Responses in estuarine macrobenthic invertebrate assemblages to trace metal contaminated sediments

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This thesis is submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in Applied Science (Environmental Chemistry).

University of Canberra

May, 2005

In any general discussion of structure, relating to an isolated part of the Universe, we are faced with an initial difficulty in having no a priori *criteria as to the amount of structure it is reasonable to expect. We do not, therefore, always know, until we have had a great deal of empirical experience, whether a given example of structure is very extraordinary, or a mere trivial expression of something which we may learn to expect all the time.*

G.A. Hutchinson, 1953

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Anthony A. Charriton

17/5/05

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Date

Acknowledgments

This thesis, and the research from which it is founded, would not have come to fruition without the assistance, advice, support, skill and intellect of numerous people.

To my primary supervisor, mentor and friend Prof. Bill Maher, I thank you for your interest in my research and career, and the support you have provided throughout my academic life. You have continually permitted and supported my diverse interests, and have always endeavoured to find a way for me to continue my interests, both academically and financially. I also wish to thank you for your assistance in the field and, the 'open door' policy to queries and problems, and for your after hours commitment. I apologise for the hair loss, greying and any chronic health problems that I may have attributed too. However, your grievances about my effects on your health are correlative, and hence, unsubstantiated.

To my supervisor Dr Tony Roach (NSW Department of Environment and Conservation), your knowledge of marine ecology and biometry has been pivotal in both this project and my career as a whole. I appreciate all the time you have made available, your attention and detail in refining the chapters, and your overall commitment to the project. Finally, I wish to thank you for your continual support of my professional career, and the guidance you have provided.

I wish to express my gratitude to my collaborators and colleagues at the CSIRO Centre for Environmental Contaminants Research: Dr Graeme Batley, Dr Stuart Simpson, Dr Jenny Stauber and Dr Simon Apte, and Dr Catherine King. It has been both and honour and pleasure to work with the group, and to be able to tap into their vast wealth of knowledge. I would especially like to thank Dr Graeme Batley for his guidance and unconventional approach to multi-disciplined problems. I am also most grateful to Dr Stuart Simpson for his skills and knowledge in trace metal biogeochemistry, advice on sediment spiking and his patience in teaching me various analytical skills. Thank you to Dr John Chapman, Dr Ross Hyne and Ms Sharyn Gale from the NSW EPA, it has been a pleasure to work with you all.

My deepest thanks go to Frank Krikowa (University of Canberra) who developed the analytical technique for the trace metal analysis of the porewaters, and who performed a vast majority of the analysis. I appreciate all the time, effort and skill which went into the method development. As per usual, I would be lost without your help.

I would especially like to thank my fellow environmental chemistry post-grads Simon Foster, Jason Kirby and Daniel Spooner for their commitment to my field work and assistance in the laboratory. I appreciate that you all had your own research to complete, and that field conditions were often less than desirable – however, we still always had a great time. I would need to write another chapter to thank you individually for all that you guys have done.

A special thank you to Dr Dianne Jolley (University of Wollongong), who initially directed me towards environmental chemistry and marine sciences, assisted me in the field, guided my career, and who continues to play a pivotal role in my research. Thank you to Mathew Barwick (Fisheries Research and Development Council) for his continual assistance in the field, support, fisheries permits, excellent joke telling, and friendship over the years.

Thank you to Dr Allan Jones and Ms. Anna Murray from the Australian Museum. Wayne Robinson (University of the Sunshine Coast), Dr Bob Clarke (Plymouth

Marine Laboratory), Dr David Williams (University of Canberra), Dr Jim Hone (University of Canberra) for their statistical advice. Dr Phil Gibbs (NSW Fisheries) for the many discussions on Lake Macquarie. Dr Chris Hickey (NIWA) for his help with the porewater collection devices which he developed. Anne Taylor (University of Canberra) for the nutrient analysis. Huge thanks to Scott Rowan, Rod Strauss, Melissa Spooner, Ali, Rajani, Enzo, Fiona, Jules, Mirin, and Monique for their help in the field. Thanks to the technical, support and administrative staff in the School and of Health, Design and Science for their day to day help, especially Hailey, Sue, Brian and Patrick.

I would also like to thank all my friends both in Sydney and Canberra for their continual support and understanding, and I apologise for my hermit like characteristics over the last 18 months. I'm also grateful to Scott Keyworth and Jim Barrett at Murray-Darling Basin Commission for allocating me time to write up during my term of employment.

Without the support of the NSW Environmental Trust neither the research nor the collaborations would have been possible. I further wish to thank the Trust for continuing to support the research of contaminants in the marine and estuarine systems.

From the bottom of my heart I wish to thank my family for their support over the years – many more than I initially envisaged. You have continually shown great interest in what I am doing and my achievements along the way. For this, I am eternally indebt.

Finally, I wish to thank my beautiful wife Gabrielle, who would have to be one of the most tolerant people I know. I thank you all your support, increase in domestic duties, loss of holidays, boring weekends when I am writing, brilliant editing skills, commitment and love.

Abstract

Three approaches were employed to examine the effects of elevated sediment trace metal concentrations on estuarine/marine macrobenthic invertebrate assemblages. The initial study examined macroinvertebrate communities along a known polymetallic gradient, Lake Macquarie, NSW (gradient study). The second study experimentally tested if sediments sourced from different locations within Lake Macquarie differentially influenced the recolonisation of benthic invertebrates. The third study investigated the different recolonisation patterns of benthic invertebrates into sediments spiked with increasing concentrations of sediment-bound cadmium.

In the Lake Macquarie gradient study, four locations (Cockle Bay, Warner's Bay, Kooroora Bay and Nord's Wharf) were sampled in winter 2000 and summer 2003 using a hierarchical design (location > site > plot). On both sampling occasions, the sediments showed strong gradients in lead, cadmium and zinc concentrations emanating from the Cockle Bay industrialised region in the lake's north, with concentrations being significantly lower in the most southern and less urbanised location (Nord's Wharf). In general, concentrations of lead, cadmium and zinc in the sediments increased among locations in the following order: Nord's Wharf > Kooroora Bay > Warner's Bay > Cockle Bay. AVS/SEM analyses indicated that in some sites in Cockle Bay, and to a lesser extent Warner's Bay, SEM concentrations exceeded their molar equivalence of AVS, indicating the potential for trace metals to be labile within the porewaters. Granulometry also changed along the gradient, with a

higher proportion of silt/clay occurring in the locations with high metal concentrations. Conversely, the percentage of total organic carbon was higher in the less contaminated locations.

In winter 2000, changes in benthic communities along the gradient supported the *a priori* hypotheses, with diversity and richness being greater in locations with lower concentrations of metals. Polychaetes were most numerous in Cockle Bay and Warner's Bay, whilst bivalves and gastropods were more abundant in Nord's Wharf and Kooroora Bay. Crustaceans were more numerous in Nord's Wharf; with all other locations having similar, lower, abundances. Ordination maps of the assemblages provided relatively clear separation of the assemblages among locations, with non-parametric multivariate analysis of variance (NPMANOVA) and subsequent pair-wise comparisons finding significant differences among the assemblages from all locations. SIMPER analyses found the highest level of dissimilarity was between the Nord's Wharf and Cockle Bay assemblages – primarily attributable to differences in the relative contributions of isopods; tellenid bivalves; and the polychaete families Spionidae, Opheliidae and Nephytidae. Weighted Spearman rank correlations (BIO-ENV) identified cadmium (P_w =0.74) as the strongest environmental (single or combination) variable to correlate with biotic assemblages.

Benthic patterns along the gradient were less defined in summer 2003 due to a dramatic reduction in the abundance and diversity of fauna in Nord's Wharf. This decline was possibly attributable to a sustained reduction in salinity caused by a prolonged rainfall event. With the exception of Nord's Wharf, trends in the community indices and abundances of key taxa among the other locations were similar to those reported in winter 2000. Multivariate analyses discriminated the benthic assemblages from the four locations, with the findings from the NPMANOVA pair-wise comparisons indicating that the assemblages from all four locations were significantly different. SIMPER analyses showed the highest level of dissimilarity was between Nord's Wharf and Warner's Bay, with these differences being primarily attributable to their relative abundances of amphipods and polychaetes from the families Spionidae, Cirratulidae, Opheliidae and Capitellidae. BIOENV found that the combination of the sedimentary concentrations of cadmium and iron provided the best correlation (P_w =0.73) with biotic patterns, with similar correlations occurring with the addition of lead and its covariate, zinc (P_w =0.72).

The combined findings from the gradient study established a strong correlation between trace metal concentrations within the sediments and suite of univariate and multivariate measurements. The low abundance and diversity of fauna in Nord's Wharf in the summer of 2003 highlighted the dynamic changes which can occur in the distributions of macrobenthic invertebrates. Although the study indicated that there was a strong relationship between trace metal concentrations and benthic community structure, the study was correlative, and requires subsequent experimental testing to confirm the causality of the observed relationships.

The second component of the research was a translocation experiment using benthic recolonisation as an end-point. The experiment was performed to identify if the sediments, and not location, were influencing the composition of benthic assemblages in Lake Macquarie. Sediments were collected from three locations (Cockle Bay, Warner's Bay and Nord's Wharf), defaunated, and transplanted in three new locations along the south-east edge of the lake. At each location, 10 containers of each treatment were randomly placed in the sediment and allowed to recolonise for 22 weeks. Upon retrieval, the benthic communities were sampled and enumerated in conjunction with a variety of chemical and sedimentary measurements. Ten replicate invertebrate samples were also collected in the sediments adjacent to the experiment (ambient samples) at the completion of the experiment. Due to human interference, the containers from only two locations were analysed.

Upon retrieval, pH and redox profiles of the sediments were similar to those expected in natural sediments. In general, concentrations of metals were low in the porewaters; however, iron precipitation on the porewater collection devices may have artificially increased the diffusion of metals, increasing concentrations near the sediment-water interface. Concentrations of SEM exceeded their AVS equivalence in some samples taken from the Cockle Bay and Warner's Bay treatments.

Two-way ANOVAs found significant interactions between location and sediment treatments in diversity, evenness and the number of polychaetes, as well as significant differences in the number of capitellids and crustaceans among locations. *Post-hoc* comparisons of means found the Nord's Wharf sediment contained a higher mean number of individuals than the other treatments, including the ambient samples. nMDS ordination plots for both locations provided poor graphical discrimination of the assemblages among treatments; however, NPMANOVA detected significant location and treatment interactions. In both locations, pair-wise comparisons indicated that the assemblages within the Nord's Wharf treatments were significantly different to the Cockle Bay, Warner's Bay and ambient assemblages. No significant differences were detected between the Cockle Bay and Warner's Bay assemblages at either location. SIMPER analyses found the highest level of dissimilarity occurred between the ambient assemblages in Location 2 and the Nord's Wharf treatment, primarily due to the relative difference in the abundances of Capitellidae, Spionidae, Oweniidae, Nereididae and isopods among the assemblages.

The findings from the translocation experiment suggest that the sediments are influencing the recolonisation of benthos. However, because differences were not detected between the Cockle Bay and Warner's Bay treatments, the approach used in the study shows potential as an *in situ* technique which could be used to assess the potential ecological risks of sediments from specific locations. Excluding cost and time considerations, the technique's primary disadvantage is the lack of a true control. As a result, the technique can only identify if the sediments are modifying benthic recolonisation, and not causality.

The final component of the research experimentally tested if elevated concentrations of sediment-bound cadmium affected benthic invertebrate recolonisation. Sediments from the south coast of New South Wales (Durras Lake) were defaunated, and spiked with cadmium under anaerobic conditions to obtain three targeted cadmium concentrations: control (<0.1 Cd μg/g), Low-Cd (15 Cd μg/g) and High-Cd (150 Cd μg/g). The physio-chemical properties of the waters and porewater concentrations of cadmium were monitored over a 28-day equilibration period, with declines in pH mediated with the addition of $NaOH_{(aq)}$. At the end of the equilibration period, porewater concentrations of cadmium were low in the Low-Cd and High-Cd treatments (maximum <1.5 μg/L in High-Cd), and below the detection limit in the control. Cadmium was not detected in the control sediments, with concentrations in the Cd-Low and Cd-High sediments exceeding their targeted concentrations, with final mean concentrations of 17 μg/g and 183 μg/g, respectively.

The experimental design was similar to that employed in the translocation experiment, with 10 containers from each treatment transplanted into the sediments at three locations within Lake Macquarie. After 20 weeks, the containers were collected, along with benthic invertebrate samples from the ambient sediments. Data was not used from Location C due to extensive sediment deposition on the transplanted treatments. Significant declines occurred in the concentrations of cadmium in both the Low-Cd and High-Cd sediments, with the greatest loss occurring in the surficial sediments. The loss of cadmium was probably due to the differential loss of the fine fraction through physical means (hydrodynamic) rather than fluxing, as it assumed that the cadmium was primarily sediment-bound and relatively insoluble under anoxic conditions. Mean porewater concentrations of cadmium were below the detection limit in the control treatments; < 1 μg/L in the Low-Cd treatment, and generally < 2μg/L in the High-Cd, with the exception of some samples in Location B (maximum 5.6 μg/L). Concentrations of ammonia were low in the porewaters from the surficial sediments, with concentrations being significantly higher, and potentially toxic, in the anoxic porewaters (7 cm depth).

In comparison to the previous recolonisation experiment, the number of individuals which recolonised the cadmium-spiked treatments was low, and significantly lower than the mean number of individuals sampled in the ambient sediments. No significant differences were detected among the treatments or locations (and their interactions) in diversity (H'), richness (d) or evenness (J). The number of polychaetes and molluscs significantly differed among the treatments, with *post-hoc* analyses indicating these differences were not among the cadmium-spike treatments, but were due to a greater mean abundance of these taxa in the ambient sediments. A significant interaction between treatment and location was detected in the mean abundance of crustaceans, with the ambient sediments having significantly lower mean abundances in both Location A and B. Ordination plots of the experiments in Location A and B provided poor graphical discrimination among the spiked treatments, although the ambient assemblages appear to be separated from the cadmium-spiked assemblages. NPMANOVA detected a significant interaction between treatments and locations, as well as among treatments. In both Location A and B, pair-wise analyses found the assemblages in the ambient sediments to be significantly different to the assemblages in all three cadmium treatments, with no differences being detected among the latter. SIMPER analyses found the highest levels of dissimilarity occurred between the spike-treatments and the ambient sediments, with these differences being primarily due to the relatively higher abundance of decapods in the spiked treatments, and capitellids in the ambient sediments.

The cadmium-spiking component of the experiment clearly illustrated that artificially increasing the trace metal concentrations of metals in estuarine sediments is a complex process which needs to be performed in a methodological manner in order to obtain homogenous treatments with low porewater concentrations, and minimal artefacts. Furthermore, the results confirmed that the equilibration time for sediments can be extensive (several weeks), even in the case of organically rich sediments. The timing of the experiment (commenced late summer, February, 2003) appears to the major factor for the relatively low recolonisation rates, with the experiment missing the main larval recolonisation period between spring and early summer. Even in the highest treatment, elevated concentrations of cadmium did not appear to affect benthic recolonisation. This finding is supported by other experimental studies which suggest that concentrations of a single isolated metal must considerably exceed current guideline values (or contain high porewater concentrations) in order to elicit a biological effect. Nevertheless, as trace metals generally co-occur with other contaminants – with the response of multiple contaminants being possibly additive or synergistic – a conservative guideline value may be suitable in the interim as a precautionary measure.

The findings of this thesis suggest that elevated concentrations of trace metal mixtures in estuarine sediments can affect the structure and composition of benthic communities; however, identifying causality is difficult. Although there has been an increase in the use of manipulative field experiments as a means of reducing the confounding influence of covariables found in field studies, this approach also has limitations, e.g. spatial and temporal scale issues, container effects, cost and biogeochemical changes to the sediments. Measuring stress at a community level is a fundamental component of estuarine risk assessment programs; and in isolation this approach can produce subjective and confounded findings. In order to accurately assess the risks associated with trace metal contaminated sediments, an integrated approach (e.g. weight of evidence) is required, one which uses multiple lines of evidence sourced from various chemical, environmental biological measurements.

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