



Research Journal of
**Environmental
Toxicology**

ISSN 1819-3420



Academic
Journals Inc.

www.academicjournals.com



Research Article

Metal Concentrations in the Helderberg Marine Protected Area, False Bay, Cape Town

C. Sparks and B. Mullins

Department of Conservation and Marine Sciences, Cape Peninsula University of Technology, P.O. Box 652, 8000 Cape Town, South Africa

Abstract

Background: The release of metals is increasing in industrial and urban areas and the impacts thereof are poorly understood. In an attempt to protect areas from anthropogenic impacts, certain areas are declared protected. The assumption thus could be that protected areas are free from the effects of pollutants. The Helderberg Marine Protected Area (HMPA) is situated in an urbanised region of False Bay, Cape Town, South Africa. Although considered a protected area, the question is raised whether metals from the surrounding area are affecting the coastal environment of the MPA. **Materials and Methods:** The study assessed the concentrations of 8 metals (Al, Mn, As, Mo, Cd, Fe, Cu and Zn) in the water, sediment and mussel *Mytilus galloprovincialis*. Samples were collected from within the HMPA, at its border (Lourens river) and adjacent to the HMPA (Strand) in August, 2012. **Results:** The results showed that metal concentrations were higher in the sediment than ambient coastal waters. Furthermore, metal concentrations were higher in mussels than the sediment for As, Mo, Cd, Cu and Fe. **Conclusion:** The most important result was that mussel Al, Mn, Cd, Cu and Fe concentrations were similar in and adjacent to the HMPA. The results suggested that the environment of the HMPA was exposed to contaminants (such as metals sampled in this study) from areas outside the MPA and management authorities should consider the effects of these and other contaminants in management plans of MPA's.

Key words: *Mytilus galloprovincialis*, biomonitoring, metal contamination, marine protected area, sediment pollution, pollutant load index

Received: June 23, 2016

Accepted: October 05, 2016

Published: December 15, 2016

Citation: C. Sparks and B. Mullins, 2017. Metal concentrations in the Helderberg marine protected area, False Bay, Cape Town. Res. J. Environ. Toxicol., 11: 11-19.

Corresponding Author: C. Sparks, Department of Conservation and Marine Sciences, Cape Peninsula University of Technology, P.O. Box 652, 8000 Cape Town, South Africa

Copyright: © 2017 C. Sparks and B. Mullins. This is an open access article distributed under the terms of the creative commons attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Coastal environments are under considerable threat due to the increased pressures of urbanization and industrialization. In southern Africa, the marine environment is considered to be relatively pristine in terms of global standards^{1,2}. However, taking into account the multiple use of areas and increased population growth and development, localised anthropogenic activities in coastal areas may be increasing the habitat destruction and loss of vulnerable ecosystems. To ameliorate these effects, coastal areas are closed and declared marine protected areas. Although closed to the general public, a key question is whether declaration of protected areas are indeed protecting the ecosystems and organisms that are intended to be protected.

The long term release of metals into the coastal and aquatic environment may have negative impacts on the physical and chemical composition of biota, productivity, diversity and abundance³. Metals have different impacts on the environment and species, depending on organismal and system sensitivity to the metals^{4,5}. Therefore, each study site might be influenced differently by metal contamination, based on the sites' proximity to the sources of contamination and its level of exposure⁶.

To ascertain the level of metal contamination in the environment is a challenging task to undertake. Not only do metals occur naturally in the environment and integral to biochemical function, they can also occur in various forms of ionic speciation, depending on a host of chemical and physical factors⁷. Despite these challenges, biomonitoring is used to assess and monitor the levels of contamination in the environment that may be used as an indicator of accumulation and bioconcentration⁵. The use of biota to assess the quality of a habitat is based on the assumption that some species are more tolerant to chemicals than others and therefore can provide information on the types and level of contamination in the environment^{4,8,9}.

Biomonitoring studies are based on the assumptions that organisms reflect the environmental conditions they live in^{6,9}. Mussels have the ability to accumulate metals directly from the surrounding environment and absorb these into the tissue at levels much higher than that of the existing water and sediment^{10,11}. The mussel, *Mytilus galloprovincialis* species has been the preferred indicator species for most biomonitoring programmes along coastal environments¹⁰⁻¹⁶. Mussels are suitable biomonitor species as they provide important information relating to the levels of heavy metal contamination in the environment through the analysis of the mussel soft tissue (or whole mussel)¹². Analysing mussels to

indicate areas of elevated metal concentration in mussel soft tissue, water and sediment¹⁷ can be useful in identifying and describing the relationship between the concentrations in mussels and the environment^{18,19}.

Coastal and terrestrial based sources of pollution in False Bay and surrounding areas of the bay are the major contributors of contamination in the area²⁰ with coastal ecosystems under considerable stress caused by non-point (maritime transportation) and point source contamination (treated sewage effluent, agricultural, commercial and urban development)^{21,22}. Anthropogenic activities contribute largely to the poor water quality and the loss of sensitive invertebrate species along False Bay²³⁻²⁵.

Contamination discharged into river systems find their way into estuaries and coastal zones, which may result in the accumulation of contamination in the sediment and the bioaccumulation of contaminants in living organisms^{26,27}. A high sensitivity to heavy metal bioaccumulation has been observed in the development stages of bivalves and the increase of metals concentrations at levels above the threshold are often toxic to the organisms^{28,29}. Heavy metal contamination in areas of high anthropogenic activity is increasing to levels much higher than the levels found in the earth crust⁷. The Cd, Cu, Co, Zn, V and Mn occur naturally in the environment and are important to plant and animal health and the increase in non-essential metals released by anthropogenic activity are polluting the environment at alarming rates^{7,30}.

The HMPA in False Bay, Cape Town (South Africa) was proclaimed in 2000 as a strategy to rehabilitate, conserve and protect a relatively small marine and coastal environment in Cape Town²⁷. The MPA consists of 4 km of sandy beaches on the northern shore of False Bay and is situated between the Eerste river and Lourens river mouth. There are three potential land based pollution sources in and close to the HMPA, namely the Macassar Waste Water Treatment Works (WWTW), SOMCHEM national defence testing facility and the Lourens River and catchment area (urban run-off)³¹. Little to no information regarding the environmental history of HMPA and the impacts of contaminants from pollution sources and these are inhibiting effective management of the HMPA^{32,33}.

Mytilus galloprovincialis are being used in Mussel Watch Programmes (MWP) by Department of Environmental Affairs (DEA)²² to assess the metal concentrations in False Bay. However, metal contamination in the HMPA has never been monitored^{33,34}. Therefore, establishing a baseline of the metal contamination in and outside the HMPA will assist management authorities in developing a monitoring system

to mitigate potential risk of toxic levels of contamination in and outside the MPA. The objectives of the study were to determine the level of metal concentration in the intertidal water, sediment and mussels (*Mytilus galloprovincialis*) in and outside the Helderberg Marine Protected Area.

MATERIALS AND METHODS

Study area: False Bay ($34^{\circ}06'21.29''S$ and $18^{\circ}46'31.27''E$) is one of the largest true bays in South Africa³¹ (Fig. 1). The bay formation is almost square with an approximate dimension of about 35×30 km in length³¹. The False Bay coastline is largely occupied by human settlement and commercial development activities with numerous small storm water outlets that drain into the bay^{22,35,36}.

Three study sites along False Bay were chosen for the study: the Helderberg Marine Protected Area (HMPA), Lourens river mouth (Lourens) situated at the Eastern

border of the HMPA and Strand situated in an urban coastal area approximately 2 km from the HMPA (Fig. 1). The land used at the three sites range from light industrial, agricultural, commercial and residential developments, waste water treatment works and solid waste dumpsites²².

Sampling: Specimens of the mussel *Mytilus galloprovincialis* ($n = 5$) were collected at low tide from the three sites in August, 2012. *Mytilus galloprovincialis* of similar sizes were collected from the three sites at low tide when mussels beds were exposed. On collection the mussels were stored in cooler boxes at the site and transported to the laboratory mussels where the mussels were depurated for 24 h, before being stored in a freezer at $-20^{\circ}C$ until further analysis. The mussel samples were treated by washing with deionized water, the wet weight, length and width of each mussel sample was measured before the mussels were dried in the oven for 48 h at $60^{\circ}C$ ³⁷.

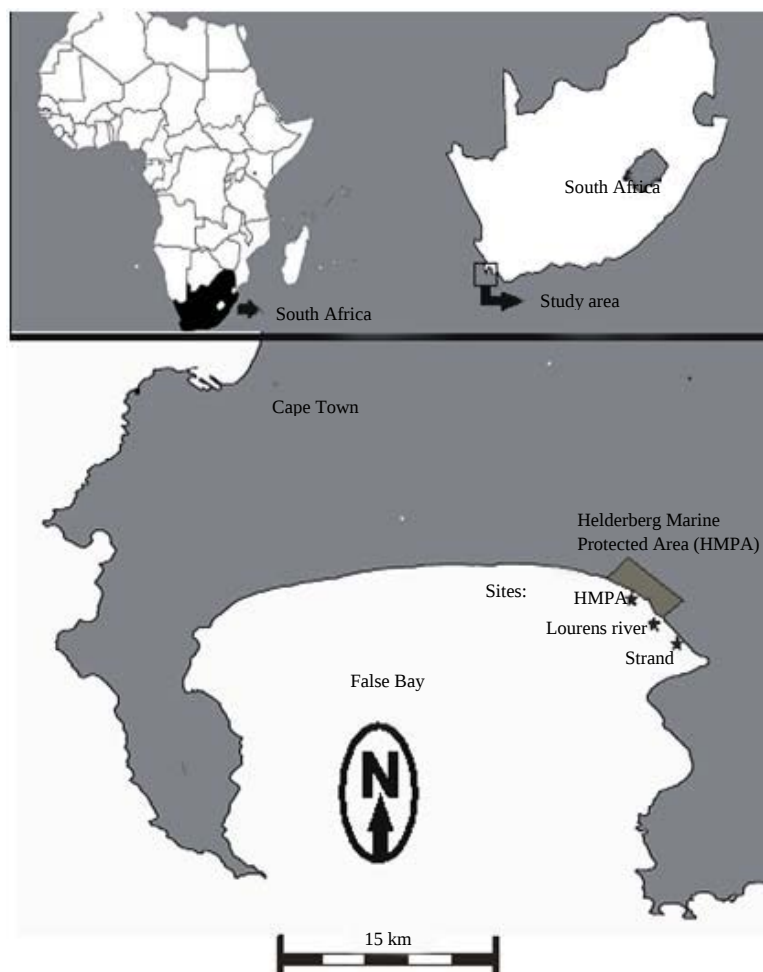


Fig. 1: Study area and location of sampling sites at the Helderberg Marine Protected Area (HMPA), Lourens river and Strand

Sediment and water samples (n = 5) were collected simultaneously as the mussels at the three sites. Surface sediment samples were taken at low tide in the intertidal zone, using a pre-cleaned 500 mL plastic sample jar. Water samples were collected at a depth of 30 cm above the sediment, using a 500 mL pre-cleaned plastic sample jars. Water, temperature and pH was measured using an Hanna portable meter. Samples were transported to the laboratory where these were stored at -20°C until further analysis.

Frozen sediment samples were defrosted, where after they were oven dried for 48 h at 60°C in a Memmert drying oven. Sediment was ground with a mortar and pestle and subsamples (± 0.2 g) used for metal analysis. Ground sediment aliquots and defrosted water samples (5 mL water) were digested using 10 mL of nitric acid (analar grade 60% HNO₃). Samples were then heated to 40°C in a grant UBD heating block for one hour, thereafter to 120°C for 3 h. The digestates were allowed to cool and then filtered through Whatman No. 6 filter paper and then through 0.45 µm membrane micro-filter (Millipore) paper using a syringe. Samples were then placed in plastic centrifuge tubes containing 5 mL digestate and 10 mL distilled water and stored in a refrigerator until further analysis was done.

A blank accompanied all samples when analysis of samples took place. The concentrations of the metals were analysed with 5 replicates being done for each metal using an Inductively Coupled Plasma-Mass Spectrophotometer (ICP-MS), according to the methods of Mdzeke³⁷ and the concentrations of Al, Mn, As, Mo, Cd, Fe, Cu and Fe analysed. Water concentrations of metals are presented as µg L⁻¹ and sediment and mussel tissue as µg L⁻¹ dry weight. Analytical standards (quality control standards) were used for all metals to determine the analytical variation. All metal concentrations were within 2% Relative Standard Deviation (RSD) of the certified concentrations (except for Al which 9% RSD).

The level of metal contamination in sediment is expressed in terms of a Contamination Factor (CF). An equation previously used by Varol³⁸ was used to calculate the contamination factors for each heavy metal at each site³⁹, CF = Metal concentration in sediment/background levels for marine sediment. The background concentrations for the sediment were from concentrations recorded by Hennig⁴⁰.

The extent of pollution at each site was evaluated using methods based on Pollution Load Index (PLI). The pollution load index is an equation that makes use of the contamination factor³⁹:

$$PLI = (CF_{\text{metal 1}} \times CF_{\text{metal 2}} \times CF_{\text{metal 3}} \dots \times CF_{\text{nth metal}})^{1/\text{nth metal}}$$

Statistical analysis: Statistical analyses were performed using SPSS 19.0 programme. Metal concentrations in water, sediment and soft tissue of mussels were tested for normality using the Levene's test and for variance using the Shapiro-Wilke test. Variability of mean data was represented using the Standard Error of the Mean (SEM). Statistical significance differences were assumed at p<0.05.

RESULTS AND DISCUSSION

The coastal water temperatures ranged between 13.80 and 14.10°C with an overall mean of 13.91°C (SEM $\pm$ 0.12°C), with no significant differences recorded between the three sites. These measurements are similar to that previously reported in the study area³⁴. The pH ranged between 6.93 and 7.83 with pH decreasing from Helderberg Marine Protected Area (HMPA) towards Strand. The mean pH at Strand (6.93 $\pm$ 0.09) was significantly lower than the HMPA (7.83 $\pm$ 0.03) and Lourens river (7.5 $\pm$ 0.15), respectively (p<0.05). These pH levels were similar to that measured by Taljaard *et al.*³¹ where the average water pH at Lourens river, between 1990 and 1999, ranged between 7.4 and 7.7.

Metal concentrations in the water sampled from all three sites were lower than sediment and mussels (Table 1). Of the three sites, the highest concentrations of metals within the water of the HMPA were reported for 50% of the metals measured: Mn, As, Cu and Zn. The Zn concentrations were 3 times higher than the other two sites sampled with a maximum of 15.31 µg L⁻¹ recorded at HMPA. According to Taljaard²² the waste water treatment and sewage out fall from the urban-industrial areas that discharge directly into False Bay, carry with it a wide range of chemical effluents and pollutants that increase the heavy metal contamination in the bay and may thus be potential sources of metal contamination at the sites sampled.

According to Taljaard *et al.*³¹ the monthly inflows from the Lourens river estuary into False Bay increases between May and October with an inflow peak reached between June and August. The high flow rate from the Lourens river into the bay suggests that there is a higher flushing and distribution rate of metals into the bay during these periods of the year. This could account for the relatively lower metals concentrations measured and the Lourens river as sampling took place during August.

Except for Cd, sediment metal concentrations increased from HMPA towards Strand. Concentrations of Mn, As, Cd, Fe, Cu and Zn were lower at the Lourens river than the HMPA (Table 2). Significantly higher (p<0.05) Al, Mn and Fe concentrations were recorded in the sediment than mussels

Table 1: Metal concentrations ($\mu\text{g L}^{-1}$, n = 5) in coastal water samples collected at the HMPA, Lourens river and Strand

Station	Al	Mn	As	Mo	Cd	Fe	Cu	Zn
HMPA								
Mean	0.20	0.07	0.03	0.09	<l.d	<l.d	0.07	8.81
SEM	0.10	0.01	<l.d	<l.d	<l.d	<l.d	0.01	3.42
Minimum	0.07	0.05	0.02	0.09	<l.d	<l.d	0.04	3.75
Maximum	0.40	0.09	0.03	0.10	<l.d	0.01	0.08	15.31
Lourens river								
Mean	1.45	0.04	0.02	0.09	<l.d	1.42	0.05	2.03
SEM	0.49	0.02	<l.d	0.01	<l.d	0.36	0.02	1.53
Minimum	0.68	0.01	0.01	0.08	<l.d	0.69	0.02	0.20
Maximum	2.37	0.08	0.02	0.10	<l.d	1.79	0.08	5.07
Strand								
Mean	0.39	0.02	0.02	0.09	<l.d	0.11	0.01	2.45
SEM	0.06	0.01	0.01	0.00	<l.d	0.08	<l.d	0.88
Minimum	0.28	<l.d	0.01	0.09	<l.d	<l.d	<l.d	1.41
Maximum	0.46	0.05	0.03	0.10	0.01	0.28	0.02	4.19

<l.d: Below level of detection

Table 2: Metal concentrations ($\mu\text{g g}^{-1}$ dry weight, n = 5) in coastal sediment samples collected at the Helderberg Marine Protected Area (HMPA), Lourens river and Strand

Station	Al	Mn	As	Mo	Cd	Fe	Cu	Zn
HMPA								
Mean	256.12	6.93	1.07	0.03	0.09	723.29	0.53	4.58
SEM	12.50	0.39	0.10	<l.d	0.01	53.85	0.07	1.62
Minimum	239.35	6.25	0.93	0.03	0.08	664.20	0.45	2.70
Maximum	280.57	7.59	1.25	0.04	0.11	830.82	0.67	7.80
Lourens river								
Mean	287.77	5.94	0.83	0.03	0.08	661.97	0.47	3.13
SEM	18.17	0.40	0.03	0.01	0.01	29.50	0.04	1.63
Minimum	257.67	5.14	0.80	0.02	0.06	623.93	0.43	1.13
Maximum	320.44	6.43	0.88	0.06	0.10	720.04	0.55	6.36
Strand								
Mean	378.14	8.87	1.20	0.05	0.13	1054.55	0.75	7.84
SEM	15.87	0.22	0.05	<l.d	0.01	12.41	0.06	1.62
Minimum	348.34	8.64	1.11	0.04	0.10	1036.80	0.65	5.19
Maximum	402.51	9.32	1.27	0.05	0.15	1078.45	0.86	10.78

<l.d: Below level of detection

at all the sites sampled (Fig. 2). When comparing differences between sites, concentrations of sediment Al, Mn and Fe were significantly lower ($p < 0.05$) at the HMPA than Strand. Both water and sediment metal concentrations were below the sediment quality guidelines proposed for the Benguela region²², indicating that all the sites sampled were not heavily polluted. The elevated Mn and Zn concentrations could be related to the intensity of urban development and the run-off related contamination from surrounding agricultural and urban-industrial activities^{22,34}.

Sediment plays an important role in the transportation of metals across the bay as it influences the amount of metals that are available in the water column and ultimately the bioavailability to filter-feeding organisms³⁴. According to Taljaard *et al.*³¹ the hydrodynamics in False Bay is influenced by the shape of the bay and this could have accounted for similar metal concentrations at the HMPA, Lourens river and Strand.

The high coastal water Mn concentrations in the HMPA and Lourens river may be due to the industrial discharge from industrial activities to the north of the HMPA and the Macassar waste water works located to the west of the HMPA³⁷. Due to the constant movement and fluctuation of water currents, majority of the metal concentrations in the water ranged from very low and undetectable levels³¹. The elevated sediment Mn concentrations at the HMPA may be due to the circular movement of longshore coastal currents along the three sites.

Concentrations of As, Mo, Cd, Cu and Zn were significantly higher ($p < 0.05$) in the mussel *M. galloprovincialis* than sediment (Fig. 2). As filter feeding organisms, these mussels have the potential to accumulate a significant amount of metals from the ambient environment (water and sediment) as metals are bioavailable to accumulate in mussels³⁰. Of the metals measured in mussels, Cd was higher in the HMPA than the other two sites sampled. The uptake of Cd in the soft tissue of mussels is influenced by the

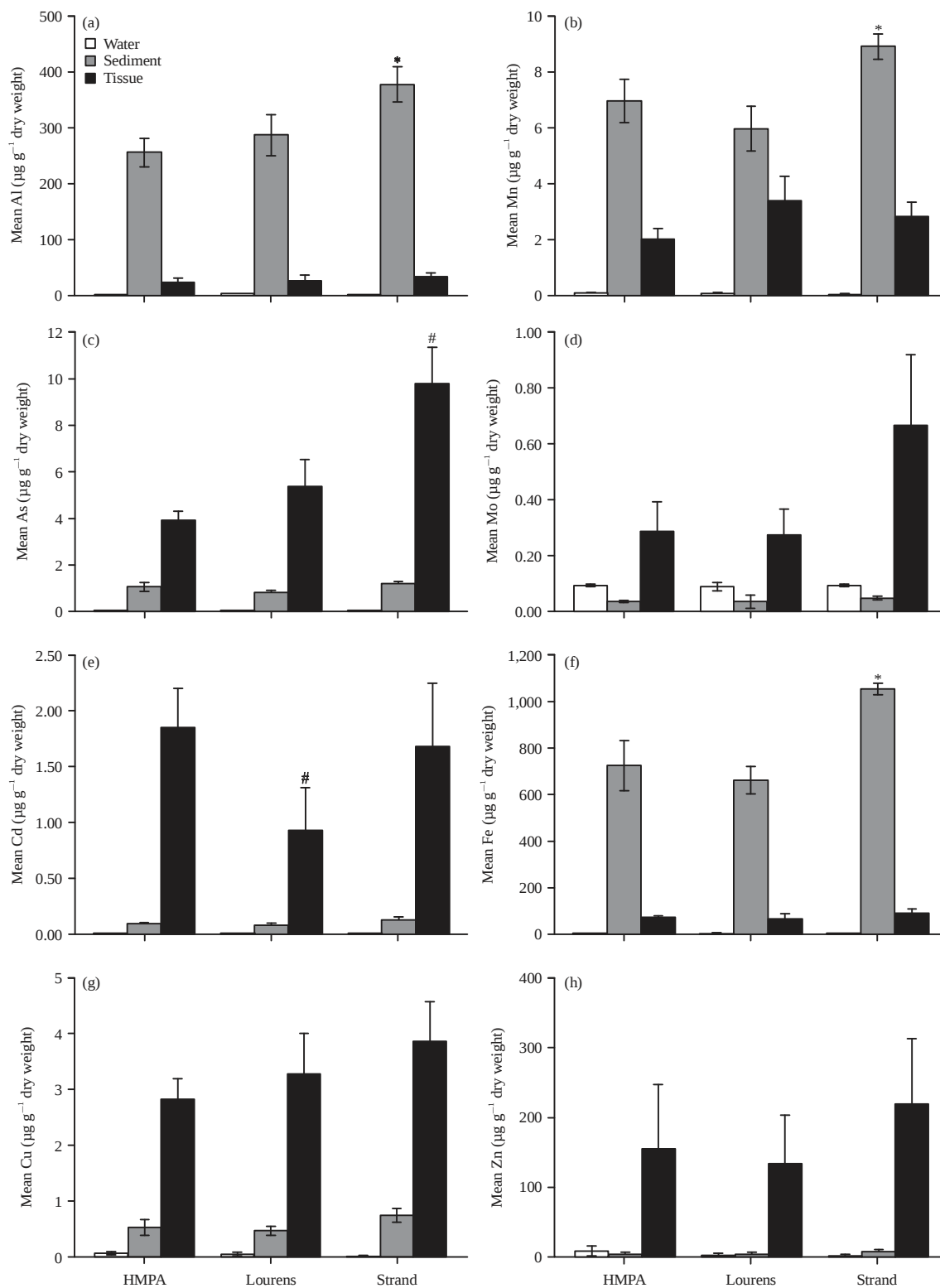


Fig. 2(a-h): Mean (a) Al, (b) Mn, (c) As, (d) Mo, (e) Cd, (f) Fe, (g) Cu and (h) Zn concentrations ($\mu\text{g g}^{-1}$ dry weight) ($M \pm \text{SEM}$, $n = 5$) measured in water, sediment and *Mytilus galloprovincialis* (soft tissue) at the Helderberg Marine Protected Area (HMPA) Lourens river (Lourens) and Strand, *Indicates that sediment metal concentrations are significantly different from HMPA and #Indicates that mussel tissue metal concentrations are significantly different from HMPA

Table 3: Metal concentrations ($\mu\text{g g}^{-1}$ dry weight, $n = 5$) in the mussel *Mytilus galloprovincialis* collected at the Helderberg Marine Protected Area (HMPA), Lourens river and Strand

Station	Al	Mn	As	Mo	Cd	Fe	Cu	Zn
HMPA								
Mean	23.50	2.00	3.92	0.29	1.84	69.68	2.81	154.86
SEM	3.53	0.19	0.19	0.05	0.17	4.08	0.19	46.28
Minimum	13.88	1.53	3.37	0.16	1.22	55.83	2.26	35.44
Maximum	39.17	2.59	4.58	0.47	2.34	82.21	3.52	360.44
Lourens river								
Mean	25.39	3.38	5.37	0.27	0.92	66.21	3.26	133.50
SEM	4.95	0.43	0.57	0.05	0.19	10.77	0.37	34.82
Minimum	7.54	1.51	3.20	0.12	0.20	23.25	1.78	42.99
Maximum	42.22	4.39	7.21	0.41	1.55	90.35	4.25	263.82
Strand								
Mean	32.44	2.80	9.75	0.67	1.67	89.91	3.84	219.34
SEM	3.72	0.26	0.79	0.13	0.28	8.82	0.36	46.79
Minimum	25.06	1.72	7.45	0.48	0.76	73.14	2.58	122.94
Maximum	48.33	3.48	11.91	1.27	2.86	132.27	4.97	435.57

Table 4: Sediment Contamination Factors (CF) and Pollution Load Index (PLI) of metals at the Helderberg Marine Protected Area (HMPA), Lourens river and Strand

	Al	Mn	As	Mo	Cd	Fe	Cu	Zn	PLI
HMPA	ND	1.54	ND	ND	0.31	1.46	0.25	1.64	0.98
Lourens	ND	1.32	ND	ND	0.26	1.34	0.22	1.12	0.97
Strand	ND	1.97	ND	ND	0.43	2.13	0.36	2.80	1.01

ND: Not determined, Background concentrations based on values from Hennig⁴⁰

physio-chemical factors such as pH, temperature and the bioavailability of Cd in the environment²⁸. Although the Cd concentrations in mussels were lower than that reported by Sparks *et al.*² for the region, the results suggests that anthropogenic sources of Cd could be the cause of elevated Cd concentrations reported in the HMPA and requires further investigation, even though the concentrations were below the recommended limit for shellfish⁴¹.

The As, Mo and Cu metals in mussels increased from HMPA to Strand with Cd and Zn decreasing from the HMPA to the Lourens river and then increasing to Strand (Table 3). The Mn concentrations increased from the HMPA to the Lourens river and then decreased towards Strand. The As with the sediment metal concentrations recorded, the increase in metals in mussel (As, Mo and Cu) may be attributed to the coastal dynamics of False Bay³¹.

Contamination Factor (CF) of metal concentrations in the sediment (except for Al, As and Mo) were calculated at each site (Table 4), using the background levels of metals recorded in False Bay by Hennig⁴⁰. Contamination factors were highest at Strand for all metals analysed, followed by the HMPA and the Lourens river. Pollution Load Indices (PLI) calculated for the sediment for the three sites is illustrated in Table 4. Categorization of PLI from highest to lowest per site was: Strand>HMPA>Lourens river. The mean PLI results reported here are lower than that reported by El-Sammak and Aboul-Kassim⁴² where an average of 1.279 was recorded for

all the sites sampled. The mean PLI recorded for the three sites sampled in False Bay was 0.99. El-Sammak and Aboul-Kassim⁴² reported that sites that had PLI's>1.2 were considered to be affected by pollutants. Given that none of the site PLI values were greater than 1.2, it is suggested that none of the sites samples were negatively affected by exposure to metals and should not be considered polluted based on PLI values. Furthermore, the PLI values are similar to other sites in Cape Town. Relatively though, the PLI of HMPA is higher than the Lourens river, suggesting that, comparatively the HMPA is not protected from coastal metal contaminants. The relatively higher PLI level in the HMPA may be due to the release of industrial effluent to the north of the MPA and domestic sewage from the adjacent Macassar waste water treatment facility³¹. This postulation however, needs further investigation as the degree of metal released into the environment is influenced by the type, source and quantity of these metals.

CONCLUSION

The research provided an account of metal concentrations in and outside a marine protected in South Africa. The main findings of this study were that metal concentrations were generally not lower inside the MPA as would have been expected, suggesting that coastal dynamics and long shore movement may be responsible for

the metal concentrations in the HMPA. Furthermore, metal concentrations in sediment may be related to the settling rates of sediment from surrounding industrial catchment areas and domestic effluent released into False Bay. The elevated metal concentrations in mussels in the HMPA (relative to sediment) suggests bioaccumulation of the metals and requires further investigation.

ACKNOWLEDGMENTS

The research was funded by the Cape Peninsula University of Technology (CPUT) (University Research Fund). We thank the technical staff at CPUT for assistance with collecting samples and laboratory analysis as well as the support from the City of Cape Town and Denel for granting access to the HMPA.

REFERENCES

- Branch, G.M., C.L. Griffiths, M.L. Branch and L.E. Beckley, 2007. Two Oceans: A Guide to the Marine Life of Southern Africa. Struik Publishers, Cape Town, South Africa, ISBN-13: 9781770076334, Pages: 360.
- Sparks, C., J. Odendaal and R. Snyman, 2014. An analysis of historical Mussel Watch Programme data from the west coast of the Cape Peninsula, Cape Town. Mar. Pollut. Bull., 87: 374-380.
- Jose, J., R. Giridhar, A. Anas, P.A.L. Bharathia and S. Nair, 2011. Heavy metal pollution exerts reduction/adaptation in the diversity and enzyme expression profile of heterotrophic bacteria in Cochin estuary, India. Environ. Pollut., 159: 2775-2780.
- Hylland, K., 2006. Biological effects in the management of chemicals in the marine environment. Mar. Pollut. Bull., 53: 614-619.
- Hawkins, A., 2007. Biomonitoring: Guide for the use of biological endpoints in monitoring species, habitat and projects. Naval Facilities Engineering Service Center, Port Hueneme, CA., pp: 1-48.
- Schulz, R. and S.K.C. Peall, 2001. Effectiveness of a constructed wetland for retention of nonpoint-source pesticide pollution in the Lourens River catchment, South Africa. Environ. Sci. Technol., 35: 422-426.
- Lam, P.K.S. and J.S. Gray, 2001. Predicting effects of toxic chemicals in the marine environment. Mar. Pollut. Bull., 42: 169-173.
- Day, J., 2000. Biomonitoring: Appropriate technology for the 21st century. Proceedings of the 1st WARFSA/WaterNet Symposium on Sustainable Use of Water Resources, November 1-2, 2000, Maputo, Mozambique.
- Li, L., B. Zheng and L. Liu, 2010. Biomonitoring and bioindicators used for river ecosystems: Definitions, approaches and trends. Procedia Environ. Sci., 2: 1510-1524.
- Taleb, Z.M., S. Benghali, A. Kaddour and Z. Boutiba, 2007. Monitoring the biological effects of pollution on the Algerian west coast using mussels *Mytilus galloprovincialis*. Oceanologia, 49: 534-564.
- Yaqin, K., B.W. Lay, E. Riani, Z.A. Masud and P.D. Hansen, 2011. Hot spot biomonitoring of marine pollution effects using cholinergic and immunity biomarkers of tropical green mussel (*Perna viridis*) of the Indonesian waters. J. Toxicol. Environ. Health Sci., 3: 356-366.
- Goldberg, E.D., M. Koide, V. Hodge, A.R. Flegal and J. Martin, 1983. U.S. Mussel Watch: 1977-1978 results on trace metals and radionuclides. Estuarine Coastal Shelf Sci., 16: 69-93.
- Goldberg, E.D. and K.K. Bertine, 2000. Beyond the mussel watch-new directions for monitoring marine pollution. Sci. Total Environ., 247: 165-174.
- Lobel, P.B., C.D. Bajdik, S.E. Jackson and H.P. Longerich, 1991. Improved protocol for collecting mussel watch specimens taking into account sex, size, condition, shell shape and chronological age. Arch. Environ. Contam. Toxicol., 21: 409-414.
- UNEP., 2006. Methods for sediment sampling and analysis. Proceedings of the Meeting of the Mediterranean Action Plan, December 12-15, 2005, Palermo, Italy.
- Wade, T.L., J. Sericano, P.R. Gardinali, G. Wolff and L. Chambers, 1998. NOAA's 'mussel watch' project: Current use organic compounds in bivalves. Mar. Pollut. Bull., 37: 20-26.
- Palmer, M., 1984. Methods manual for bottom sediment sample collection. U.S. Environmental Protection Agency Region V, Great Lake National Program Office, Chicago, IL., USA., March 1984.
- NRC., 1980. The international mussel watch. Report on Workshop by the Environmental Studies Board, Commission of National Resources, National Research Council, Washington, DC., USA.
- Rainbow, P.S., M. Wolowicz, W. Fialkowski, B.D. Smith and A. Sokolowski, 2000. Biomonitoring of trace metals in the Gulf of Gdansk, using mussels (*Mytilus trossulus*) and barnacles (*Balanus improvisus*). Water Res., 34: 1823-1829.
- Ngwenya, F., 2006. Water quality trends in the Eerste River, Western Cape, 1990-2005. M.Sc. Thesis, Faculty of Natural Science, University of the Western Cape, South Africa.
- Harris, T.W.F., 1978. Review of coastal currents in Southern African waters. CSIR, SANSP Report No. 30, South African National Scientific Programme Unit, Cape Town, South Africa, August 1978, pp: 1-103.
- Taljaard, S., 2006. Baseline assessment of sources and management of land-based marine pollution in the BCLME region (Project BEHP/LBMP/03/01). CSIR Report No. CSIR/NRE/ECO/ER/2006/0010/C, Stellenbosch, South Africa.

23. Bredenhand, E., 2005. Evaluation of macro-invertebrates as bioindicators of water quality and the assessment of the impact of the Klein Plaas dam on the Eerste River. Master's Thesis, Stellenbosch University, Stellenbosch, South Africa
24. Dabrowski, J.M., S.K.C. Peall, A.J. Reinecke, M. Liess and R. Schulz, 2000. Runoff-related pesticide input into the Lourens River, South Africa: basic data for exposure assessment and risk mitigation at the catchment scale. *Water Air Soil Pollut.*, 135: 265-283.
25. DWAF., 1995. South African Water Quality Guidelines for Coastal Marine Waters, Volume 1: Natural Environment. 1st Edn., Department of Water Affairs and Forestry, Pretoria, South Africa, ISBN: 0-621-17464-5, Pages: 332.
26. Jebali, J., M. Banni, E.A. de Almeida and H. Boussetta, 2007. Oxidative DNA damage levels and catalase activity in the clam *Ruditapes decussatus* as pollution biomarkers of Tunisian marine environment. *Environ. Monit. Assess.*, 124: 195-200.
27. RHP., 2003. State-of-Rivers Report: Diep, Hout Bay, Lourens and Palmiet River Systems. Department of Water Affairs and Forestry, Pretoria, ISBN-13: 9780620307574, Pages: 39.
28. Reinecke, A.J., N.P. Mdezeke and S.A. Reinecke, 2012. Spatial and temporal variation in cadmium body loads of four intertidal invertebrates from False Bay, South Africa. *Afr. Zool.*, 47: 12-25.
29. Beiras, R., J. Bellas, N. Fernandez, J.I. Lorenzo and A. Cobelo-Garcia, 2003. Assessment of coastal marine pollution in Galicia (NW Iberian Peninsula); metal concentrations in seawater, sediments and mussels (*Mytilus galloprovincialis*) versus embryo-larval bioassays using *Paracentrotus lividus* and *Ciona intestinalis*. *Mar. Environ. Res.*, 56: 531-553.
30. McCarthy, H.T. and P.C. Ellis, 1991. Comparison of microwave digestion with conventional wet ashing and dry ashing digestion for analysis of lead, cadmium, chromium, copper and zinc in shellfish by flame atomic absorption spectroscopy. *J. Assoc. off. Anal. Chem.*, 74: 566-569.
31. Taljaard, S., R.C. van Ballegooyen and P.D. Morant, 2000. False Bay water quality review. Volume 1: Executive summary. Report to the False Bay Water Quality Advisory Committee, CSIR Report ENV-S-C 2000-086/1, Stellenbosch, South Africa.
32. CMC., 1998. Towards an Integrated Metropolitan Environmental Policy (IMEP) for the Cape metropolitan area: Summary of the proposed principles and stages of the policy formulation process. Cape Metropolitan Council, South Africa, October 1998.
33. Tunley, K., 2009. State of management of South Africa's marine protected areas. WWF South Africa Report Series-2009/Marine/001, Department of Environmental Affairs, South Africa, October 2009.
34. Taljaard, S., R.C. van Ballegooyen and P.D. Morant, 2000. False Bay water quality review. Volume 2: Specialist assessments and inventories of available literature and data. Report to the False Bay Water Quality Advisory Committee, CSIR Report ENV-S-C2000-086/2, Stellenbosch, South Africa.
35. Grundlingh, M.L. and E. Potgieter, 1993. Unique thermal record in False Bay. *South Afr. J. Sci.*, 89: 510-512.
36. Wells, P.G., 1999. Biomonitoring the health of coastal marine ecosystems: The roles and challenges of microscale toxicity tests. *Mar. Pollut. Bull.*, 39: 39-47.
37. Mdezeke, N.P., 2004. Contamination levels in and cellular responses of intertidal invertebrates as biomarkers of toxic stress caused by heavy metal contamination in false bay. Ph.D. Thesis, University of Stellenbosch, Cape Town
38. Varol, M., 2011. Assessment of heavy metal contamination in sediments of the Tigris River (Turkey) using pollution indices and multivariate statistical techniques. *J. Hazard. Mater.*, 195: 355-364.
39. Mmolawa, K.B., A.S. Likuku and G.K. Gaboutloeloe, 2011. Assessment of heavy metal pollution in soils along major roadside areas in Botswana. *Afr. J. Environ. Sci. Technol.*, 5: 186-196.
40. Hennig, H.F.K.O., 1985. Review of metal concentrations in Southern African coastal waters, sediments and organisms. SANSP Report No. 108, South African National Scientific Programmes Unit, South Africa, August 1985, pp: 1-140.
41. DOH., 2004. Regulations relating to maximum levels for metals in foodstuffs. Department of Health, No. R. 500, April 30, 2004.
42. El-Sammak, A.A. and T.A. Aboul-Kassim, 1999. Metal pollution in the sediments of Alexandria Region, Southeastern Mediterranean, Egypt. *Bull. Environ. Contam. Toxicol.*, 63: 263-270.