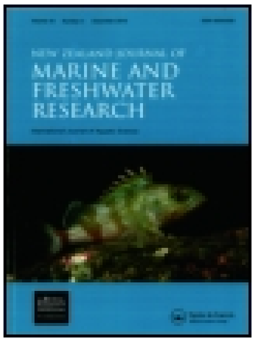

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HEAVY METAL LEVELS IN NEW ZEALAND MOLLUSCS

STEPHEN A. NIELSEN and ADRIENNE NATHAN

Fisheries Research Division, Ministry of Agriculture and Fisheries, P.O. Box 19062, Wellington, New Zealand

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ABSTRACT

Cadmium, lead, copper, mercury, zinc and iron were analysed by atomic absorption spectrophotometry in 13 species of edible molluscs from 199 sites around New Zealand; these included all molluscs commonly eaten in New Zealand. From each sampling site, a minimum of 14 specimens were combined and analysed together, so that the result would be representative of the population in that area. Wide variations are shown to occur in heavy metals from one location to another, and explanations for some of these variations are given.

INTRODUCTION

Much of the past work on heavy metal levels in marine organisms was directed toward understanding the mechanisms and rate of metal uptake, the effect of metals on the organism, and the concentration factor between organism and environment (Galtsoff 1964). The recent appreciation of the toxicity to human consumers of certain heavy metals, especially mercury, cadmium, and lead has directed research toward delineating potential health hazards among the consumable marine organisms (Thrower & Eustace 1973).

Shellfish, particularly filter feeders such as bivalve molluscs, are especially prone to accumulate certain heavy metals. Cadmium levels in excess of 3 $\mu g \cdot g^{-1}$ wet weight (Nielsen, in press) and zinc levels in excess of 1000 $\mu g \cdot g^{-1}$ wet weight (Thrower & Eustace 1973) in oysters are not uncommon. Lead levels of over 7 $\mu g \cdot g^{-1}$ wet weight have been found in New Zealand green-lipped mussels, *Perna canaliculus* (this study).

Previous studies of heavy metal levels in New Zealand shellfish (Brooks & Rumsby 1965, 1967) have been done on a few species from a small area. The present study comprises a comprehensive survey of heavy metal levels in some marine molluscs from New Zealand. An effort was made to obtain samples from as many widely separated areas as possible with special emphasis on edible species, particularly bivalves, of commercial importance. A total of 13 molluscan species (including one gastropod) and 199 sampling sites were examined. Species analysed were: rock oyster *Crassostrea glomerata*, dredge oyster *Ostrea lutaria*, green-lipped mussel *Perna canaliculus*, blue mussel *Mytilus edulis*, scallop *Pecten novaezelandiae*, toheroa *Paphies ventricosa*, ridged mussel

Aulacomya maoriana, paua (abalone) *Haliotis iris*, pipi *Paphies australis*, tuatua *Paphies subtriangulata*, saddle oyster *Anomia walteri*, cockle *Chione stutchburyi*, and black mussel *Modiolus neozelanicus*.

Primarily, cadmium, lead, zinc, copper, and iron were analysed, but some representative analyses of mercury were done. In three instances, namely, Wellington, Foveaux Strait, and Tasman Bay, sampling sites were planned so that information regarding the geographic distribution of heavy metals in species from these areas could be obtained. The results from Foveaux Strait have been reported elsewhere already (Nielsen, in press), but the Wellington and Tasman Bay results are presented here (see Figs 2 and 3).

METHODS

Samples were collected from the intertidal zone by hand, by diving, or by wading, or, when deeper water species were required, with either of the two Fisheries Research Division vessels. The samples were then returned frozen to the laboratory for analysis. A minimum of 14 individuals (unusually large or small individuals were not included) of each species from each point of collection were combined and homogenized for the analyses, in order to give an average value which would be representative of the total population in that area. After homogenization with a Waring Blender, 10 g aliquots were dried for 12 h at 100°C, then ashed for 12 h at 450°C. At this relatively low ashing temperature, recovery of the metals examined (with the exception of mercury) was good (Pijck *et al.* 1961). Metals in the ash were dissolved in 10 ml 3M HNO_3 and analysed by atomic absorption spectrophotometry. For the recovery experiments, three analyses were done for each metal, with 2 μg of metal added per millilitre of homogenate. The percent recoveries and ranges were: Cd 100 ± 2%, Zn 99 ± 2%, Pb 93 ± 4%, Fe 84 ± 3%, Cu 100 ± 1%. The results in the Appendix are not corrected for the above recovery factors. A hydrogen lamp was not used to compensate for scattering effects for lead. Thus, the reliability of lead values less than 0.5 $\mu g \cdot g^{-1}$ is questionable, but they have been included to indicate the probable existence of trace levels.

Because of its volatility, mercury analysis cannot be done by the dry ashing technique described above, but the cold vapour method of Stux & Rothery (1971) was excellent for analysing large numbers of samples. To obtain complete digestion of molluscs 1.0 g (wet weight) of sample should be refluxed in a mixture of 5 ml 16M HNO_3 and 2 ml 36M H_2SO_4 for one hour. Analysis may then proceed as described by Stux & Rothery. Recovery of 1.0 $\mu g \cdot g^{-1}$ added mercury was 100 ± 3%.

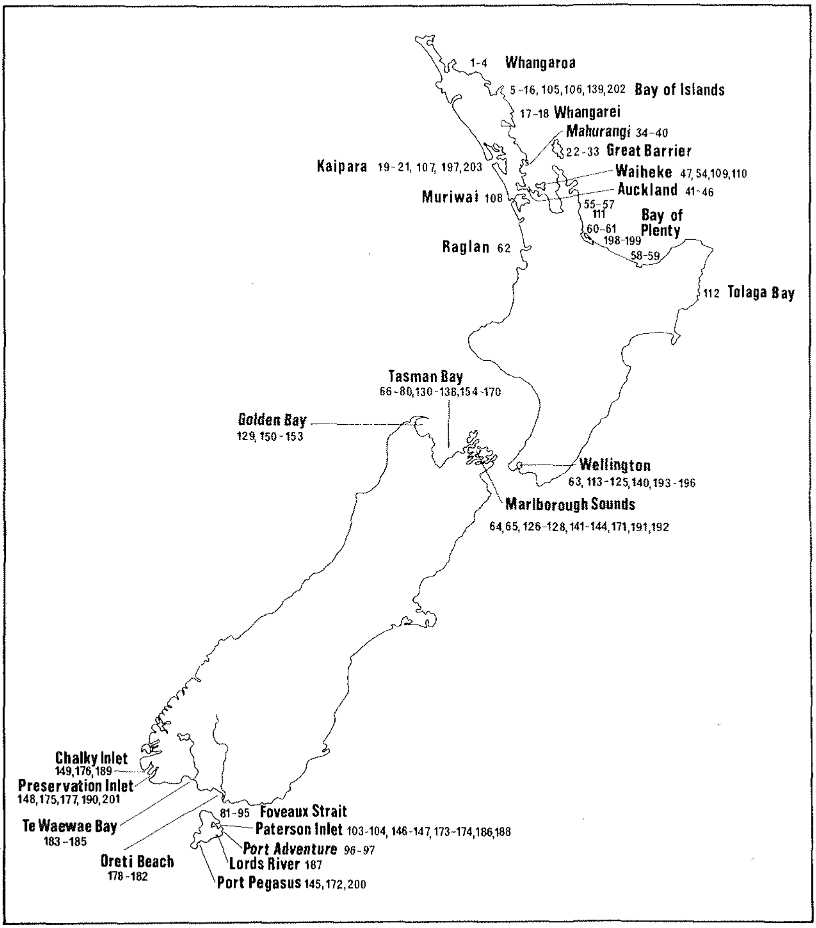

FIG. 1—Location around the New Zealand coast of numbered samples of molluscs analysed for heavy metal concentrations. Numbers correspond with sample numbers in Appendix 1.

RESULTS AND DISCUSSION

The Appendix includes the species and location index and gives metal analyses in micrograms per gram wet weight. Dry weight figures are available from the authors, but are not included here because the present paper is orientated towards consumable levels of heavy metals.

Figure 1 shows the areas of collection. The analyses are arranged by species and then by geographic location from north to south. Unless otherwise specified, the whole soft part of the mollusc was used for analysis. The one exception was the scallop *Pecten novaezelandiae*, in

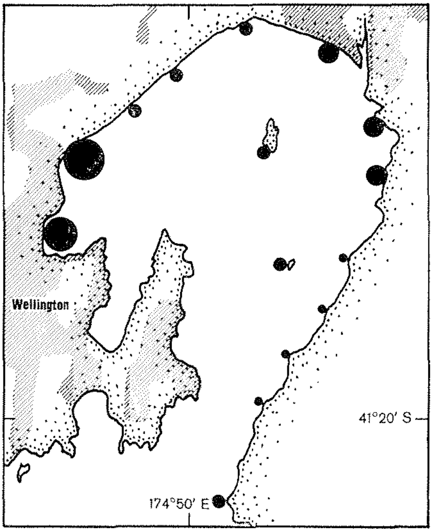

FIG. 2—Lead concentrations in green-lipped mussels *Perna canaliculus* from Wellington, January 1972. The diameters of the circles are proportional to the concentration of lead; the largest circle represents 7.8 μg.g⁻¹, wet weight. Populated areas shaded.

which only the stomach was analysed unless otherwise noted. This is because the scallop stomach has a unique ability to accumulate cadmium (Brooks & Rumsby 1965), and so was used as a bioindicator.

SOURCES OF HEAVY METALS IN NEW ZEALAND

New Zealand is basically an agricultural country, and there is relatively little heavy metal pollution from industrial sources. Mining, chemical, and refining industries exist only on a small scale. Generally, liquid industrial wastes go into the sewage systems. However, New Zealand is a geologically young country of volcanic origin and relatively rich in minerals, many of which may leach out and ultimately arrive in the sea via run-off from streams and rivers. This leads to large local variation in heavy metal levels. For example, oysters from one location in the Bay of Islands (Brampton Shoals, Sample 15) have nearly twice the cadmium levels of oysters from a location (Wairoa Bay, Sample 9) less than a kilometre distant. This may be because Brampton Shoals lies in the mouth of a river and Wairoa Bay does not.

There are a few examples of suspected man-made heavy metal pollution in New Zealand. The green mussel, *Perna canaliculus*, which seems to have a predilection for accumulating lead, generally has higher lead levels in the vicinity of large cities. Figure 2 shows the great difference in lead levels in mussels collected near Wellington from those collected further from the city. There are at least two possible reasons for this. First, the leaching of lead from the widely used lead-based roofing paints may enter the storm drain system and be carried into the

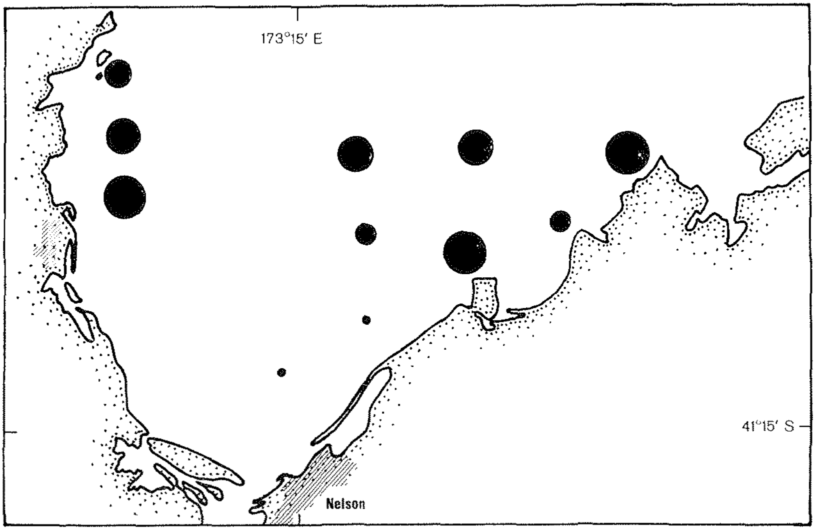

FIG. 3—Cadmium concentrations in the stomachs of scallops *Pecten novaezelandiae* from Tasman Bay, July 1973. The diameters of the circles are proportional to the concentration of cadmium; the largest circles represent 329 $\mu g.g^{-1}$, wet weight. Populated areas shaded.

harbour. Secondly, lead from automobile exhaust emissions may ultimately enter the harbour in greater amounts in the vicinity of the city.

Industrial pollution is not suspected, since the authors know of no industries in Wellington which could contribute significant amounts of lead into the harbour. As stated previously, liquid industrial wastes enter the sewage system, which then enters Cook Strait south of Wellington.

Recently it has been found that much of the type of superphosphate used widely in aerial crop dusting in New Zealand contains relatively large amounts of cadmium (Williams & David 1973). Some of this cadmium may ultimately reach the sea via run-off, which could explain some of the relatively high cadmium levels in oysters and scallops, particularly in the Tasman Bay area.

Figure 3 shows average cadmium levels in the stomachs of scallops from Tasman Bay, the highest value being 329 $\mu g.g^{-1}$. The Nelson City sewage outfall projects into Tasman Bay, but it is not known to what extent the effluent contributes cadmium to the environment. To determine this the effluent itself would have to be analysed.

The metals analysed will now be discussed separately by mollusc species examined (– indicates the sample size was too small for a range to be given).

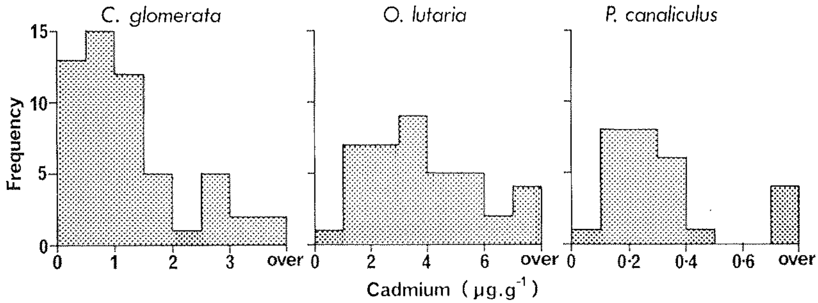

FIG. 4—Cadmium concentrations ($\mu g.g^{-1}$, wet weight) against frequency of occurrence in all samples of rock oysters *Crassostrea glomerata*, dredge oysters *Ostrea lutaria*, and green-lipped mussels *Perna canaliculus.*

CADMIUM

The average for each species examined was:

SPECIES	AV. Cd, $\mu g.g^{-1}$	RANGE
Crassostrea glomerata	1.3	0.12–5.0
Ostrea lutaria	3.9	0.12–7.9
Perna canaliculus	0.30	0.10–1.0
Mytilus edulis	0.63	0.26–1.6
Pecten novaezelandiae	0.18	0.14–0.28
Stomach	137	15–329
Gonad	1.5	0.59–2.4
Adductor muscle	0.51	0.20–0.82
Haliotis iris	0.17	0.09–0.24
Paphies ventricosa	0.11	0.07–0.17
Paphies australis	0.13	0.12–0.14
Paphies subtriangulata	0.29	0.29–0.34
Aulacomya maoriana	0.94	0.16–2.40
Anomia walteri	2.00	–
Chione stutchburyi	0.19	–
Modiolus neozelanicus	0.04	–

Ostrea lutaria and *Pecten novaezelandiae* appeared to accumulate cadmium to an unusually high degree, and this may be true to a lesser extent for *Anomia walteri* and *Crassostrea glomerata*. Figure 4 shows the frequency of occurrence of cadmium in *C. glomerata, O. lutaria,* and *Perna canaliculus*. Values of over 2 $\mu g.g^{-1}$ are uncommon in *G. glomerata*, but in *O. lutaria* cadmium is widely distributed at 1–6 $\mu g.g^{-1}$. In *P. canaliculus* only a few samples had greater than 0.5 $\mu g.g^{-1}$ cadmium.

High cadmium levels in the stomachs of *Pecten novaezelandiae* have already been mentioned by Brooks & Rumsby (1965). Average levels of up to 329 $\mu g.g^{-1}$ were found in the present study in one group of specimens from Tasman Bay (Sample 164). However, the stomachs are not often eaten, and the cadmium does not appear to accumulate significantly in the adductor muscle and gonad which are normally eaten.

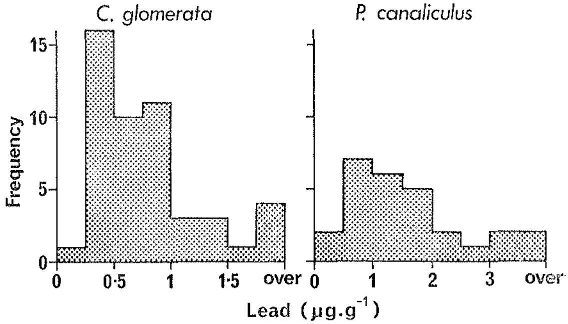

FIG. 5—Lead concentrations ($\mu g \cdot g^{-1}$, wet weight) against frequency of occurrence in all samples of rock oysters *Crassostrea glomerata* and green-lipped mussels *Perna canaliculus*.

LEAD

The average lead levels for all species examined were:

SPECIES	AV. Pb, $\mu g \cdot g^{-1}$	RANGE
Crassostrea glomerata	0.90	0.2–21.0
Ostrea lutaria	0.69	0.1–2.2
Perna canaliculus	1.8	0.1–7.8
Mytilus edulis	0.67	0.1–2.0
Pecten novaezelandiae	1.14	0.4–3.5
Stomach	1.2	0.4–4.0
Gonad	0.25	0.1–0.4
Adductor muscle	0.45	0.2–0.7
Haliotis iris	0.50	0.40–0.65
Paphies ventricosa	0.76	0.5–1.0
Paphies australis	0.4	–
Paphies subtriangulata	0.65	0.4–0.9
Aulacomya maoriana	0.52	0.2–0.8
Anomia walteri	0.4	–
Chione stutchburyi	1.8	–

The average lead levels found in the species examined were not generally high, but samples of some species from a few locations had quite high lead values. For example, a sample of *Crassostrea glomerata* from the vicinity of a sewer outfall (Sample 61) had 21 $\mu g \cdot g^{-1}$ lead (Sample 61 is considered an abnormal sample and was excluded from the average, but included in the range. Lead levels in *Perna canaliculus* are about twice as high as in other species (except in *Chione stutchburyi*, the New Zealand cockle, which is less commonly eaten). As mentioned previously, this tendency to accumulate lead may lead to unusually high levels near cities. Mussels from one sample location near Wellington had 7.8 $\mu g \cdot g^{-1}$ lead.

Figure 5 shows histograms for lead in *C. glomerata* and *P. canaliculus*. Most of the *C. glomerata* samples had less than 1 $\mu g \cdot g^{-1}$ lead, while *P. canaliculus* generally had greater than 1 $\mu g \cdot g^{-1}$ lead. Furthermore, the spread of data is wider for *P. canaliculus*, which may indicate a greater physiological ability to accumulate or tolerate lead.

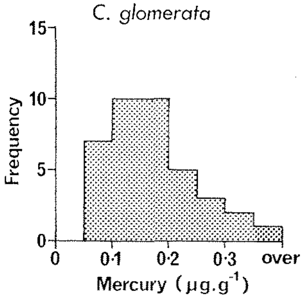

FIG. 6—Mercury concentrations ($\mu g{\cdot}g^{-1}$, wet weight) against frequency of occurrence in all samples of rock oysters *Crassostrea glomerata*.

MERCURY

Average mercury levels were generally quite low (much less than 0.50 $\mu g{\cdot}g^{-1}$) in all six species examined. At 0.23 $\mu g{\cdot}g^{-1}$, *Mytilus edulis* had the highest average level. The averages for *Crassostrea glomerata* and *Ostrea lutaria* were 0.18 $\mu g{\cdot}g^{-1}$ and 0.19 $\mu g{\cdot}g^{-1}$. In *Haliotis iris*, *Perna canaliculus*, and *Pecten novaezelandiae* the averages were 0.10, 0.09, and 0.05 $\mu g{\cdot}g^{-1}$ respectively.

Figure 6, the histogram for mercury in *C. glomerata*, shows the distribution of mercury to be quite regular, with the greatest frequency between 0.1 and 0.2 $\mu g{\cdot}g^{-1}$.

ZINC

The average for each species was:

SPECIES	AV. Zn, $\mu g{\cdot}g^{-1}$	RANGE
Crassostrea glomerata	337	97–900
Ostrea lutaria	66	19–246
Perna canaliculus	21	0.5–28.0
Mytilus edulis	14	3.8–26.0
Pecten novaezelandiae	20.8	18–31
Stomach	24	0.8–35.0
Gonad	27	–
Adductor muscle	16	–
Haliotis iris	13.5	12.9–15.3
Paphies ventricosa	9.8	6.9–15.0
Paphies australis	13	–
Paphies subtriangulata	7.0	–
Aulacomya maoriana	8.1	3.2–11.0
Anomia walteri	19	–
Chione stutchburyi	10	–

The outstanding feature was the high average for *Crassostrea glomerata*. It was five times the average for *Ostrea lutaria* and more than ten times the average of all other species.

Figure 7, the histograms for zinc in *C. glomerata* and *O. lutaria*, show that only a few samples of *C. glomerata* had less than 100 $\mu g{\cdot}g^{-1}$ zinc, but most of the *O. lutaria* had less than 100 $\mu g{\cdot}g^{-1}$ zinc.

The ability of oysters to accumulate zinc is well known, and the average of 337 $\mu g{\cdot}g^{-1}$ for *Crassostrea glomerata* lies well within the

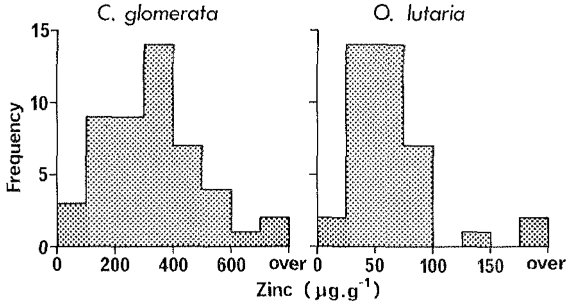

FIG. 7—Zinc concentrations ($\mu g.g^{-1}$, wet weight) against frequency of occurrence in all samples of rock oysters, *Crassostrea glomerata* and dredge oysters *Ostrea lutaria*.

range of oysters from other parts of the world, according to Thrower & Eustace (1973). These authors have analysed zinc levels in oysters from polluted waters of Tasmania and found average levels of over 9000 $\mu g.g^{-1}$.

It is interesting to note the relative levels of cadmium and zinc in the two species of oysters examined. *O. lutaria* had three times the cadmium level of *C. glomerata*, but *C. glomerata* had almost ten times the zinc levels of *O. lutaria*. Whether this reflects physiological differences in concentrating ability or differences in the relative availability of cadmium and zinc in the areas of natural occurrence of the two species is not known.

COPPER

With the exception of *Crassostrea glomerata*, copper levels were relatively low in the species examined. The averages are:

SPECIES	AV. Cu, $\mu g.g^{-1}$	RANGE
Crassostrea glomerata	40.0	4.4–380.0
Ostrea lutaria	11.0	1.0–41.0
Perna canaliculus	1.8	0.2–28.0
Mytilus edulis	8.3	1.7–18.0
Pecten novaezelandiae	1.46	0.9–2.5
Stomach	10.0	2.5–40.0
Gonad	2.1	–
Adductor muscle	6.6	6.5–6.7
Paphies ventricosa	1.7	1.1–2.9
Paphies australis	1.0	0.7–1.3
Paphies subtriangulata	5.1	1.4–8.7
Aulacomya maoriana	9.0	3.3–19.0
Anomia walteri	14.0	–

Crassostrea glomerata appears to have a definite tendency to accumulate copper compared with the other species. It is interesting to note the copper levels in specimens taken at various distances away from a defunct copper mine on Kawau Island. Copper levels at the mine averaged 380 $\mu g.g^{-1}$, 20 m from the mine average 305 $\mu g.g^{-1}$, and 40 m from the mine average 165 $\mu g.g^{-1}$. Some of the individual oysters from this area had slightly greenish tissue, and green deposits inside the shell. Green colouration due to copper has been found in oysters from America (Galtsoff 1966).

IRON

Iron was relatively high in most species, values of up to 280 $\mu g.g^{-1}$ being found in *Perna canaliculus*, but since iron is not a toxic heavy metal, averages are not presented here. The reader is asked to refer to the Appendix for iron values.

CONCLUSION

The purpose of this study was to establish average or normal metal levels for the molluscs examined. In fact the variations in metal levels from one location to another may be so great that it is often difficult to determine what a "normal" metal level is. The histograms (Figs. 4–7) are presented as being the most useful means of establishing normal metal levels. Another and perhaps better method would be to study the individual sample locations in conjunction with geological data and knowledge of possible industrial or agricultural pollution.

ACKNOWLEDGMENTS

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APPENDIX—Sampling localities and concentrations of heavy metals ($\mu g . g^{-1}$, wet weight) in 13 species of New Zealand molluscs; in each sample, 14 or more average-sized specimens were analysed whole unless otherwise stated (– = not analysed; * = gonad only, Sample 150, † = stomach only, Samples 151, 153, 159–177; ‡ = adductor muscle only, Sample 152; § = foot only, Sample 192).

Sample No.	Location	Sampling Site	Cd	Pb	Hg	Zn	Cu	Fe
Rock oyster *Crassostrea glomerata*								
1	Whangaroa	Whangaroa wharf	3.3	3.3	0.12	330	34	33
2		*Whangaroa Heads*	0.90	0.8	0.18	438	33	50
3		Cable Bay river mouth	3.0	0.9	0.08	255	20	90
4		West Cavalli Islands	5.0	0.9	0.08	130	6.3	35
5	Bay of Islands	Kawakawa River mouth	0.60	0.7	—	350	16	—
6		Russell wharf	1.5	0.5	0.25	345	62	25
7		Waitangi	2.0	1.2	0.28	63	—	25
8		Waitangi River mouth	1.1	0.2	—	200	34	16
9		Wairoa Bay, 0 m culture	0.55	0.7	—	500	13	45
10		Wairoa Bay, 0.3 m culture	—	—	0.25	—	—	—
11		Wairoa Bay, 0.6 m culture	0.75	1.3	—	77	—	24
12		Wairoa Bay reef, central	—	—	0.23	—	—	—
13		Wairoa Bay reef, eastern	0.91	1.2	0.22	47	—	16
14		Wairoa Bay reef, western	1.2	0.3	0.36	200	9.8	25
15		Brampton Shoals	1.0	1.3	0.11	350	11	50
16		Opito Bay	—	—	0.27	—	—	—
17	Whangarei	Whangarei Heads	0.56	—	—	—	30	24
18		Whangarei Harbour	0.38	—	0.16	—	53	14
19	Kaipara	Kellys Bay	0.46	—	—	—	22	35
20		Tinopai	0.50	—	0.14	—	24	18
21		*Ruawai*	0.21	—	0.16	—	12	29
22	Great Barrier	Shoal Bay	1.5	0.6	0.14	350	40	63
23		Whangaparapara whale stn	0.71	0.6	—	313	20	17
24		Tryphena town	1.9	0.5	—	275	9.2	71
25		Tryphena wharf	2.2	1.0	—	312	24	17
26		Arid Island	3.0	0.5	—	350	22	18
27		Blind Cove stream	1.8	0.3	—	238	21	27
28		Nagle Cove	3.0	0.6	0.13	213	25	27
29		Port Fitzroy	2.7	0.5	0.23	450	33	36
30		Whangaparapara wood mill	1.4	0.4	—	350	29	63
31		Harataonga Bay	3.8	3.1	—	288	32	36
32		Blind Cove, central	2.7	1.6	—	200	11	18
33		Miners Head	3.4	1.4	—	—	—	33
34	Mahurangi	Jacksons Bay oyster farm	0.42	—	0.16	—	22	40
35		Jacksons Bay	0.91	1.0	—	175	28	65
36		Sandspit	0.44	—	—	—	18	34
37		Martin Bay	0.42	—	0.46	—	10	20
38	*Kawau Island*	*Copper Mine*	1.1	0.7	—	130	380	25
39		20 m E of copper mine	1.7	0.8	0.12	180	305	28
40		40 m E of copper mine	1.5	0.8	0.14	232	165	35
41	Auckland	Browns Island	0.60	0.4	0.11	550	45	11
42		Rangitoto Channel beacon	0.45	0.5	—	325	28	18
43		Naval pier, Rangitoto	0.68	0.7	0.15	825	52	28
44		Devonport ferry wharf	0.42	0.9	0.11	550	40	17
45		Hobson Wharf	0.72	0.8	0.38	900	100	36
46		Motuihe Island pier	0.80	0.7	—	475	58	35

APPENDIX—*continued*

Sample No.	Location	Sampling Site	Cd	Pb	Hg	Zn	Cu	Fe
Rock oyster *Crassostrea glomerata* (continued)								
47	Waiheke Island	Rocky Bay	0.77	0.4	—	313	21	8.9
48		Awaawaroa Point	1.1	0.4	—	525	23	20
49		Putiki Point	0.98	0.5	—	275	28	27
50		Matiatia Bay	1.2	0.7	—	650	28	16
51	Ponui Island	North Bay	1.3	0.4	—	350	25	24
52		Kauri Point	1.0	0.7	—	275	15	14
53		Scullys Reef	1.6	0.5	—	475	20	20
54		Second Bay	1.1	0.4	—	350	4.4	18
55	Coromandel	Coromandel oyster farm	0.94	1.2	0.08	320	30	43
56		Tapu	0.12	0.8	—	145	10	5.0
57		Te Kouma	1.2	0.7	—	210	28	33
58	Bay of Plenty	Ohiwa oyster farm	0.90	0.9	0.10	530	21	58
59		Ohiwa Harbour pier	0.44	4.7	0.06	193	21	70
60		Omokoroa Heads	0.50	0.8	—	500	14	68
61		Omokoroa sewer outfall	0.48	21	0.09	425	24	58
62	Raglan	Raglan Harbour	—	—	0.26	—	—	—
Dredge oyster *Ostrea lutaria*								
63	Wellington	Evans Bay	0.12	1.4	—	—	41	45
64	Marlborough Sounds	Ships Cove pier	—	—	0.66	—	—	—
65		Kenepuru Sound	1.3	2.2	—	210	—	122
66	Golden Bay	No details	1.4	0.4	—	99	10	36
67	Tasman Bay	41° 11.3'S, 173° 13.7'E	2.9	1.0	—	19	4.8	29
68		41° 2.4'S, 173° 5.2'E	3.3	1.2	—	40	4.7	104
69		41° 9.0'S, 173° 10.7'E	2.1	0.8	—	35	3.6	77
70		41° 2.4'S, 173° 8.1'E	1.9	1.1	—	38	4.3	72
71		40° 45.0'S, 172° 50.1'E	3.5	0.5	—	51	4.3	49
72		40° 48.2'S, 173° 3.0'E	5.4	1.3	—	48	2.9	89
73		41° 6.7'S, 173° 18.0'E	3.8	0.9	—	44	3.9	66
74		41° 3.6'S, 173° 16.6'E	2.8	1.0	—	47	3.1	56
75		40° 53.3'S, 173° 6.0'E	3.6	0.5	—	53	3.2	73
76		40° 45.0'S, 172° 56.3'E	4.0	1.1	—	57	3.9	53
77		41° 4.0'S, 173° 24.5'E	5.9	0.9	0.06	55	2.7	70
78		40° 59.8'S, 173° 4.1'E	3.0	1.1	—	34	2.6	106
79		41° 2.5'S, 173° 34.0'E	4.4	0.4	—	33	3.3	62
80		41° 7.0'S, 173° 23.7'E	4.7	1.2	—	39	2.0	104
81	Foveaux Strait	46° 34.5'S, 168° 5.6'E	6.8	0.2	—	75	11	25
82		46° 47.0'S, 168° 4.8'E	4.3	0.3	—	37	13	35
83		46° 41.8'S, 168° 25.4'E	3.7	0.4	—	58	1.0	16
84		46° 48.0'S, 168° 11.7'E	5.2	0.3	—	40	17	18
85		46° 34.5'S, 167° 54.6'E	7.5	0.2	0.08	85	22	25
86		46° 38.7'S, 168° 16.6'E	3.0	0.1	—	54	7.3	18
87		46° 41.9'S, 168° 31.3'E	4.4	0.2	0.03	58	9.8	25
88		46° 44.4'S, 168° 23.8'E	4.0	—	—	44	11	25
89		46° 44.0'S, 168° 12.4'E	3.4	0.3	0.10	24	17	8.2
90		46° 42.0'S, 167° 59.4'E	4.3	0.3	—	34	20	15
91		46° 31.4'S, 167° 55.2'E	6.4	0.4	—	69	24	39
92		46° 38.5'S, 167° 54.0'E	7.9	0.9	—	94	12	73
93		46° 42.3'S, 168° 26.2'E	3.9	0.9	—	100	9.0	30

APPENDIX—*continued*

Sample No.	Location	Sample Site	Cd	Pb	Hg	Zn	Cu	Fe
Dredge oyster *Ostrea lutaria* (continued)								
94	Foveaux Strait	46° 48.5'S, 168° 18.7'E	5.8	0.8	—	57	4.5	99
95		46° 43.7'S, 168° 15.2'E	7.3	1.0	—	77	10	143
96	Stewart Island	Port Adventure, Oyster Cove	1.8	0.1	—	73	2.0	17
97		Port Adventure North Arm	1.4	1.0	—	68	4.8	150
98		Shipbuilders Cove	3.7	0.3	—	30	9.8	25
99		Port Pegasus, North Arm	1.7	0.2	—	77	17	45
100		Port Pegasus, Islet Cove	2.2	0.6	—	69	13	26
101		Paterson Inlet	1.7	0.6	—	246	30	44
102		*Lords River*	2.2	0.6	—	127	13	36
103		Black Rock Point	7.1	1.1	—	89	22	36
104		Bravo Island Bay	5.2	0.1	—	94	13	27
Green-lipped mussel *Perna canaliculus*								
105	Bay of Islands	Kawakawa River mouth	0.22	0.1	—	—	28	—
106		Russell	0.31	1.3	—	20	1.5	36
107	Kaipara	Ruawai	0.20	0.6	—	6.0	5.0	26
108	Auckland	Muriwai Beach	—	—	—	7.0	—	280
109	Waiheke Island	Matiatia Bay	0.20	0.7	—	33	1.8	57
110		*Cultured mussels*	0.27	1.2	—	1.2	1.6	60
111	Coromandel	Cultured mussels	0.22	0.9	0.10	15	1.9	298
112	East Cape	Tolaga Bay	0.10	0.9	—	11	2.0	55
113	Wellington Harbour	Somes Island, north	0.14	2.0	—	21	—	65
114		Somes Island, south	0.15	1.6	—	16	—	65
115		Ward Island, north	0.15	1.9	—	17	—	58
116		Ward Island, south	0.16	1.7	—	8.8	—	49
117		Pencarrow Head	0.15	2.4	—	—	0.8	—
118		Hinds Point	1.0	1.5	0.12	72	1.7	—
119		Point Arthur	0.24	1.6	—	26	1.0	—
120		Mahina Bay	0.24	3.1	—	46	1.2	—
121		Point Howard	0.26	3.0	0.08	36	0.9	—
122		Petone Beach	0.16	3.1	—	34	1.7	—
123		Ngauranga Stream mouth	0.24	2.1	0.14	46	1.7	—
124		Kaiwharawhara Stream mouth	0.86	7.8	—	76	0.5	—
125		Inter Island Ferry Wharf	0.16	6.4	—	30	1.0	—
126	Marlborough Sounds	Cultured mussels	—	—	0.08	12	—	122
127		Bird Rock	—	—	0.04	—	—	—
128		Nikau Bay wharf	—	—	0.19	—	—	—
129	Golden Bay	No details	0.74	0.7	—	9.3	7.0	88
130	Tasman Bay	41° 6.7'S, 173° 18.0'E	0.30	0.7	—	7.8	0.4	65
131		41° 2.4'S, 173° 5.2'E	0.40	0.7	—	7.8	1.2	92
132		41° 11.9'S, 173° 13.7'E	0.22	0.7	—	8.0	1.2	67
133		41° 9.0'S, 173° 10.7'E	0.36	0.2	—	4.8	0.4	47
134		41° 7.0'S, 173° 23.7'E	0.31	1.3	—	—	0.2	96
135		41° 2.4'S, 173° 5.2'E	0.31	1.3	—	7.1	0.3	122
136		41° 11.3'S, 173° 13.7'E	0.35	0.5	—	7.0	0.4	70
137		41° 9.7'S, 173° 18.3'E	0.29	0.7	—	7.9	0.4	66
138		41° 4.0'S, 173° 24.5'E	0.42	1.3	0.06	10	0.4	51
Blue mussel *Mytilus edulis*								
139	Bay of Islands	Waitangi River mouth	0.41	0.4	—	19	18	49

APPENDIX—*continued*

Sample No.	Location	Sampling Site	Cd	Pb	Hg	Zn	Cu	Fe
Blue mussel *Mytilus edulis* (continued)								
140	Wellington Harbour	Somes Island	0.26	2.0	—	26	—	33
141	Marlborough Sounds	Bird Rocks	—	—	0.02	—	—	—
142		Maude Island pier	—	—	0.25	—	—	—
143		Ships Cove	—	—	0.48	—	—	—
144		Scenic Reserve pier	—	—	0.05	—	—	—
145	Stewart Island	Shipbuilders Cove	0.88	0.1	—	8.7	17	18
146		Paterson Inlet	0.60	1.2	—	22	8.7	27
147		Bravo Island Bay	1.6	0.4	—	11	2.0	16
148	Fiordland	Preservation Inlet	0.36	0.2	—	6.5	2.5	8.3
149		Chalky Inlet	0.30	0.4	0.35	3.8	1.7	11
Scallop *Pecten novaezelandiae*								
150*	Golden Bay	No details	0.59	0.1	—	32	—	—
151†		"	21	0.7	—	35	9.1	117
152†		"	0.20	0.2	—	18	6.7	9.1
153†		40° 39.9'S, 172° 46.7'E	15	1.2	—	25	4.9	228
154	Tasman Bay	No details	0.19	0.4	0.03	18	1.2	13
155		"	0.14	0.6	0.06	18	1.1	12
156		"	0.28	3.5	0.06	31	2.5	19
157		"	0.05	0.6	0.06	18	0.9	11
158		"	0.14	0.6	0.06	19	1.6	14.7
159†		40° 45.0'S, 172° 56.3'E	126	1.3	—	18	6.2	233
160†		41° 6.7'S, 173° 18.0'E	99	1.0	—	28	7.7	255
161†		41° 3.6'S, 173° 16.6'E	200	1.2	—	28	5.9	26
162†		41° 9.7'S, 173° 18.3'E	25	1.3	—	19	2.5	698
163†		41° 4.0'S, 173° 24.5'E	224	1.0	—	33	8.4	259
164†		41° 6.5'S, 173° 8.6'E	329	1.2	0.03	31	8.5	428
165†		40° 59.8'S, 173° 4.1'E	156	1.1	—	20	6.1	260
166†		41° 2.5'S, 173° 34.0'E	260	1.3	—	30	8.3	281
167†		41° 7.0'S, 173° 23.7'E	257	1.2	—	30	8.7	289
168†		41° 5.7'S, 173° 30.0'E	122	0.9	—	20	7.6	222
169†		40° 48.2'S, 173° 3.0'E	244	1.2	0.06	30	7.5	298
170†		41° 2.4'S, 173° 5.2'E	217	1.0	—	29	5.0	211
171†	Admiralty Bay	No details	165	1.1	—	25	6.7	209
172†	Stewart Island	Shipbuilders Cove	111	0.5	—	6.7	17	107
173†		Brava Island Bay	80	0.5	—	8.6	17	149
174†		Paterson Inlet	45	4.0	—	24	40	164
175†	Fiordland	Preservation Inlet	79	0.4	—	23	9.8	81
176†		Chalky Inlet	63	1.3	—	0.8	18	151
177†		Isthmus Sound (Pres. Inlet)	70	0.4	—	30	8.4	60
Toheroa *Paphies ventricosa*								
178	Oreti Beach	New River mouth	0.14	0.8	—	15	2.9	80
179		3 km W of New River	0.08	0.8	—	8.0	2.4	72
180		6 km W of New River	0.13	1.0	—	12	2.1	87
181		9 km W of New River	0.12	0.8	—	8.9	1.2	64
182		12 km W of New River	0.09	0.8	—	9.1	1.1	70
183	Te Wae Wae Bay	Waiau River mouth	0.07	0.5	—	6.9	1.5	116
184		2 km E of Waiau River	0.17	0.6	—	9.8	1.4	81
185		1 km E of Waiau River	0.12	0.8	—	8.9	1.2	64

APPENDIX—*continued*

Sample No.	Location	Sampling Site	Cd	Pb	Hg	Zn	Cu	Fe
Ridged mussel *Aulacomya maoriana*								
186	Stewart Island	Paterson Inlet	0.90	0.8	—	11	5.0	25
187		Lords River	0.84	0.5	—	10	3.3	34
188		Bravo Island Bay	2.4	0.3	—	10	19	33
189	Fiordland	Chalky Inlet	0.44	0.2	—	6.3	8.7	18
190		Preservation Inlet	0.16	0.8	—	3.2	—	16
Paua or abalone *Haliotis iris*								
191	Marlborough Sounds	Bird Rocks	—	—	0.07	—	—	—
192§		Bird Rocks	—	—	0.13	—	—	—
193	Wellington	Oteranga Bay	0.24	0.5	—	15.3	8.1	46
194		Oteranga Bay	0.09	0.4	—	12.9	2.5	32
195		Oteranga Bay	0.14	0.4	—	13.6	4.2	35
196		Oteranga Bay	0.19	0.6	—	13.2	6.2	36
Pipi *Paphies australis*								
197	Kaipara	Kellys Bay	0.14	—	—	—	1.3	24
198	Tauranga	Papamoa Beach	0.12	0.4	—	13	0.7	21
Tuatua *Paphies subtriangulata*								
199	Tauranga	Papamoa Beach	0.34	0.9	—	7.2	1.4	43
200	Stewart Island	Port Pegasus	0.24	0.4	—	6.7	8.7	18
Saddle oyster *Anomia walteri*								
201	Fiordland	Preservation Inlet	2.0	0.4	—	19	14	41
Cockle *Chione stutchburyi*								
202	Bay of Islands	Wairoa Bay	0.19	1.8	—	10	—	31
Black mussel *Modiolus neozelanicus*								
203	Kaipara	Ruawai	0.04	—	—	—	2.6	144