sediment physical properties monitored are described briefly below:

Extractable metals – copper (Cu), lead (Pb), and zinc (Zn) – are measured on the <63 µm sediment fraction using a weak acid extraction (cold 2 M HCl) which is intended to approximate the "reactive", and potentially more bioavailable, metal fraction.

Total recoverable metals – Cu, Pb, and Zn – are determined from hot, strong acid digestion (HNO_3/HCl, USEPA Method 200.2). Samples are analysed on the <500 µm (<0.5 mm) fraction, which approximates the total sediment. The total metal results are used to compare with sediment quality guidelines (SQG), which have generally been derived using metals' concentrations obtained via strong acid digests of total sediment samples.

Polycyclic aromatic hydrocarbons (PAH) and **total organic carbon** (TOC) are measured on freeze-dried, sieved (<500 µm) samples. TOC is used for calculating TOC-normalised concentrations, the units used for organic contaminant SQG (usually expressed as ng/g at 1% TOC). This reduces the variability associated with differences in the organic matter content between samples or sites.

Particle size distribution (PSD) has been determined by two different methods. The method used in the SoE and RDP programmes, up to 2008, was laser particle size analysis. Since 2009, PSD has been determined by wet sieving/pipette analysis (Lundquist et al. 2010). This is also the method used in ARC/AC benthic ecology programmes, including the UWH programme. The particle size distribution data are used primarily to assess whether there have been changes in texture over time (e.g. increasing muddiness) that may influence contaminant concentrations or affect benthic fauna; e.g. increasing amounts of fine muddy sediment could increase the total metals' concentrations and could change the benthic faunal assemblage.

2.4 GUIDELINES USED FOR STATUS ASSESSMENT

Contaminant concentrations were compared with sediment quality guidelines (SQG), using the ARC Environmental Response Criteria (ERC; ARC 2004) to provide an indication of the potential effects of these contaminants on benthic ecology. Those relevant to this paper are summarised in Table 2-1. The basis for these guidelines and their relationship to other SQGs is described in ARC (2004). Briefly the ERC are designed to provide early warning signs for management action and are linked to the more conservative guidelines for adverse effects on sediment dwelling (benthic) animals from contaminants in the sediment (the TEL and ERL shown below)

Table 2-1 Environmental Response Criteria (ERC) and associated sediment quality guidelines (SQGs). Units are mg/kg dry weight for copper, lead, and zinc, and mg/kg at 1% Total Organic Carbon (TOC) for high molecular weight polycyclic aromatic hydrocarbons (HWPAH).

	ERC (ARC 2004)[1]			MacDonald et al. (1996)		Long and Morgan (1990)		ANZECC (2000)	
Substance	Green	Amber	Red	TEL	PEL	ERL	ERM	ISQG-Low	ISQG-High
Copper	<19	19–34	>34	18.7	108.2	34	270	65	270
Lead	<30	30–50	>50	30.2	112.2	47	218	50	220
Zinc	<124	124–150	>150	124	271	150	410	200	410
HWPAH[2]	<0.66	0.66–1.7	>1.7	0.66	6.7	1.7	9.6	1.7	9.6

[1] Values for metals are for total recoverable metals in the <0.5 mm fraction in the settling zone (SZ), and the greater of the total recoverable metals in the <0.5 mm fraction or the weak acid extractable metals in the mud fraction (<63 µm) within the outer zone (OZ).

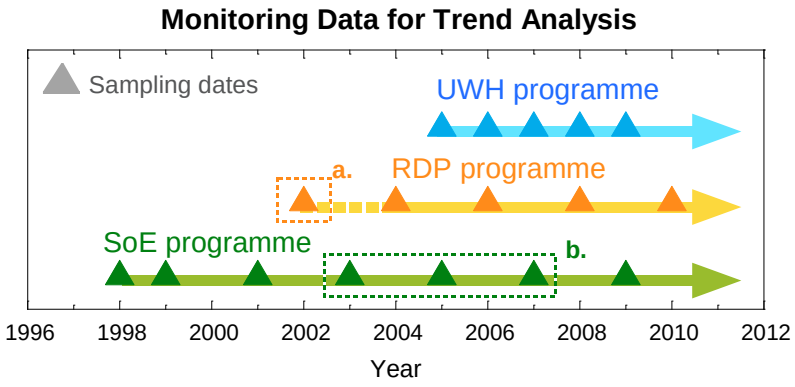
[2] Guidelines for organic contaminants are given in concentrations "normalised" to a sediment organic carbon content of 1%. High Molecular Weight (HW) PAH is the sum of the concentrations of benzo(a)anthracene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluoranthene and pyrene (as defined in ANZECC 2000).

2.5 APPROACH USED FOR STATUS ASSESSMENT

The latest available data for metals were used back to 2006 and for PAHs back to 2002 because PAHs have been monitored less frequently than metals. The median concentrations at each site were used for status assessment as they were deemed to be less affected by outliers at some sites. Overall, 81 sites were selected for status assessment.

2.6 APPROACH USED FOR TRENDS ASSESSMENT

All sites that had 4 or more sampling years, and data considered reliable enough, were included in the trends analysis (see Section 3.2.1 below for factors affecting the robustness of trend results). This equated to 51 sites for extractable metals analysis, 57 sites for total metals analysis and 39 sites for PAH analysis. No site had data from more than seven samplings available for analysis or a sampling record longer than 11 years so this represents relatively few sampling and a short data record for trend analysis. For this reason (and those outlined in section 3.2.1) the trend picture presented here should only be considered as 'emerging' and not be treated as definitive. A summary of the data used for trend assessment (broken down by programme) is outlined below.



a. 2002 data from RDP not used for trend analysis

b. Extractable metals in SoE excluded 2003-2007

Statistical analysis of trends was carried out using the non-parametric Mann-Kendall (MK) trend test. This is the most commonly used trend analysis method for environmental data. It does not rely on the data having any particular underlying distributional form (e.g. normality) and accommodates missing values and "less than detection limit" values well. The magnitude of the trend (or "rate of change") was obtained using the "Sen Slope Estimate" (SSE), another non-parametric test method. The SSE can be expressed in absolute concentration units per unit time (e.g. mg/kg/year) or in relative terms (e.g. as a percentage of the median concentration per year). The MK and SSE (or "Relative Sen Slope Estimate"; RSSE) were determined using the "Time Trends" software package (NIWA and Jowett Consulting, version 3.31). A trend was considered statistically significant if the MK test p values were $p<0.05$.

Trends (Sen Slopes) were divided into three groups for summarising the strength and possible real world significance of the changes.

- <±1% per annum change probably indicates no (or very little) trend. Changes in this range are unlikely to have any real world significance, and have been assigned as "no change";
- ±1–2% per annum indicates a small, or emerging, trend. Changes of this magnitude could be largely associated with analytical and/or sampling variation, so trends in this range may not have any real world significance. Trends in this range have been assigned as "possibly increasing/decreasing" trends; and
- >±2% indicates a stronger trend, equivalent to > ±20 % per decade, which is probably worth investigating further to better understand possible causes. These changes have been termed "probably increasing/decreasing" trends.

3 STATUS AND TRENDS RESULTS

3.1 STATUS RESULTS OVERVIEW

The spatial distribution of contaminants in sediments broadly followed the same patterns reported previously in ARC sediment contaminant monitoring reports (e.g. Williamson and Kelly 2003; Diffuse Sources 2004; Kelly 2007). Highest concentrations of the metals (Cu, Pb, and Zn) are generally found in the muddy upper reaches of estuaries receiving runoff from the older, intensively urbanised and/or industrialised catchments, particularly in the Tamaki Estuary and along the southern shores of the Central Waitemata Harbour. These areas also often display a gradient of contamination with higher levels of contaminants in upper estuary settling zones and a reduction in levels of contaminants as you move into adjacent lower estuary and harbour zones. Lowest concentrations are found in rural/forested catchment estuaries and on open coastal beaches.

Regionally, the proportions of monitoring sites included in the current status assessment with overall ERC status of Green, Amber and Red were as follows: These results are also summarised visually in *Figure 3-1*. Detailed results for individual contaminant status can be found in Mills et al. (2012).

- 41% of sites were rated as ERC Green (i.e. having no contaminants (Cu, Pb, Zn or HWPAH) exceeding the green/amber ERC threshold), reflecting a relatively low level of contaminant impact. At these sites, effects on benthic ecology from individual metals or PAH are considered unlikely to be significant. Note, however, that benthic health modelling has shown that subtle, but measurable, effects on benthic ecology may be occurring in the ERC green range (Hewitt et al. 2009).

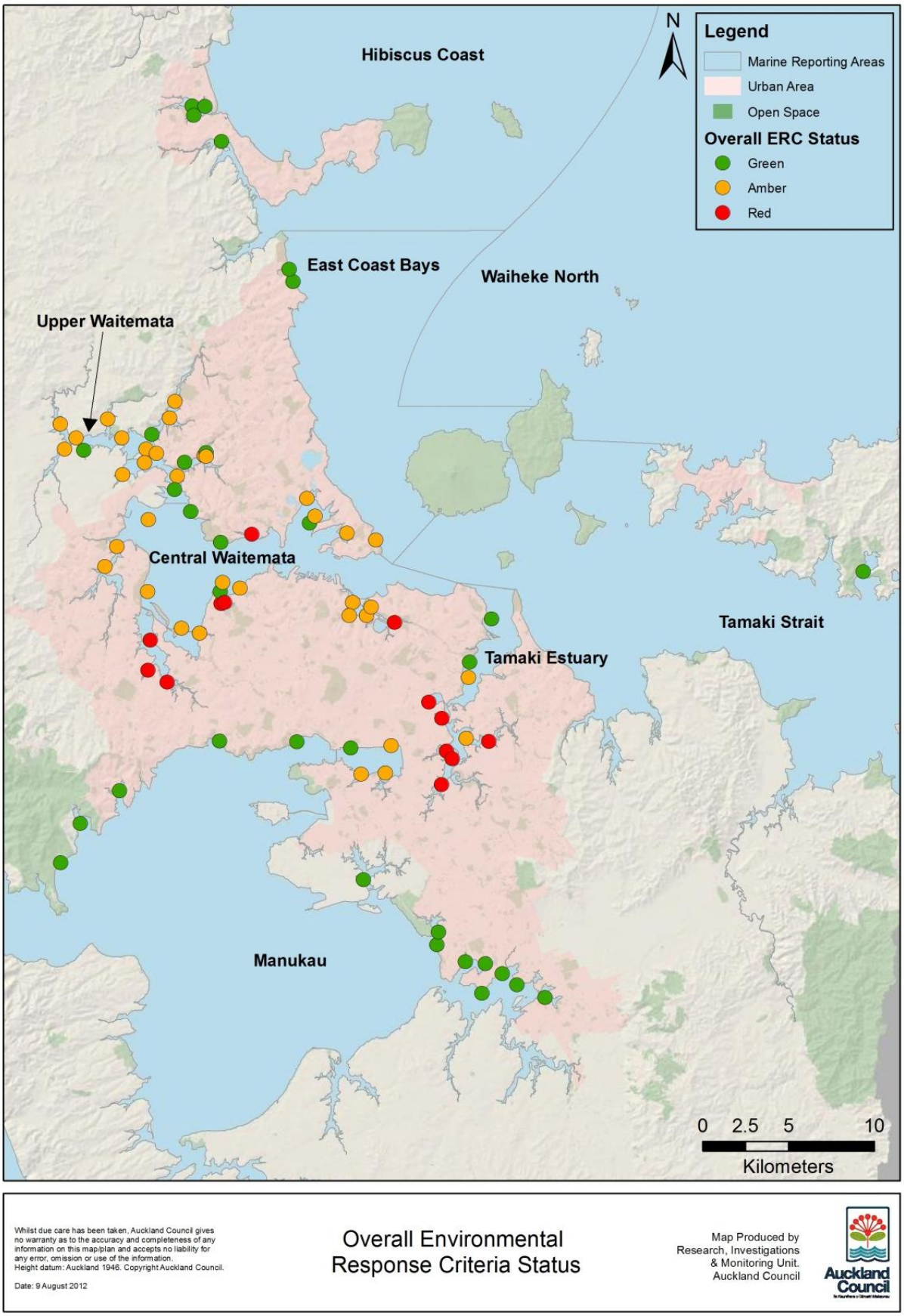
- Approximately 43% of the sites were in the ERC Amber range i.e. where at least one of the four contaminants falls in the ERC-amber concentration range. These sites are showing signs of chemical contamination, at levels where adverse effects on benthic ecology may begin to appear. Amber sites are widely distributed throughout the central and upper Waitemata Harbour, in Mangere Inlet, and in the Tamaki Estuary.

- Approximately 16% of the sites were rated as ERC Red i.e. where at least one of the four contaminants falls in the ERC-Red range. These sites are the most highly contaminated of the monitored locations. Adverse effects on benthic ecology would be expected to occur more frequently at these sites than at the less contaminated ERC Amber or Green locations. ERC Red sites were present mostly in the Upper Tamaki Estuary, and in the urbanised Central Waitemata Harbour catchment sub-estuaries.

Zinc was the metal that most often reached the ERC Red concentrations, while copper was in the ERC Amber range most frequently, followed by lead.

PAH concentrations at the majority of sites were well below the ERC Amber threshold, and are therefore considered unlikely, on their own, to be causing adverse effects on benthic ecology at most sites. However, it is possible that they may contribute to cumulative effects that might be associated with the presence of multiple contaminants. PAH concentrations were generally correlated with metals' concentrations. Motions and Meola estuaries (in the Central Waitemata Harbour) were notable exceptions, having unusually high PAH levels (indicating additional PAH sources to these estuaries).

Figure 3-1 Map of overall contamination status of sites based on combined Cu, Pb, Zn and PAH values. Colours refer to the ERC Criteria (see Table 2-1). <500 µm fraction metals' concentrations are compared with ERC for Settling Zone (SZ) sites while the greater of the <63 µm or <500 µm fraction data are used for Outer Zone (OZ) sites



3.2 TRENDS RESULTS

3.2.1 TREND ANALYSIS CAVEATS

There are a number of factors affecting the robustness of the trends results. The main factors affecting trend robustness are briefly detailed below and are covered in more detail in the full report (Mills et al., 2012)

- Data has been drawn from three different programmes with different monitoring periods and sampling frequencies and there have been relatively few, and variable, numbers of samplings (see the graphic in section 2.6). Therefore caution must be taken when comparing trend results between the programmes. Furthermore, because the number of samplings is small, any trends measured may be sensitive to the effects of additional data.

- A variety of sampling and analysis providers and methods have previously been used in the three programmes. Use of multiple providers and methods is acceptable, provided that quality assurance (QA) data is obtained to verify that comparable results are obtained by the various approaches used. While QA data have been acquired within each of the programmes and the sampling and analysis methods are generally very similar, the comparability of the results obtained by the various providers and methods is still not known. Since 2009 however, most aspects of the programmes have been standardized.

- Exclusion of some extractable metals' data from the SoE programme: The data record for the SoE programme sites was reduced for trend assessment by exclusion of extractable metals' data from samplings conducted in 2003, 2005, and 2007, because of quality assurance issues associated with the results from these years. Details are to be provided in the programme review report (Diffuse Sources, in prep.).

- Analytical variability: A full assessment of the influence of analytical variability on laboratory results is currently being undertaken as part of the programme review (Diffuse Sources, in prep.). However the results reviewed to date indicate that differences in individual sample metals' concentrations between years of less than about ±20% could largely be due to analytically-sourced variability. This is just a general rule but monitoring results need to be considered in this light.

Some of these issues have already been addressed and changes made for future monitoring. Approaches for dealing with the remaining issues will be discussed in a programme review report to be released later in 2013 (Diffuse Sources, in prep.).

3.2.2 TREND RESULTS OVERVIEW

Trends over time in metals' and PAH concentrations across the region were generally small, and, on average, few large changes have occurred over the monitoring period. However, decreases in Pb concentrations have been recorded at most urban sites, which may reflect the effect of removal of Pb from petrol (a key source of Pb) in the mid-1990s. Trends in Cu and Zn were more variable, with no obvious consistent pattern among sites. However, where significant changes in Zn concentrations have occurred, these were mainly increases. This supports a commonly held view (which is generally consistent with modelling predictions) that Zn concentrations are likely to increase over time at most urban sites. *Figure 3-2* provides an overview of trend results for Cu Pb and Zn. There were few significant trends observed for PAHs. Trends at rural and reference sites were predominantly flat and not statistically significant, which was expected for these sites.

While statistically significant trends have been measured at some sites, definitive conclusions regarding the real-world significance of these trends cannot be made at this stage. This is because of:

- Uncertainties associated with the analytical data. In particular, a lack of "benchmarking" over time prevents us from assessing whether the observed trends are real, or if some component of the trends is due to analytical variation over time. As a result of the trend assessments carried out in this project, improved benchmarking measures have been added to the monitoring programme's quality assurance protocols. These are detailed in a separate review of the sediment chemistry monitoring programme (Diffuse Sources, in prep.).

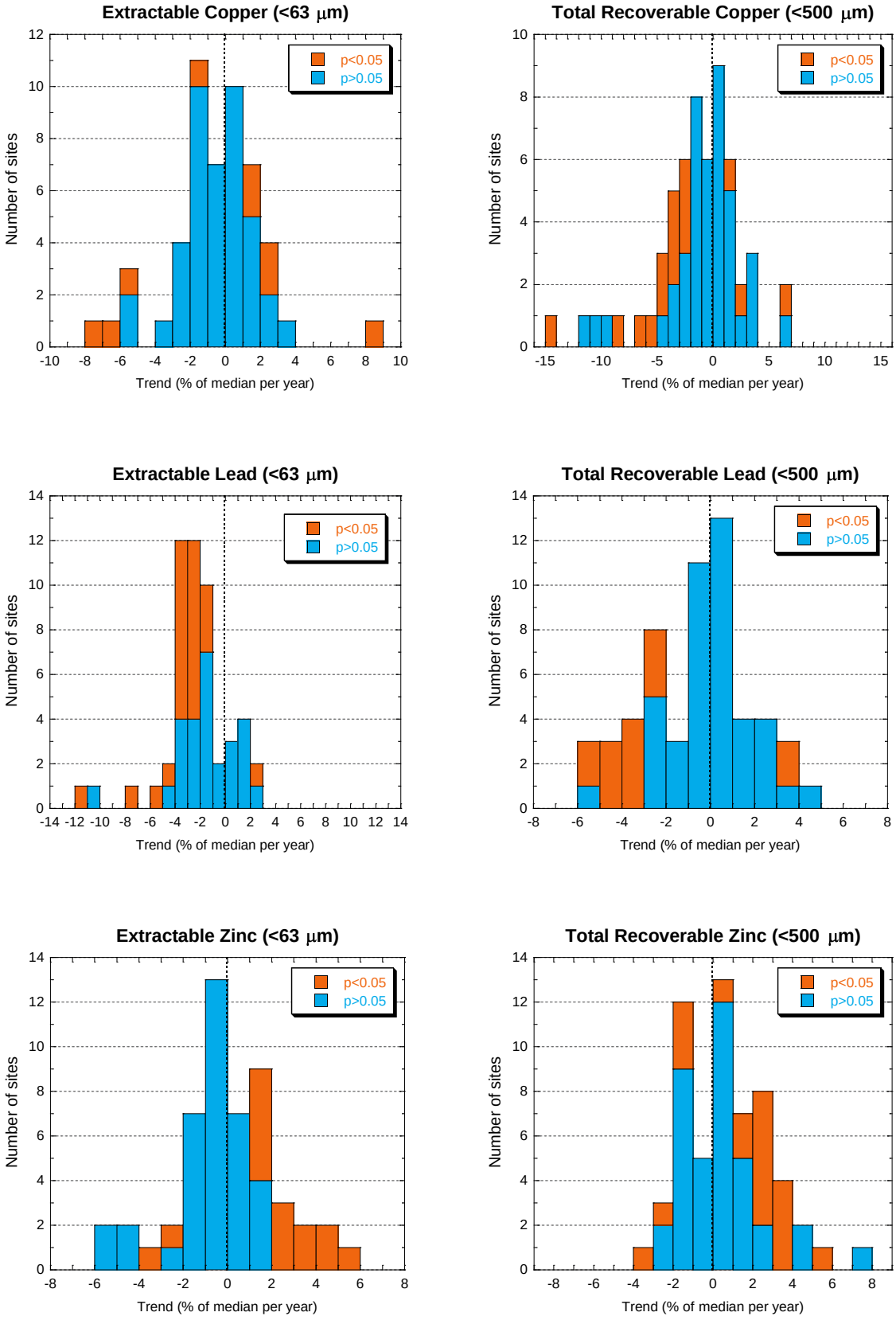
- The relatively short length of time that the monitoring programme has so far been conducted, and the small numbers of samplings at many sites. A more robust picture of trends will emerge as the trend record grows with future monitoring.

In regard to spatial patterns in trends the overall picture for Pb is one of generally decreasing trends in urban estuaries, particularly in the older developed catchments of the Central Waitemata Harbour, Tamaki Estuary, and Mangere Inlet. Zn appears to have increased in the Whau Estuary (Central Waitemata Harbour) and the Tamaki Estuary, decreased in Mangere Inlet, and mixed changes have occurred elsewhere. Overall, increases in Zn have outnumbered decreases, but the spatial picture is not yet convincingly clear. For Cu and PAHs there was no consistent spatial pattern of trends. Detailed trend data, plots and maps on a site by site basis are provided in Mills et al. (2012)

Despite some issues with data quality and QA the predominantly stable results from rural and reference sites (where no significant changes would be expected) and the confirmation of expected decreases in Pb across most sites (and possibly increases in Zn)

provides assurance that the programme to date is robust and capable of detecting large scale trends across the region. Improvements to the programme already implemented, and further recommendations arising from the programme review report currently underway (Mills et al., in prep), should provide greater ability to detect trends and increased robustness of the programme going forward.

Figure 3-2 Distribution of trends (Relative Sen Slope; % median per year) in metals showing statistically significant results in orange (p<0.05) and non-significant results in blue (p>0.05).



4 MODELLING VS. MONITORING RESULTS

Changes in Zn and Cu concentrations over time have been predicted from computer modelling in a variety of locations across Auckland's estuaries. A summary of these data as average trends for the period 2001 to 2011are presented in *Figure 4-1*. These results show that Cu and Zn concentrations are predicted to increase over time, at varying rates, at most sites. Near-zero rates of change have been predicted for primarily rural estuaries, for example Paremoremo and Brighams estuaries (Upper Waitemata Harbour).

In theory, the modelling predictions could be compared with the sediment chemistry monitoring results to provide benchmarking of the modelling predictions, or alternatively a check on the robustness of the monitoring results. Increased confidence in trend results, either measured or modelled, would result if the two lines of evidence produced a similar picture of trends at a range of locations.

Comparing the modelling and monitoring results is not, however, straightforward. Reasons include:

- The scale of sites/locations/areas sometimes differs between the modelling studies and monitoring.
- The nature and assumptions of the modelling procedures means that modelling predicts very broad long-term changes and not short-term changes as observed in the monitoring.
- Models make many simplifications and assume relatively simple conditions of transport and deposition over very broad regions. Monitoring will reflect all the processes occurring in the environment, and may be picking up more complex short-term and small-scale processes.
- As described earlier, monitoring data may be susceptible to potential errors (including those arising from laboratory analysis, monitoring design and implementation and data analysis) as well as real environmental variability. Modelling "smoothes out" all the variation, but may also contain inherent errors in terms of the assumptions built into the models.

Therefore, taking these differences into account, at this time we should only compare modelling and monitoring in a general way, using an "order of magnitude" context. Such a general comparison reveals:

- The changes predicted by modelling and monitoring are of a similar order of magnitude and both are relatively small. This is an important result – the modelling

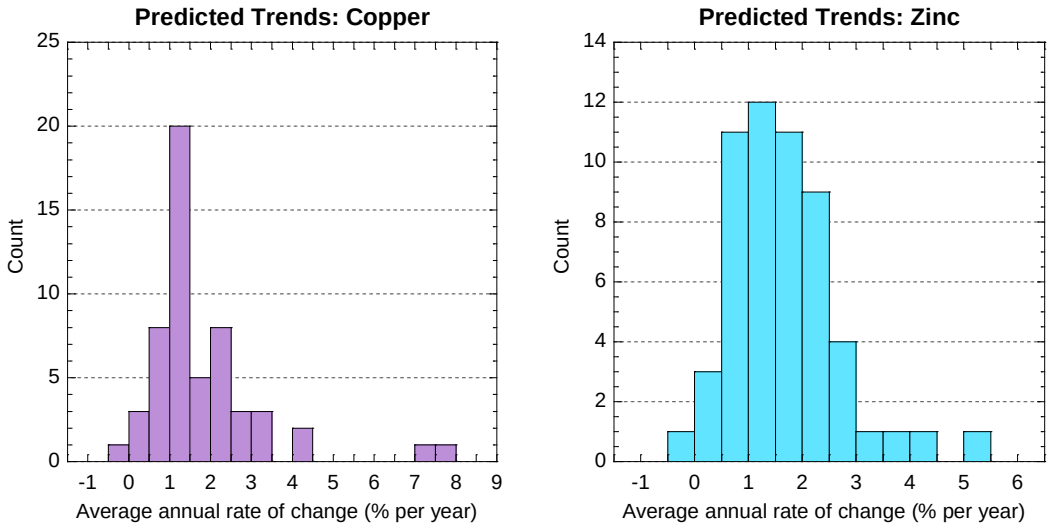
and monitoring results are generally consistent in that predicted and measured rates of change are mostly small.

- While there is general agreement, modelling predictions and monitoring trends do not show consistent agreement at all sites. However, given the uncertainties associated with both the monitoring and modelling, this is probably not unexpected.

- In predominantly urban estuaries, modelling predicts increasing trends. In contrast, monitoring sometimes shows decreases in concentrations, especially for Cu. This difference is rather interesting, but it would not be sensible to make conclusive comparisons until a longer monitoring record is obtained – many of the negative trends measured from monitoring may yet be due to data variability (e.g. analytically-sourced changes). It is also possible that this may be highlighting some shortcomings in the models, which do not include processes that lead to decreases in concentrations in sediments.

Overall, the modelling results predict relatively small changes over the monitoring period. Monitoring has also generally found this – overall, trends are mostly small. A longer monitoring period, and possibly more accurate monitoring data, are required before comparisons at each site can be made with confidence. More robust comparisons of modelling and monitoring results would also require additional surveys to obtain sediment contaminant data over spatial scales consistent with modelling predictions.

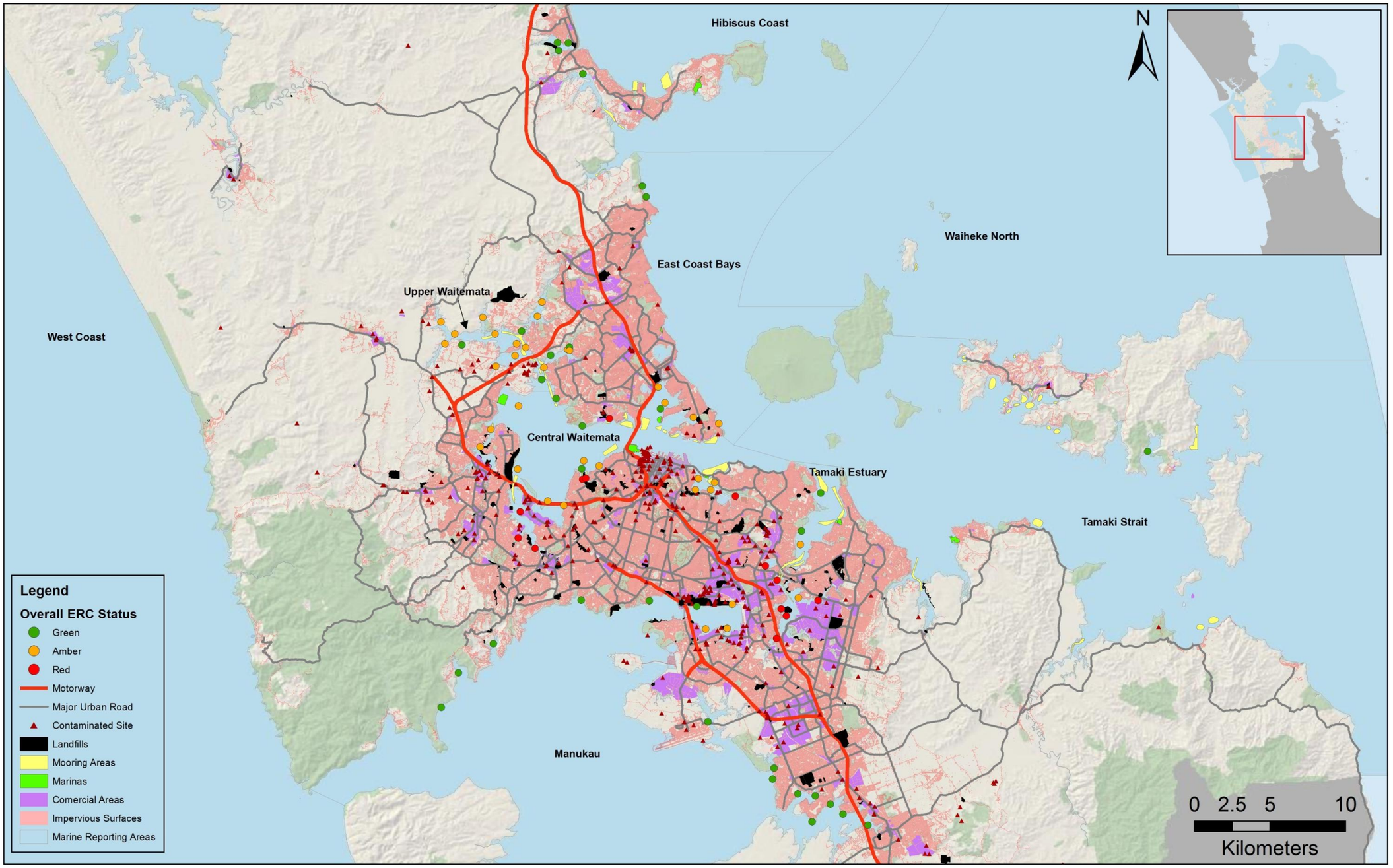
Figure 4-1 Trends in Cu and Zn predicted from contaminant accumulation modelling



5 POTENTIAL SOURCES OF CONTAMINANTS

A wide range of potential contaminant sources may influence the levels and spatial distribution of contaminants present in Auckland's marine receiving environment. These include urban stormwater (the major "diffuse" pollution source from the urbanised land area), runoff from current and historic horticultural land, landfill leachate, contaminated sites, industrial processes, marinas, and boat mooring areas. The distribution of some of these potential contaminant sources and the overall contaminant ERC status of the monitoring sites is shown in *Figure 5-1*. However, it is important to note that the current study did not carry out a comprehensive analysis of potential sources of contaminants or their transport and fate. Therefore, factors such as catchment characteristics, point source discharges, land use change, management initiatives, hydrodynamics and any associated changes in ecological health should be taken into account when interpreting results for individual sites. For example a recent study by Gadd and Cameron (2012) estimated copper loads being exported from Auckland marinas as a result of leaching from antifouling paints on vessel hulls and concluded that as much copper could be being exported from the four marinas in the Waitemata Harbour as is coming from stormwater for the entire Waitemata Harbour catchment (see *Figure 5-2*).

Figure 5-1 Potential contaminant sources contributing to metal and PAH contamination of Auckland's marine receiving environment. Monitoring sites and their ERC grades are shown.



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Potential contaminant sources and location of sediment sampling sites

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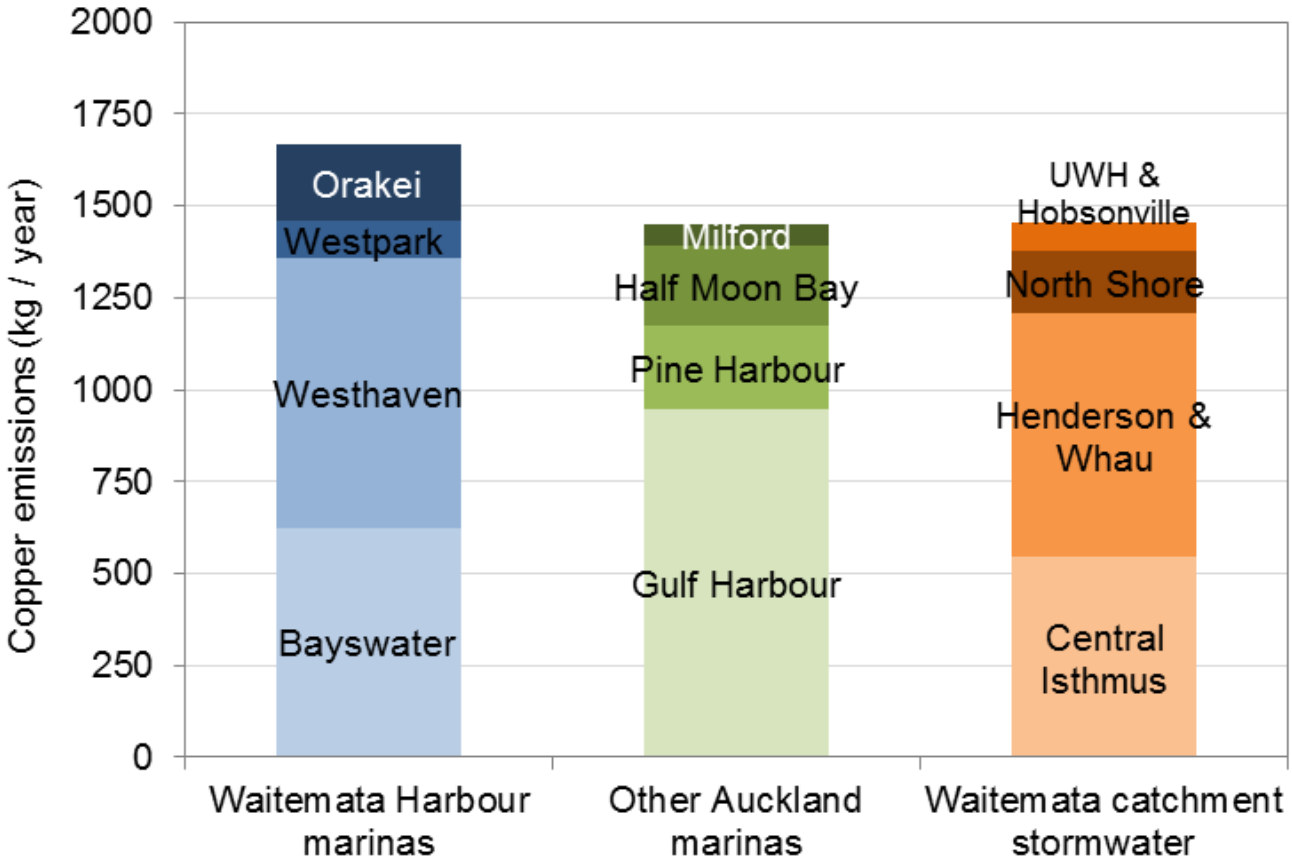
Figure 5-2 Comparison of copper loads estimated to be exported from Auckland marinas with those from stormwater discharges in the Waitemata Harbour catchment.



6 CONCLUSIONS

Despite some issues associated with monitoring data quality (variability and uncertain consistency over time), the sediment contaminant monitoring programmes have delivered a wealth of useful information on the spatial distribution and general trends in key urban contaminants in Auckland's marine sediments.

The monitoring data clearly identify areas with differing levels of contamination, and now provide a comprehensive spatial picture of contaminant levels in the Auckland coastal zone. This has provided a better understanding of the impacts of land use on receiving environments, and (via integration with ecological health monitoring and modelling) the potential ecological impacts of this contamination. An updated ecological assessment, using the Benthic Health Model (BHM), is to be reported separately in 2013 (Hewitt et al., in prep).

The overall picture obtained from trend analysis is that while there is considerable complexity (with differences between sites, contaminants, and programmes), broad-scale changes in sediment contamination by metals and PAHs since 1998 have generally been

small. A decrease in Pb concentrations at most urban sites has been measured, which may reflect the beneficial effect of removal of a key Pb source (leaded petrol) in the mid-1990s. Trends in Cu and Zn were more variable, with no obvious consistent pattern among sites. Where significant changes in Zn concentrations have occurred, these were mainly increases. However, it is important to note that the current study did not carry out a comprehensive analysis of potential sources of contaminants or their transport and fate. Therefore results should be interpreted in the context of the individual site and its catchment. Factors such as point source discharges, land use change, management initiatives, hydrodynamics and any associated changes in ecological health should therefore be taken into account.

The data analysis conducted in this status and trends review has also improved our understanding of the capabilities and limitations of current sediment contaminant monitoring methods. This information is being used to improve the quality of future monitoring data, and hence provide greater certainty for future trend assessments.

Overall, the sediment contaminant monitoring data analysed in this project indicate that the spatial patterns of contamination are broadly the same as reported previously, and that contaminant concentrations in most areas have not changed greatly since 1998. This picture is generally consistent with modelling predictions, and provides some reassurance that rapidly increasing contamination in Auckland's estuaries, as a result, for example, of stormwater discharges, is not a widespread occurrence. However, because of uncertainties associated with the monitoring data, continued monitoring is recommended to provide greater surety in future trend assessments. Furthermore, continued monitoring will allow the success of current and proposed contaminant discharge and land use management policies to be appropriately evaluated.

7 FURTHER INFORMATION

This paper summarises elements of a much wider report on the status and trends of marine sediment contaminants in the Auckland region (Mills et al., 2012). The Mills et al. (2012) report expands on the information provided here and also includes information on other metals (Arsenic, cadmium, mercury, antimony, and tin) as well as providing individual site reports for 110 sites across the region. Further information and results from freshwater and marine monitoring in Auckland can also be found in the State of Auckland report cards at http://stateofauckland.aucklandcouncil.govt.nz/

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