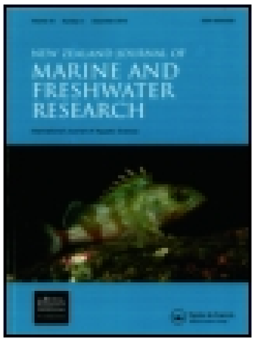

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Cadmium, lead, copper, and zinc in *Elminius modestus* Darwin (Crustacea, Cirripedia) from Waitemata and Manukau Harbours, Auckland, New Zealand

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†In memoriam B. A. Foster who died on 25 June 1992

Abstract Concentrations of cadmium (Cd), lead (Pb), copper (Cu), and zinc (Zn) were measured in adult barnacles (*Elminius modestus* Darwin) from Waitemata and Manukau Harbours in the Auckland area, New Zealand. As in studies on sediments reported in the literature, it was possible to identify areas of likely anthropogenic influence, e.g., around the Auckland Harbour Bridge for Pb, Cu, and Zn. Groups of individuals with highest concentrations for these metals showed 19.8–23.8 mg Pb kg^{-1}, 198–266 mg Cu kg^{-1}, and 4460–6530 mg Zn kg^{-1} (95% confidence limits, dry weight basis). Cd concentrations found for all barnacles from the Auckland area ranged from 0.8 to 3.1 mg kg^{-1}. Two samples from Omaha Beach, 60 km north of Auckland, were used as a reference. Accordingly, groups of individuals with lowest concentrations for Pb, Cu, and Zn could be allocated to this site using the Student-Newman-Keuls Multiple Range Test (0.5–1.3 mg Pb kg^{-1}, 8–10 mg Cu kg^{-1}, and 144–214 mg Zn kg^{-1}; 95% confidence limits). Only Cd concentrations were highest at Omaha Beach (8.6–12.1 mg Cd kg^{-1}). This result may have arisen from "naturally" increased bio-availabilities of certain metals in mangrove systems which are reported in the literature. Generally, metal concentrations in barnacles from the Auckland Harbour area and from Omaha Beach were within the wider range for *E. modestus* as well as other barnacle species reported in the international literature.

Keywords heavy metals; biomonitoring; Cirripedia; *Elminius modestus*

INTRODUCTION

The animal communities in the Auckland harbours, New Zealand, were described first by Powell (1937). More recent examinations on fouling species in Auckland harbour areas were undertaken by Skerman (1959), Luckens (1976), and Dromgoole & Foster (1983). The barnacle *Elminius modestus* Darwin is a common and readily available species (Foster 1978). Because barnacles are sessile and relatively long-lived they reflect prolonged conditions of the place where they occur. Generally, barnacles show selective uptake of some metals, for example, zinc (Zn) (Walker et al. 1975a, 1975b; Walker & Foster 1979; Zauke et al. 1985, 1988; Rainbow 1987; Pullen & Rainbow 1991). According to their accumulation strategy, they can be classified as "non-regulators" (Phillips & Rainbow 1989; Rainbow & White 1989). As biomonitors they can be used to differentiate between general background levels and responses to increased bio-available environmental supply (Phillips & Rainbow 1988; Powell & White 1990; Al-Thaqafi & White 1991). In this paper we have extended this approach to *E. modestus* from Auckland waters in New Zealand where industrial development and associated pollution is less intensive than in European waters.

STUDY AREA

Elminius modestus was sampled in the two harbours of the Auckland area, and at Omaha Beach (Whangateau) near Leigh, 60 km north of Auckland's

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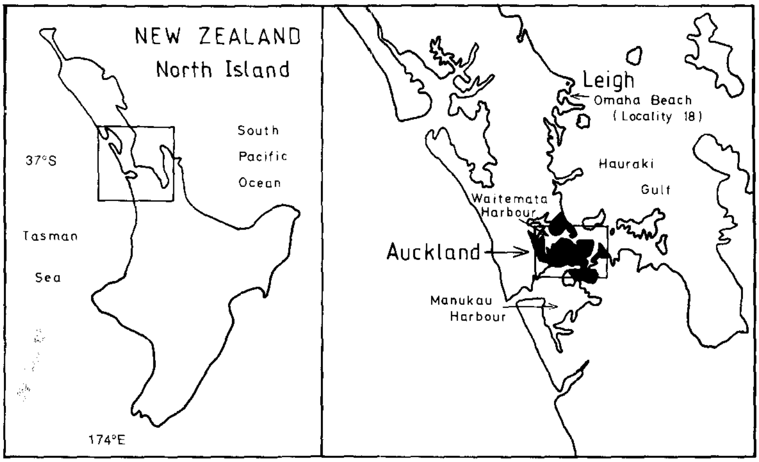


Fig. 1 Study area in the North Island of New Zealand covering the Waitemata and Manukau Harbours (Auckland) and Omaha Beach (Site 18), 60 km further north.

urban and industrial area (Fig. 1). Both the Waitemata and Manukau Harbours are typically drowned river valleys containing extensive intertidal mudflats (Bartrum 1917). Apart from the main channels, the harbours are very shallow, mostly 2 m deep or less. More detailed information is given in Chart NZ 5322 of the Royal New Zealand Navy, Hydrographic Branch. Hydrological data are summarised by Slinn (1968).

METHODS

Adult *E. modestus* were collected in May 1984 at 17 sites around Auckland (Fig. 2). The Manukau Sewage Purification Works (MSPW), which collects the bulk but not all of the urban water-borne wastes, discharges into the Manukau Harbour. Storm water drain overflows, containing non-sewage-borne pollutants, occur periodically around all Auckland's shores. For each site, two independent samples were taken from various substrates during low tide within the upper intertidal zone (see Table 2). For Sites 5, 6, and 7 only one sample could be collected. The number of individual barnacles in each independent sample varied from 60 to 200. Two additional samples were taken at Omaha Beach (Site 18, Fig. 1). We tried to collect organisms within a rather narrow range of size (Table 2). Defaecation was not applicable in this study, as in many other field studies on barnacles. In any event, it has been suggested that depuration has little effect on trace metal levels in the species studied (e.g., Phillips & Rainbow 1988).

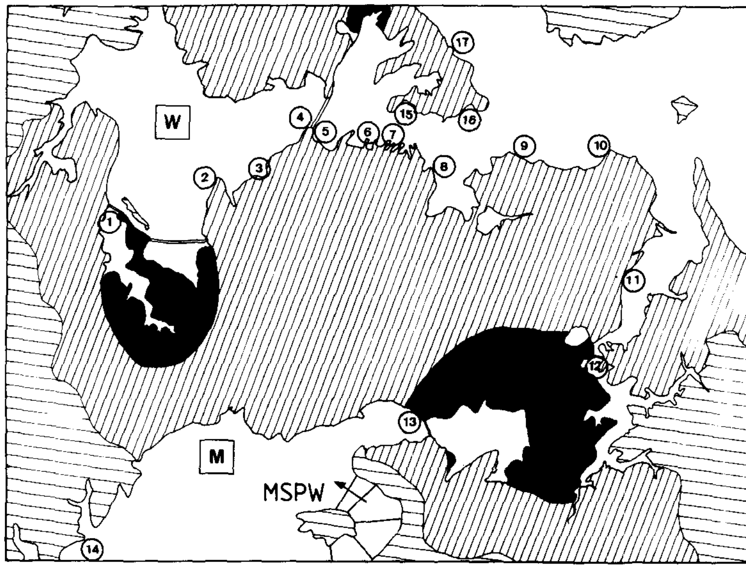
In the laboratory, the organisms were briefly heated to ease separation of soft tissues from shells (including bodies, mantle tissue, membranous base, and egg masses), dried at 50°C for 12 h, and stored in polypropylene Eppendorf tubes. The dried material was transferred to the University of Oldenburg, Germany, for determination of selected heavy metals.

ANALYTICAL PROCEDURES

The samples were homogenised using a boron carbide mortar and pestle, followed by a wet ashing micro-procedure. Aliquots of about 5 mg dried material were first digested with 50 µl HNO_3 (70–71%, Baker Instra-Analysed) in 1.5 ml polypropylene Eppendorf tubes (4 h; 96°C) and then treated with 20 µl H_2O_2 (30%, suprapure, Merck; 1 h; 56°C). This procedure had been validated by comparison with a pressure digestion method (Kotz et al. 1972; Zauke et al. 1986). Precautions were taken to avoid contamination: the digested samples came into contact with only the polypropylene reaction tubes and white micropipette tips (Finnpipette Ky, Helsinki). After appropriate dilution, the final sample and standard solutions were adjusted to concentrations of 1.75% HNO_3 and 2% Triton X-100.

Cadmium (Cd), lead (Pb), and copper (Cu) concentrations were determined by sequential multi-element graphite tube atomic absorption spectroscopy (Varian Techtron, AA-975, GTA-95, platform atomisation). Samples were dried in the GTA-95 at 150°C (40 s). For Cd and Pb, a palladium nitrate-magnesium nitrate matrix modifier was applied (Yin et al. 1987), allowing for ashing temperatures of 800 and 1000°C, respectively (ramp 10 s, hold 20 s). The ashing temperature for Cu was 700°C. Atomisation

Fig. 2 Auckland area with harbour sampling sites:
1, Whau-River, Bridge Ave wharf; 2, Pt Chevalier; 3, Coxs Bay, Coxs Creek; 4, Harbour Bridge; 5, Harbour Bridge, Westhaven boat harbour; 6, Port of Auckland, Princes Wharf; 7, Port of Auckland, Marsgen Wharf; 8, Hobson Bay, Point Resolution; 9, Mission Bay; 10, St Heliers Bay; 11, Tamaki Inlet, Riverside Ave Wharf; 12, Panmure Basin, end of Penrose Rd; 13, Onehunga Wharf; 14, Titirangi Beach, south-west of Auckland; 15, Stanley Bay; 16, Torpedo Bay; 17 Narrow Neck Beach. Site 18 (Omaha Beach) is outside this area (see Fig. 1). W, Waitemata Harbour; M, Manukau Harbour.



Near vertical hatching indicates domestic areas; near horizontal hatching indicates non-domestic areas; main industrial areas are indicated black. ← Discharge of Manukau Sewage Purification Works (MSPW) at Manukau Harbour.

temperatures were 1800°C for Cd, 2400°C for Pb, and 2300°C for Cu; the wavelengths used were 228.8, 217.0, and 324.8 nm, respectively. Zn was determined in an air-acetylene flame at 213.9 nm using a manual micro-injection method (100 µl sample volume). For all determinations, deuterium background correction was applied.

For each sample collected in the field, five independent parallel subsamples were analysed randomly to avoid possible systematic errors of the complete analytical procedure. Quality assurance was performed using the following criteria: stability of recalibration; precision of parallel injections (normally showing a coefficient of variation between 1 and 5%); analytical blanks (also reflecting the digestion procedure); and precision and validity of two certified reference materials which were randomly allocated within the determinations (see Table 1). Limits of detection were calculated as 2.6 standard deviations of a "low sample" (Büttner et al. 1980), preferably using reference materials. All metal concentrations are expressed as mg kg^{-1} dry weight.

STATISTICAL PROCEDURES

The statistical analysis was performed using the package BMDP 88 (IBM PC/DOS), especially Programs 7d and 2d (Dixon et al. 1988). Groups were identified by the Student-Newman-Keuls Multiple Range Test at the 95% level of significance. The results were confirmed by the Tukey Studentised Range Method adjusted for multiple comparisons (not shown in this paper).

RESULTS

In general, analysed values for two reference materials agreed well with certified ones (Table 1). Larger differences for Pb in the oyster tissue occurred because these concentrations were close to our limits of detection: 0.10 mg Cd kg^{-1}, 0.7 mg Pb kg^{-1}, 4 mg Cu kg^{-1}, and 16 mg Zn kg^{-1}. Coefficients of variation in the reference samples were in most instances between 5 and 25 % which is within the expected range of the analytical procedure (Zauke et al. 1986). The same was true for concentrations of Cd, Cu, and Zn in five independent subsamples of *E. modestus* from the Auckland area (Table 2); we found a greater variability only for Pb. The two independent parallel samples taken at the majority of the sites (referred to as 1.1 and 1.2 etc.) in most instances agreed well, whereas the variability between sites was notable.

Correlation analyses using metal concentrations in barnacles and biological variables (Table 2) did

Table 1 Quality assurance using certified reference materials randomly allocated within the determinations. Values given are means ± SD (dry weight).

	NIST SRM 1566 (Oyster tissue)			IAEA MA-A-1 (Copepod)		
	Analysed (mg kg^{-1})	*N*	Certified (mg kg^{-1})	Analysed (mg kg^{-1})	*N*	Certified (mg kg^{-1})
Cd	3.7 ± 0.4	7	3.5 ± 0.4	0.58 ± 0.03	7	0.75 ± 0.03
Pb	0.74 ± 0.22	6	0.48 ± 0.04	1.7 ± 0.4	7	2.1 ± 0.3
Cu	72 ± 9	7	63 ± 3.5	6.4 ± 1.3	7	7.6 ± 0.2
Zn	723 ± 77	4	852 ± 14	127 ± 35	4	158 ± 2

N, number of independent determinations.

Table 2 Metal concentrations and some biological data of soft tissues of *Elminius modestus* from Waitemata and Manukau Harbours and adjacent waters. Metal values given are means ± SD representing five independent determinations of dry weight, biological data are means. Two numbers for the same locality refer to independent parallel samples taken in the field. Size, basal diameter; DW, dry weight; Fec, fecundity (egg-carrying females); Sub, substrates from which barnacles were collected: S, shells; L, lava; W, wood; SG, shells and gravel; G, gravel; C, concrete; M, mangroves.

No. Site	Cd (mg kg^{-1})	Pb (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Size (mm)	DW (mg)	Fec (%)	Sub
1.1 Whau-River	2.5 ± 0.1	14.3 ± 0.9	232 ± 27	3130 ± 359	6.2	1.4	5	S
1.2 Whau-River	0.8 ± 0.1	6.7 ± 1.6	56 ± 4	974 ± 97	6.6	1.7	50	S
2.1 Point Chevalier	0.9 ± 0.1	7.8 ± 1.7	32 ± 4	790 ± 57	7.1	1.6	70	L
2.2 Point Chevalier	1.5 ± 0.3	8.4 ± 1.6	31 ± 2	1530 ± 214	6.7	1.5	70	L
3.1 Coxs Bay	1.0 ± 0.1	21.5 ± 5.2	37 ± 9	3020 ± 168	4.0	0.6	20	W
3.2 Coxs Bay	1.0 ± 0.1	18.4 ± 0.6	40 ± 2	3330 ± 495	4.2	0.6	20	W
4.1 Harbour Bridge	2.9 ± 0.2	19.8 ± 2.9	95 ± 6	2420 ± 252	4.5	0.3	5	SG
4.2 Harbour Bridge	2.7 ± 0.1	21.6 ± 2.9	84 ± 26	2410 ± 74	4.5	0.3	5	SG
5.0 Westhav. Harb.	2.0 ± 0.2	48.5 ± 15.2	141 ± 35	5500 ± 652	4.0	0.2	5	G
6.0 Princes Wharf	2.1 ± 0.2	19.0 ± 1.8	58 ± 3	3080 ± 257	5.5	0.6	10	C
7.0 Marsgen Wharf	1.4 ± 0.1	24.0 ± 1.6	40 ± 1	2910 ± 204	3.9	0.5	1	C
8.1 Hobson Bay	1.9 ± 0.1	6.3 ± 0.4	52 ± 2	1140 ± 117	5.2	0.6	5	SG
8.2 Hobson Bay	1.7 ± 0.1	5.5 ± 1.1	44 ± 2	1150 ± 75	5.2	0.5	5	SG
9.1 Mission Bay	1.8 ± 0.2	4.9 ± 0.3	43 ± 3	1910 ± 92	4.2	0.3	1	G
9.2 Mission Bay	1.8 ± 0.1	4.8 ± 0.9	39 ± 3	1880 ± 179	3.9	0.3	1	G
10.1 St. Heliers Bay	2.1 ± 0.1	6.7 ± 0.9	46 ± 4	1880 ± 171	4.8	0.3	5	G
10.2 St. Heliers Bay	1.8 ± 0.2	8.7 ± 3.0	27 ± 2	1580 ± 187	3.9	0.2	5	G
11.1 Tamaki Inlet	1.3 ± 0.1	12.7 ± 1.6	155 ± 21	1540 ± 154	5.5	0.7	20	W
11.2 Tamaki Inlet	1.2 ± 0.1	6.9 ± 0.5	62 ± 3	982 ± 115	5.1	1.5	70	W
12.1 Panmure Basin	1.7 ± 0.1	6.1 ± 1.0	57 ± 3	1480 ± 187	5.7	1.8	50	W
12.2 Panmure Basin	1.4 ± 0.1	5.7 ± 0.6	57 ± 4	1300 ± 273	5.9	2.2	60	W
13.1 Onehunga Wharf	3.1 ± 0.1	9.5 ± 2.7	63 ± 2	3220 ± 318	6.8	0.9	5	G
13.2 Onehunga Wharf	2.9 ± 0.1	6.8 ± 1.3	62 ± 2	3100 ± 318	6.6	0.9	5	G
14.1 Titirangi Beach	2.9 ± 0.1	4.2 ± 0.5	37 ± 5	1180 ± 138	6.4	1.3	30	SG
14.2 Titirangi Beach	2.5 ± 0.1	3.9 ± 0.8	38 ± 2	969 ± 126	6.7	1.2	30	SG
15.1 Stanley Bay	1.7 ± 0.1	19.0 ± 1.0	66 ± 2	2160 ± 475	4.9	0.3	5	G
15.2 Stanley Bay	1.9 ± 0.1	25.3 ± 6.3	67 ± 6	2230 ± 115	4.2	0.3	5	G
16.1 Torpedo Bay	2.2 ± 0.1	6.8 ± 1.2	36 ± 3	2360 ± 259	3.2	0.2	1	G
16.2 Torpedo Bay	2.3 ± 0.2	5.7 ± 1.0	36 ± 1	2260 ± 163	3.1	0.2	1	G
17.1 Nar. Neck Beach	2.6 ± 0.1	3.6 ± 0.9	27 ± 9	1250 ± 44	4.5	0.6	10	S
17.2 Nar. Neck Beach	2.8 ± 0.1	4.0 ± 2.3	33 ± 2	1230 ± 104	4.6	0.6	5	S
18.1 Omaha Beach	7.7 ± 0.3	0.9 ± 0.4	9 ± 1	176 ± 57	6.4	2.3	100	M
18.2 Omaha Beach	10.4 ± 1.4	0.8 ± 0.7	9 ± 1	182 ± 46	6.0	2.1	100	M

Correlation analyses: Pb versus dry weight ($r = -0.432$); Zn versus dry weight ($r = -0.543$)
Zn versus fecundity ($r = -0.599$); Cd versus fecundity ($r = 0.478$)

not give highly significant results. Only slight linear relationships for Pb versus dry weight, Zn versus dry weight, Zn versus fecundity, and Cd versus fecundity were indicated by the corresponding correlation coefficients.

Different groups identified for each metal by the Student-Newman-Keuls Multiple Range Test are characterised in Table 3. The geographical distributions of these groups are shown in Fig. 3–6.

For Cd, highest concentrations were found in Omaha Beach (Groups D and E, Fig. 1), whereas Group C represents the highest levels in the Auckland area (Fig. 3 and Table 3). The latter group is found in the Manukau Harbour, at the Auckland Harbour Bridge, Whau River, and Narrow Neck Beach. At Whau River a considerable heterogeneity was indicated by the presence of Group C as well as Group A.

Two different concentrations of Pb were found in the Auckland area (Fig. 4) but the lowest concentration was at Omaha Beach (Group A, Fig. 1). The higher concentrations occurred throughout the Port area and at Whau River where the same heterogeneity was observed as for Cd.

For Cu, apart from lowest Omaha Beach samples (Group A, Fig. 1), five groups could be distinguished (Fig. 5). Highest levels occurred at the Auckland Harbour Bridge and Whau River where the same heterogeneity occurred as for Cd and Pb. Furthermore, high levels occurred at the sampling site in the Tamaki Inlet.

For Zn, a similar pattern to Cu was apparent (Fig. 6), with highest levels around the Auckland Harbour Bridge and the mouth of Waitemata Harbour; concentrations were lowest again at Omaha Beach (Group A, Fig. 1). The two samples at Whau River again showed a heterogeneity. In addition, high levels were observed at Onehunga Wharf.

DISCUSSION

A statistical description of the groups identified by the Student-Newman-Keuls Multiple Range Test is given in Table 3. The narrow 95%-confidence limits indicate a significant increase in metal concentrations between the groups. The values for skewness and kurtosis, as well as for the Shapiro-Wilk statistic, support in most instances the hypothesis of a normal

Table 3 Metal concentrations (mg kg^{-1} dry weight) in soft tissues of *Elminius modestus* from Waitemata and Manukau Harbours and adjacent waters. Descriptive statistics of groups identified by the Student–Newman–Keuls Multiple Range Test. E, Element; G, group; *N*, number of independent samples; 95% CL, confidence limit; Skew: skewness; Kurt, kurtosis; W, Statistic of the Shapiro-Wilk test of normality; W_{ln}, W-statistic after ln-transformation; $P_{(W)}$ or $P_{(Wln)}$, significance level, the null hypothesis (normal or ln–normal distribution) has to be rejected if $P < 0.05$; nc, = not computed because of small *N*.

E	G	N	Mean	95% CL	Skew	Kurt	W	$P_{(W)}$	W_{ln}	$P_{(Wln)}$
Cd	A	30	1.1	1.0 – 1.1	0.42	−1.08	0.93	0.06	0.95	0.17
	B	77	1.8	1.8 – 1.9	0.19	−0.42	0.97	0.25	0.97	0.15
	C	45	2.8	2.7 – 2.8	0.01	−1.00	0.97	0.38	0.97	0.36
	D	5	7.7	7.3 – 8.2	nc	nc	nc	nc	nc	nc
	E	5	10.4	8.6 – 12.1	nc	nc	nc	nc	nc	nc
Pb	A	10	0.9	0.5 – 1.3	−0.17	−1.34	0.96	0.82	0.76	0.01
	B	103	6.5	6.0 – 7.0	1.23	1.90	0.90	0.00	0.98	0.43
	C	47	21.8	19.8 – 23.8	2.03	4.61	0.79	0.00	0.91	0.00
Cu	A	10	9	8 – 10	1.09	0.24	0.86	0.08	0.90	0.21
	B	78	37	35 – 38	−0.68	1.14	0.97	0.36	0.89	0.00
	C	50	60	59 – 62	0.29	−0.06	0.98	0.63	0.98	0.74
	D	8	96	91 – 100	0.53	−1.38	0.90	0.29	0.91	0.36
	E	9	148	128 – 169	−1.05	−0.23	0.85	0.08	0.79	0.02
	F	5	232	198 – 266	nc	nc	nc	nc	nc	nc
Zn	A	10	179	144 – 214	0.14	−1.41	0.97	0.87	0.96	0.78
	B	68	1220	1150 – 1280	0.35	−0.64	0.95	0.03	0.97	0.19
	C	40	2160	2060 – 2250	0.55	−0.13	0.96	0.32	0.98	0.74
	D	35	3110	3010 – 3220	0.29	−1.13	0.94	0.08	0.95	0.10
	E	4	5500	4460 – 6530	nc	nc	nc	nc	nc	nc

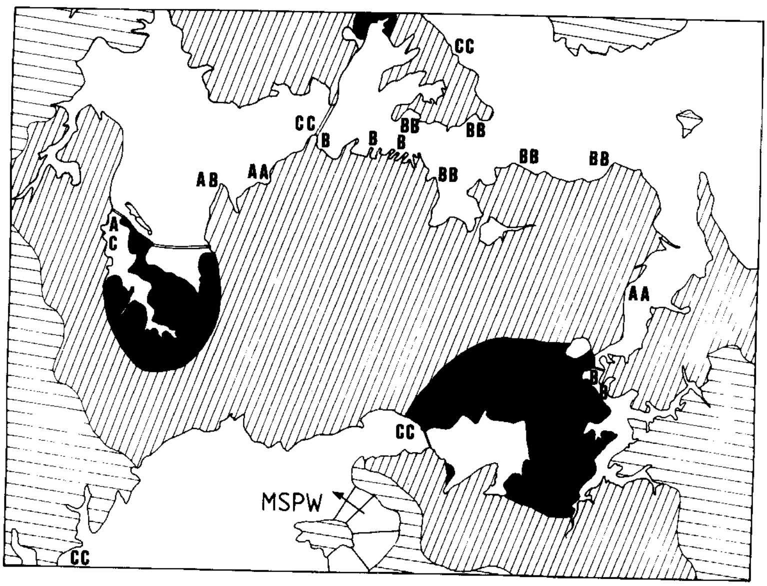


Fig. 3 Groups of Cd concentrations in *Elminius modestus* from Auckland harbours. Mean Cd concentrations (mg kg^{-1} dry weight) in parentheses, see Table 3: Group A (1.1); Group B (1.8); Group C (2.8). Omaha Beach, Group D (7.7) and E (10.4), is outside this area (see Fig. 1). Geographical distribution of groups was identified by the Student-Newman-Keuls Multiple Range Test. Two letters at one site refer to independent parallel samples. MSPW, Manukau Sewage Purification Works.

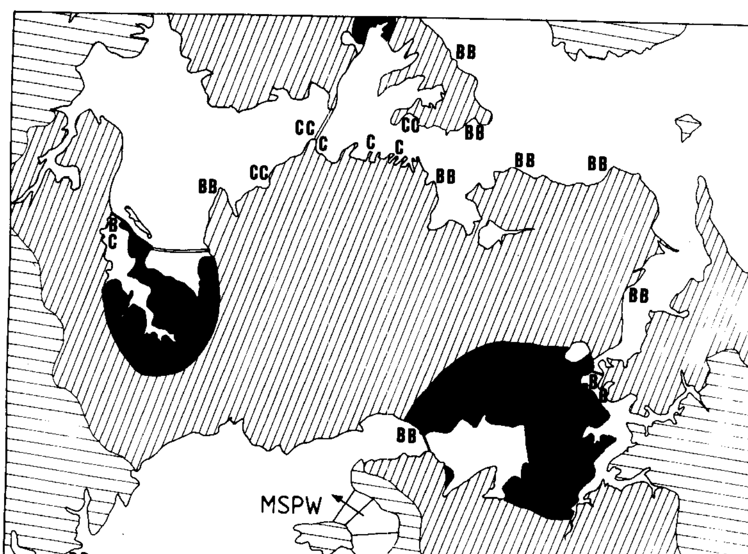


Fig. 4 Groups of Pb concentrations in *Elminius modestus* from Auckland harbours, and mean Pb concentrations (mg kg^{-1} dry weight): Group B (6.5); Group C (21.8). Omaha Beach: Group A (0.9). Otherwise as in Fig. 3.

or at least a ln-normal distribution. Therefore, we regard the groups identified by the statistical procedure as consistent sets of data.

We intended to use the site Omaha Beach as a reference for normal background contamination, since it is away from industrial and domestic areas and does not show anthropogenic influence. Accordingly, groups with lowest Pb, Cu, and Zn concentrations in barnacles could be allocated to this site but this was not the situation for Cd concentrations which were highest here.

It seems unlikely that biological variability of barnacles from Omaha Beach accounted for this result, since e.g., size and dry weight were within the range found for other sites (Table 2) and no highly significant relationships were found between Cd and these variables. Only fecundity was highest at Omaha Beach and a slight positive correlation of this variable with

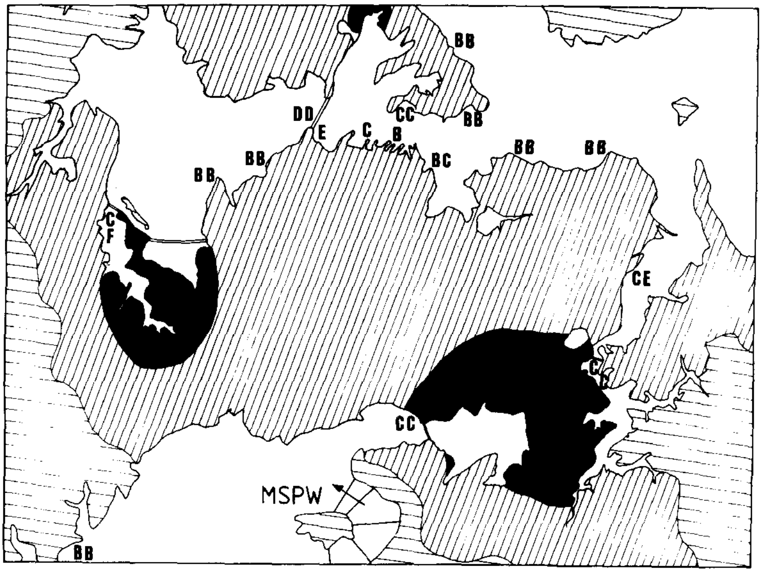


Fig. 5 Groups of Cu concentrations in *Elminius modestus* from Auckland harbours, and mean Cu concentrations (mg kg^{-1} dry weight): Group B (37); Group C (60); Group D (96); Group E (148); Group F (232). Omaha Beach: Group A (9). Otherwise as in Fig. 3.

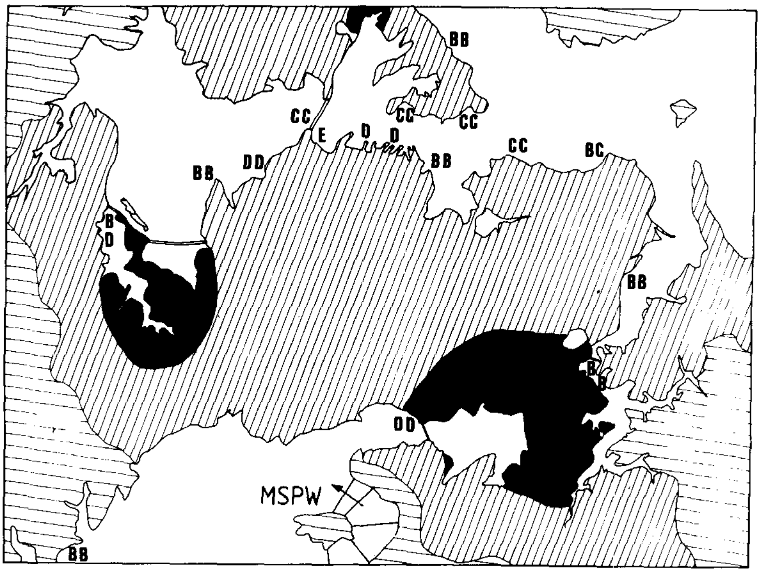


Fig. 6 Groups of Zn concentrations in *Elminius modestus* from Auckland harbours, and mean Zn concentrations (mg kg^{-1} dry weight): Group B (1220); Group C (2160); Group D (3110); Group E (5500). Omaha Beach: Group A (179) Otherwise as in Fig. 3.

Cd (r = 0.478) was noted. Salinity at this site was within the normal sea water range and no freshwater influence was recognised. In general, the salinity range was rather narrow in the entire area under investigation (33.3–35.1‰; Slinn 1968; Pridmore et al. 1990).

Only the substrates from which the barnacles were sampled at Omaha Beach differed from all other sites (mangroves, Table 2). Mangrove mud has an enhanced capacity for metal accumulation on the one hand, but extreme diurnal variations in Eh and pH on the other hand could alter the concentration of certain dissolved metals and probably increase their availability to marine organisms (Harbison 1986). Influences on the bio-availability of metals to organisms settling on other substrates (shells, lava, wood, gravel, and concrete) are not reported in the literature.

A comparison of heavy-metal concentrations in different barnacle species throughout the world is given in Table 4. It should be stressed that interspecific comparisons of metal concentrations even in closely related species may be of limited value (see Phillips & Rainbow 1988) unless a "calibration" has been done. This involves information of the kinetics of uptake and clearance of metals, for example, obtained from bio-accumulation experiments in flow-through systems under field conditions or from reciprocal transplant field experiments (see Roesijadi et al. 1984, Zauke et al. 1988, Al-Thaqafi & White 1991). Antagonistic effects as described by Elliot et al. (1985) also have to be taken into account. However, such "calibration" of monitor organisms is neglected in most field studies (including ours), since it is very expensive and requires great logistic effort.

Nevertheless, we suggest the following preliminary conclusions. Cd levels in *E. modestus* from the Auckland Harbour region were at the lower end

Table 4 Metal concentrations in barnacles from different regions of the world. Values given are means (mg kg^{-1} dry weight) based on tissues indicated. T, tissues analysed: s, soft tissues (including bodies, mantle tissue, membranous base, and egg masses); b, bodies. nd, not detectable.

Species	Region	Cd	Pb	Cu	Zn	T
Elminius modestus	Auckl. Harb. Bridge (NZ)[1]	2.8	21	90	2400	s
	Omaha Beach (NZ)[1]	9.1	0.9	9	179	s
	Southend, Essex (UK)[2]	22		80	9000	b
	Southend, Essex (UK)[3]	17		117	7200	b
	Southend, Essex (UK)[4]	7.7	5.0	94	8765	b
	Southend, Essex (UK)[4]	9.4	25	95	8569	b
	Menai Strait (Wales)[5]			80	3000	b
	Dulas Bay, Anglesey (UK)[5]			250	4000	b
Capitulum mitella	Hung Hom (Hong Kong)[6]	10.0	8.5	545	19890	b
	Queens Pier (Hong Kong)[6]	2.9	3.1	154	4170	b
Tetraclita squamosa	Hung Hom (Hong Kong)[6]	2.8	4.4	95	6963	b
	Queens Pier (Hong Kong)[6]	3.6	3.9	80	4086	b
Balanus amphitrite	North Point (Hong Kong)[6]	10.1	8.5	1010	7870	b
	Zuari-estuary (India)[7]			210	530	s
	Zuari-estuary (India)[8]			170	920	s
	Grado (Italy)[9]		10	54		s
	Venice (Italy)[9]		10	109		s
	Rio Tinto (Spain)[10]	12		580	2500	s
B. improvisus	Ems-estuary (Germany)[11]	3.6	7.4	37	7420	s
	Weser-estuary (Germany)[11]	5.7	5.3	53	12900	s
B. improvisus/B. crenatus	Elbe-estuary (Germany)[11]	2.4	4.9	47	7500	s
B. eburneus	Florida (USA)[12]			15	500	s
	Florida (USA)[12]			45	7000	s
B. balanoides	Alltwen (UK)[13]			100	7000	b
	Alltwen (UK)[13]			700	30000	b
	Constitution Hill (UK)[13]			100	3000	b
	Constitution Hill (UK)[13]			300	12000	b
	Dulas Bay, Anglesey (UK)[14]		nd	3800	50000	b
Semibalanus balanoides	Dulas Bay, Anglesey (UK)[15]	60	4.9	3230	113000	b
	Southend, Essex (UK)[15]	10		232	28000	b
Chthalamus stellatus	SW Spain and Portugal[10]	6		8	170	s

Balanus balanoides is synonymous to *Semibalanus balanoides*

References
[1]present paper
[2]Rainbow (1985)
[3]Rainbow & White (1989)
[4]Pullen & Rainbow (1991)
[5]Al-Thaqafi & White (1991), values taken from figures
[6]Phillips & Rainbow (1988)
[7]Anil & Wagh (1988), shipyard stations
[8]Anil & Wagh (1988), harbour stations
[9]Barbaro et al. (1978)
[10]Stenner & Nickless (1975)
[11]Zauke et al. (1988)
[12]Barber & Trefry (1981), values taken from figures
[13]Ireland (1974)
[14]Walker (1977)
[15]Rainbow et al. (1980)

of the range reported in the literature. Even the enhanced levels in barnacles from Omaha Beach (see above) were within the wider reported range for *E. modestus* as well as other barnacle species. However, Pb levels around Auckland Harbour Bridge seemed to be relatively high compared to literature data from outside New Zealand. Our values for Cu and Zn were at the lower end of the ranges shown in Table 4 for Omaha Beach samples and well within the reported range for Auckland Harbour Bridge samples.

Levels of heavy metals in New Zealand sea water have been reviewed by Smith (1986), who noted that for Cu, Ni, Pb, and Zn, anthropogenic inputs exceed natural inputs in some urbanised areas. In recent evaluations of Auckland's aquatic environment, heavy-metal levels in marine sediments were analysed by Agget & Simpson (1986), Glasby et al. (1988), and Roper et al. (1988). They detected high levels of Pb, Cu, and Zn in the Mangere Inlet of the Manukau Harbour (east of Site 13 in Fig. 2) and a decreasing gradient along the Wairopa Channel downstream from the Inlet. In the Waitemata Harbour, Glasby et al. (1988) detected undesirable, but not critically high levels of Pb, Zn, and Cu off Pt Chevalier (Site 2 in Fig. 2), in the Avondale-Whau River area (Site 1), and somewhat lower but still significant levels in the main shipping port. These were all higher for Pb and Zn than in Mangere Inlet sediments, but not as high for Cu. Glasby et al. (1988) concluded these were "almost certainly the result of anthro-pogenic inputs", including industrial and domestic discharges, motor vehicle exhaust emissions (Pb), and vehicle tyre wear (Zn) at stormwater run-off discharge points. Cd levels were low.

New Zealand studies on heavy-metal levels in biota tissue are limited to Manukau Harbour. In the Waiuku River near the Glenbrook Steel Mill, heavy-metals data on bivalves and crabs (reported in Smith 1986) are not comparable to our data on barnacles. Unpublished studies on oysters (Auckland Regional Water Board 1988; Auckland Regional Authority 1989) detected localised high tissue concentrations of Cu and Zn in the Mangere Inlet (Zn $\geq$ 4000 mg kg^{-1} and Cu $\geq$ 1200 mg kg^{-1}), with a decreasing gradient down harbour from Onehunga (see Pridmore et al. 1990 and Roper et al. 1991). A similar trend was indicated for Pb, Cu, and Zn in *E. modestus* when comparing Sites 13 and 14 (Table 2).

Our observed concentrations in barnacles are generally at the lower end of overseas reported data. But we can identify areas of likely anthropogenic input of Pb, Cu, and Zn, as in the Glasby et al. (1988) study on sediments: e.g., around the Auckland Harbour Bridge—probably being related to traffic, recreational boat moorings, and several stormwater inputs of the drainage system in this area.

One important conclusion from our biomonitoring study is that this anthropogenic influence did not only reflect an increased total environmental supply of metals but also enhanced bio-availability to marine organisms. Similar trends showed up by the oyster study mentioned above, and our barnacle data support this conclusion. However, the problem of "calibration" of biomonitors should be addressed in future studies as well as the possibility of "naturally" increased bioavailability, for example in the mangrove system as we found at Omaha Beach.

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