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남극연안해역 환경모니터링을 위한 예비조사

: 남극대형이매패 *Laternula elliptica*의 중금속오염에 대한 지표종으로서의 적합도 평가

Preliminary Studies on Environmental Monitoring in the Antarctic Coastal Waters

: Evaluation of the Antarctic clam *Laternula elliptica* as an indicator species in heavy metal pollution

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한 국 해 양 연 구 소

제 출 문

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본 보고서를 "남극연안해역의 환경모니터링을 위한 예비조사: 남극대형이매패 *Laternula elliptica* 의 중금속오염에 대한 인식종으로서의 적합도 평가"의 최종 보고서로 제출합니다.

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요 약

남극이매패 (bivalves) *Laternula elliptica* 는 남극근해에 널리 분포하는 endemic species 이다. 이 종이 남극근해 환경변화를 모니터링하는데 지표종(indicator species)으로 사용될 수 있는 지를 평가하기 의해, 중금속의 baseline level 을 측정하였다. 이전의 연구결과에 의해 세종기지 주변에서 *L. elliptica* 가 가장 밀집해 있는 (평균 86개체 또는 9 kg/㎡) Collins Harbor 수심 25-30 m 에서 이 종을 채집하여, 각 장기 (organ)의 중금속 함량을 측정하였다. siphon의 외피에서는 망간함량이 3920 ug/g dry weight 으로 다른 장기들에 비해 상당히 높았으며, Cu, Cr, Co, As 그리고 Ni함량도 siphon외피에서 가장 높았다. 한편, 신장 (kidney)에는 Zn, Pb, 그리고 Cd 함량이 다른 장기에 비해 높았으며, 특히 Zn 함량이 1690 ug/g 으로 다른 장기에서의 함량 (78-206 ug/g dry wt) 보다 수 배 내지 수십배 높았다. 수은함량은 장기별로 유의한 변화를 보이지 않았다. 이와같은 *L. elliptica* 의 중금속 함량은 온대수역에 널리 분포하는 대표적 이매패인 홍합, 굴 등과 비교될만큼 높은 농도로서, 채집해역이 인간활동에 의한 오염이 거의 없었던 것을 고려할 때 매우 놀랄만한 일이다. 또한 본 연구결과는 *L. elliptica* 가 남극환경오염 모니터링에 지표종으로 이용될 수 있는 가능성을 시사한다고 하겠다.

ABSTRACT

Baseline levels of a number of trace metals have been determined in the Antarctic lamellibranch *Laternula elliptica* in order to evaluate this species as an indicator species in environmental monitoring programs. *L. elliptica* and its habitat sediment were sampled at 25-30 m water depth of Collins Harbor where a high density of *L. elliptica* (average 86 ind. m^{-2}, approx. 9 kg m^{-2}) occurred presumably without any influence of anthropogenic activities. Manganese level was considerably high in siphon skin (3920 μg g^{-1} dry weight), which is part of the tissue, but tough and leathery, and exposed to external environment, compared to the values in the soft parts of the body (<20 - 190 μg g^{-1}). Copper, Cr, Co, As and Ni levels were also higher in siphon skin than any soft parts of the body. On the other hand, kidney seems the target organs for Zn, Pb and Cd. In particular, Zn level was 1 or 2 order of magnitude greater in kidney (1690 μg g^{-1}) than any other parts of the tissue (78-206 μg g^{-1}). Mercury level did not vary significantly among different soft parts of the clam. The metal levels in *L. elliptica* are comparable to the values obtained from the representative suspension-feeding bivalves in temperate waters. Thus, relatively high levels of heavy metals were measured in *L. elliptica,* a species endemic to the Antarctic, where metal contamination appears unlikely.

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I. Introduction

Antarctic marine environment, which up to now has been least affected by human activities, is characterized by stable and uniform physical environment. Temperature and salinity vary little all year round. Benthic communities show relatively high diversity and biomass comparable to highly productive areas in the world (White, 1984). However, significant chemical contaminatnion of marine environments has been documented around some human settlements as well as observable impacts to benthic communities (Lenihan et al., 1990).

The Antarctic lamellibranch *Laternula elliptica* (king and Broderip) is widely distributed in nearshore waters around the Antarctic Continent and islands. By virtue of its wide distribution and high biomass, *L. elliptica* is nowdays highly recommeded as a representative species possibly indicating human impacts on the Antarctic nearshore environments (SCAR, 1992). Ahn (1993) demonstrated that *L. elliptica* plays an important role in carbon cycle within Antarctic coastal ecosystem by enhancing organic carbon flux from water column to sea bed through biodeposition. In the early February of 1993, *L. elliptica* and habitat sediment were collected in Collins Harbor and the baseline leves of heavy metals were analyzed.

II. Study Area

Maxwell Bay is a typical U-shaped fjord characterized by a deep sill (Park et al., 1989) and a relatively small amount of freshwater input (Chang et al., 1990). Geographic location of Maxwell Bay and bathymetric contours in the bay are shown in Fig. 1. The bay is about 18 km long and 6 to 14 km wide, and surrounded by King George Island and Nelson Island which belong to South Shetland Islands. To the northwestern end of the bay, between King George and Nelson Islands, lies Fildes Strait which is 400-800 m wide and connected to Drake Passage. The mouth of the bay is open to Bransfield Strait. Water depth gently increases from the coastline to 200 m depth, but sharply increases from 200 m to 400 m. The central part of the bay is relatively flat, ranging from 400 m to 500 m in depth. The surface layer of the bay was frozen during the preceding winter, from the late July to the mid-September, 1988. As spring progressed sea ice melted, and fresh water input occurred. During the sampling period water temperature ranged from -0.1° C to 1.5° C, decreasing with depth. Salinity varied from 33.5 % to 34.6 %, gradually increasing with depth. However, at the head of the bay the surface temperature was lower than that at 5-10 m, and the salinity sharply dropped toward surface due to thawing of sea ice (Chang et al., 1990).

Mean air temperature was 2.4° C in February, 1989. Details of meteorological observation at King Sejong Station was described in Lee et al. (1990). Details of Hydrographic features of the bay during summer have been described by Chang et al. (1990).

Marian Cove, Collins Harbor and the vicinity in the Maxwell Bay have been investigated to search *Laternula elliptica* during the 1991/1992 and the 1992/1993 austral summer months. In Marian Cove, the density of *L. elliptica* ranged from 36 to 88 ind m^{-2} with the mean of 65 ind m^{-2} (SD=15, n=14) at 15±2 m water depth in early January of 1992 (Ahn, 1993). Highest densitity up to 136 inds.(9 kg) m^{-2} occurred in Collins Harbor (62°10'S, 58°47'W), a sheltered bay with a few hundred m-wide and a half km-long rocky beach which is exposed during summer time (Fig. 1). Collins Harbor was chosen as a representative habitat of *L. elliptica* (Ahn, in press).

III. Biology and Ecology of *Laternula elliptica*

The Antarctic lamellibranch *Laternula elliptica* (king and Broderip) is widely distributed in nearshore waters around the Antarctic Continent and islands. It occurs in dense patches in sheltered bays, on the order of tens of individuals per m^2, being one of the most conspicuous members of Antarctic infaunal assemblages in nearshore waters (<50 m) (Stout and Shabica, 1970; Hardy, 1972, Zamorano et al., 1986; Ahn, 1993). *L. elliptica* is known to burrow deep (frequently >50 cm) into sediment (Hardy, 1972), and grows to a shell length of 100mm in 12 to 13 years (Ralph and Maxwell, 1977). It produces relatively large eggs (220 µm) in March (Pearse et al., 1985), and embryo develops pelagically within a protective egg capsule (Bosch and Pearse, 1988). It is also one of the most common macrofossiles found on emerged beaches around the Antarctica (Berkman, 1991). There is little information on the geological history of *L. elliptica*, but it is known that the genus *Laternula* dates from the late Cretaceous. Today, the species of the genus *Laternula* are distributed over a wide area of tropical and subtropical waters from the Red Sea to Australia, and to the Far East, Japan (Dell, 1972). *L. elliptica* is the only representative of the genus *Laternula* in the Antarctic waters.

Laternula elliptica seems to be a predominantly shallow-water species, although due to the depth limitation in SCUBA diving only shallow-water habitats have been investigated. Shells have been collected in depths from 1 to 500 m, but almost all live-collected specimens have been taken from depths less than 100 m and probably commonest shallower than 20 m (Dell, 1990). Ahn (in press) suggested that physical instability due to ice abrasion may be a factor determining the upper limit of vertical distribution of this species. Ahn speculated that a trade-off between increasing physical stability and decreasing food imput with depth may determine bothe the depth range of vertical distribution and the magnitude of biomass of *L. elliptica.* From an ecological viewpoint, the mechanisms by which this bivalve species has adapted to the ice-scoured and phytoplankton-impoverished environment are of great interest.

IV. Materials and Methods

Sample Collection

Laternula elliptica was sampled in Collins Harbor, in January of 1993 (Fig. 1). Samples of *L. elliptica* were hand-collected at a depth range of 25-30 m by SCUBA divers. Collected samples were immediately transported to the laboratory at the base and wet weight and shell length of the animals were measured. The animals were then frozen at -20 ° C and maintained at this state until heavy metal analusis was conducted.

Sediment was sampled using 28 cm^2 PVC corer (n=5) to a sediment depth of 30 cm. Six cores were taken randomly at each site. Sediment cores were immediately transported to the laboratory. The cores were sectioned at depths of 0.5, 1, 2, 5, 10, 20 and 30 cm, and subsamples were taken from each core section. The subsamples were oven-dried at 60° C for later analysis of organic carbon and metals. Overlying water was sampled in 500 ml polyethylene bottle by the divers at depths of 0, 10, 20 and 30 m.

Analytical procedures

Organic carbon were determined using a Carlo Erba NA-1500 Analyzer after removing calcium carbonate with 8% sulfurous acid (Verardo et al., 1990). Sediment grain size was analyzed using a Ro-Tap sieve shaker for sediment particles larger than 4 *phi* and using Sedigraph 5000D for those smaller than 4 *phi* after removing organic matter by soaking in 30% H_2O_2 and by rinsing with distilled water.

For the determination of heavy metal contents in total sediments, aliquots of oven-dried sediments (ca. 0.1 g) were completely digested with concentrated nitric acid (HNO_3) and a drop of perchloric acid ($HClO_4$). After centrifuging, the supernatant was taken and diluted with HCl for measurement.

Frozen samples of *Laternula elliptica* were partially thawed at room temperature and the total fresh weights (with and without shell) of each sample were determined. Then each of the clams was dissected into gonad, gill, kidney, digestive gland, siphon skin and the remainder (siphon, foot, mantle etc). Parts of each dissected clam were then freeze-dried for 48 hours. After freeze-drying, samples were ground. Each specimen (0.5 g dw) was first dissolved with 10 ml of concentrated HNO_3 in a 100 ml Pyrex beaker for 2 hours to oxidize organic matter. For digestion each sample was refluxed in a teflon screw-capped beaker on a hot plate (ca. 120° C) for several hours. The sample was then cooled down at room temperature, and the residue was dissolved in 1 N HNO_3. After centrifuging, the supernatant was taken and diluted (1:5 to 1:100) for measurement. The concentrations As, Cd, Co, Cr, Cu, Mn, Ni, Pb and Zn were determined using an inductively coupled plasma mass spectrometer (PQ II+, VG Element). The concentration of Fe was determined using a flame atomic absorption spectrophotometer (Spectra AA-20, Varian), and that of Hg using a custom-made Hg automatic determinator as follows.

V. Results

Physical and chemical properties of the sediment taken at *Laternula elliptica* habitat are shown in Table 1. The sediment are sandy mud mixed with gravel particles. Organic carbon content of the sediment are very low, ranging from 0.2 to 0.8%. Analytical results of NRC Canada reference material are shown in Table 2. Concentrations of trace metals in the overlying water of *L. elliptica* habitat are shown in Table 3.

Size of the animals used for the metal analysis ranged from 77 to 94 mm (mean = 86, SD = 8) in shell length and from 63 to 127 g in total wet weight (mean = 102, SD = 22) (Table 4). Metal levels in the organs are compared statistically one another in Figs. 2-11. Manganese level was considerably high in siphon skin (3920 µg^{1} dry weight) compared to the values in other parts of the tissue (<20 - 190 µg^{-1}). Copper, Cr, Co, As and Ni levels were also higher in siphon skin than any other soft parts of the body. On the other hand, highest levels of Zn, Pb and Cd were measured in kidney. In particular, Zn level was 1 or 2 order of magnitude greater in kidney. Mercury level did not vary significantly among different organs of the clam. Metal levels in the organs and percentage contribution of each organ to the total tissue burden are shown in Table 5.

VI. Discussion

The sedimentary organic carbon content (0.2-0.8%) was very low for nearshore sediment, but falls well within the ranges reported in other Antarctic nearshore sediments (Warnke et al., 1973; Mills and Hessler, 1974; Richardson and Hedgpeth, 1977; Schnack, 1985; Ahn, 1993). The low carbon value seems to be primarily related to massive land runoff during the summer months.

Heavy metal levels in the overlying seawater at *Laternula elliptica* habitat fall well within the range obtained in the Antarctic ocean waters (Honda et al., 1987). Lead level, however, is one order of magnitude greater in the present study than the levels obtained in the Maxwell Bay in 1989 by Lee *et al.* (1990). Lee *et al.* also reported higher metal levels at nearshore waters than offshore waters within the bay and ascribed this in part to fresh water input during summer. Whether the higher lead levels are due to anthropogenic pollution or to input from natural sources in land require further studies.

Heavy metal levels in a bivalve mollusc of Antarctic waters were determined first by Mauri *et al.* (1990) using the Antarctic scallop, *Adamussium colbecki*, one of the large suspension-feeding bivalves in the Antarctic waters. The pattern of bioaccumulation in *Laternula elliptica* of a specific metal species are somewhat different from the pattern observed in *A. colbecki* (Figs. 12-16). The Mn and Cu levels were one order of magnitude higher in *L. elliptica* than in *A. colbecki*. The Zn, Cd and Cr levels of *L. elliptica* were similar to those of the Antarctic scallop, *A. colbecki*. *L. elliptica*, however, showed a strong accumulation of Zn in kidney; the value is more than 8 times higher than the value measured in the kidney of *A.*

colbecki. On the other hand, the highest level of Cd in *L. elliptica* was found in kidney (42 μg g^{-1}), whereas the highest level in *A. colbecki* was in digestive gland (142 μg g^{-1}). Overall, *L. elliptica* accumulates more heavy metals than *A. colbecki*.

Thus the kidney of *Laternula elliptica* seems the target organ for Zn, Cd and Pb, whereas siphon skin for Mn, Cu and Ni. In particular, Mn level in siphon skin (3920 μg g^{-1}) was considerably high. Since siphon skin is always exposed to external environment, and is tough and leathery. Therefore, it was not considered as soft tissue and excluded in the calculation of mean metal concentration in total soft tissue (Table 5).

In Table 6, metal levels in *Laternula elliptica* are compared with the values obtained from the representative suspension-feeding bivalves in temperate waters. The levels of most of the metals in *L. elliptica* are withing the ranges reported for mussels and oysters. Manganese level, however, is one order of magnitude higher in *L. elliptica* than in the blue mussel, *Mytilus edulis*.

It is surprising to find such high metal levels in a species endemic to the Antarctic, where metal contamination appears unlikely. The results of this study suggest that *L. elliptica* can be used as an indicator species in mornitoring environmental changes due to metal pollution in the Antarctic coastal waters.

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Table 1. Physico-chemical characteristics of *Laternula elliptica* habitat sediment. Sediment samples were collected by divers using a hand-held PVC corer (28 cm^2, n=5) at 25-30 m water depth of Collins Harbor in February 16, 1993. Means (SD) are presented for the five replicate samples. *: n=2

Depth(cm)	%mud	%sand	%gravel	%water	%org C	%$CaCO_3$
0-0.5	50.7(24.0)	46.8(22.6)	2.6(3.59)	39.4(2.28)	0.230(0.018)	0.490(0.091)
0.5-1	48.1(19.0)	50.5(18.2)	1.3(1.97)	37.7(2.49)	0.228(0.059)	0.471(0.074)
1-2	49.5(13.8)	45.3(14.8)	5.2(9.04)	38.4(5.14)	0.282(0.056)	0.470(0.044)
2-4	59.5(13.4)	36.9(12.3)	3.6(3.46)	39.6(8.99)	0.224(0.074)	0.539(0.122)
4-6	64.5(12.3)	30.7(9.07)	4.8(3.77)	42.8(11.0)	0.460(0.250)	0.313(0.132)
6-8	68.4(13.2)	28.3(11.3)	3.3(2.27)	42.1(7.32)	0.365(0.159)	0.318(0.084)
8-10	75.4(7.95)	22.0(5.58)	2.6(2.97)	44.5(6.70)	0.630(0.236)	0.188(0.162)
10-15	79.0(1.92)	19.3(1.38)	1.7(1.81)	42.8(3.67)	0.569(0.153)	0.214(0.129)
15-20	69.0(8.81)	26.6(6.62)	4.5(2.78)	36.3(2.51)	0.406(0.210)	0.361(0.102)
20-25	69.2(4.48)	26.6(4.59)	4.1(2.16)	38.3(3.65)	0.531(0.252)	0.379(0.060)
25-30*	68.0(1.64)	28.2(4.01)	3.8(2.37)	37.3(5.16)	0.328(0.068)	0.537(0.016)

Table 2. Analytical results of NRC Canada reference material (n=3, μg g^{-1} dry weight)

SRM Element	Dogfish muscle (DORM-1)	
	Certified value	This work
As	17.7±2.1	18.8±1.2
Cd	0.086±0.012	0.097±0.006
Co	0.049±0.014	0.047±0.006
Cr	3.60±0.40	4.81±0.44
Cu	5.22±0.33	5.22±0.7
Mn	1.32±0.26	1.52±0.19
Ni	1.20±0.30	1.60±0.10
Pb	0.40±0.12	0.77±0.14
Zn	21.3±1.0	21.8±0.9

Table 3. Concentrations of acid-soluble metals in the seawater taken in a *Laternula elliptica* habitat of Collins Harbor.

unit: μg/*l*

Depth (m)	Cd	Cu	Fe	Pb	Zn
0	0.034	1.03	185	0.49	1.29
10	0.036	0.29	54	0.19	0.57
20	0.040	0.52	58.1	0.22	1.04
30	0.044	0.30	48.6	6.72(?)	0.60

Table 4. Shell length and total wet weight including shell of the specimens of *Laternula elliptica* used in the analysis of metals. For the details, see Appendix A.

Specimen No.	Shell length (mm)	Wet wt. (g)
1	85.2	100.2
2	76.0	73.5
3	72.4	63.1
4	84.2	97.3
5	77.0	76.4
6	93.7	124.8
7	94.0	125.7
8	91.7	119.0
9	93.4	124.0
10	94.5	127.1
11	80.4	86.3
12	88.4	109.5

Mean shell length: 86.0 mm (SD=7.9)
Mean wet weight: 102 g (SD=22)

Table 5. Heavy metal concentration (µg g^{-1} dry weight) in the organs of *Laternula elliptica* collected on the 25th of January, 1993 in Collins Harbor. SD: Standard deviation, %: mean % contribution of the organs to the total metal burden in the tissue (n=12). For the details, see Appendices B and C.

Metals	Organs	Mean	SD	%
Mn	Dig. gland	18.6	7.5	3.85
	Gonad	30.1	22	7.75
	Gill	44.7	16.3	4.44
	Kidney	190	112	5.91
	Remainder	102	46	78.0
Cu	Dig. gland	38.1	5.0	14.9
	Gonad	15.0	6.0	7.27
	Gill	21.4	8.9	4.01
	Kidney	33.3	13.6	1.95
	Remainder	50	20.2	71.9
Zn	Dig. gland	153	39	14.8
	Gonad	84.9	13.9	10.2
	Gill	206	72	9.59
	Kidney	1687	926	24.5
	Remainder	115	22	41.0
Pb	Dig. gland	5.49	4.18	27.3
	Gonad	2.15	0.65	13.3
	Gill	2.77	1.74	6.61
	Kidney	37.7	21.9	28.1
	Remainder	1.35	0.42	24.8
Cd	Dig. gland	11.5	4.1	27.5
	Gonad	4.75	1.88	14.2
	Gill	7.21	1.82	8.33
	Kidney	41.9	14.5	15.1
	Remainder	3.9	1.25	34.6
Ni	Dig. gland	6.27	1.83	22.4
	Gonad	4.47	1.91	19.8
	Gill	6.16	1.71	10.5
	Kidney	21	13.9	11.2
	Remainder	2.74	1.00	36.1
Co	Dig. gland	2.84	0.85	18.6
	Gonad	1.48	0.85	12.1
	Gill	2.71	0.75	8.53
	Kidney	5.74	2.11	5.64
	Remainder	2.28	0.72	55.2
Cr	Dig. gland	2.9	0.72	21.8
	Gonad	1.7	0.51	15.7
	Gill	2.9	0.81	10.3
	Kidney	4.7	2.6	5.30
	Remainder	1.69	0.85	46.9
As	Dig. gland	61.4	15.9	28.8
	Gonad	35.2	10.1	20.5
	Gill	58.9	20.7	13.3
	Kidney	27.8	6.9	1.96
	Remainder	20.5	5.97	35.5
Hg	Dig. gland	0.140	0.083	30.4
	Gonad	0.055	0.013	14.7
	Gill	0.094	0.043	9.77
	Kidney	0.062	0.039	2.02
	Remainder	0.057	0.011	45.6

Table 6. Comparison of mean metal concentrations (n=12) in the soft tissues of *Laternula elliptica* with the values in other suspension-feeding bivalve species. Siphon skin was excluded in the calculation of mean body metal concentration. For the details of calculation, see Appendix C.

unit: $\mu g\ g^{-1}$ dry weight

Metal	*Laternula elliptica*	*Mytilus edulis*	*Mytilus californianus*	*Crassostrea virginica*
Mn	74	2.7/7.5[a]		
Cu	39	4.4/15*	5.2/11*	30/530*
Zn	157	67/220*	100/220*	520/3700*
Pb	3.1	0.55/14*	0.5/8.4*	0.18/1.8*
Cd	6.3	0.92/4.3*	1.4/9.2*	1.2/9.1*
Ni	4.3	0.87/4.2*	1.3/6.3*	1.7/4.5*
Co	2.3			
Cr	2.0			
As	32			
Hg	0.07	0.005/0.03[b]		

*: Lauenstein *et al.*(1990)
[a]: Choi *et al.*(1992)
[b]: Latouche and Mix (1982)

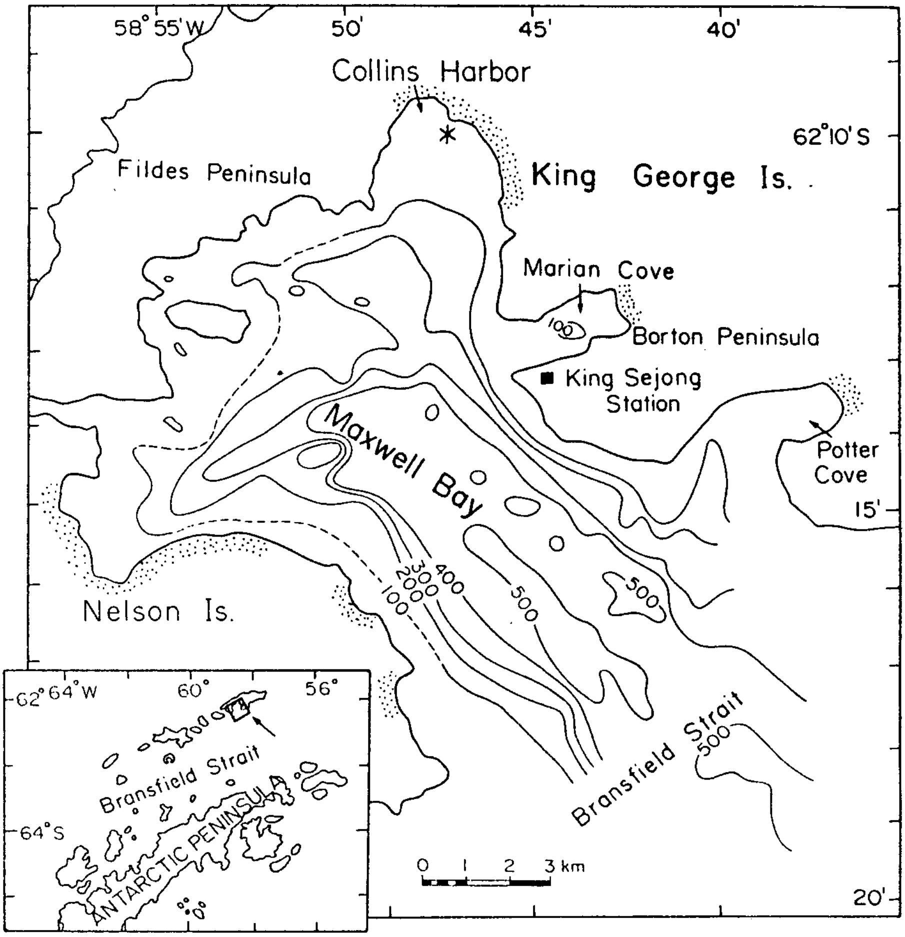

Fig. 1. Geographic location of Collins Harbor and the sampling site.

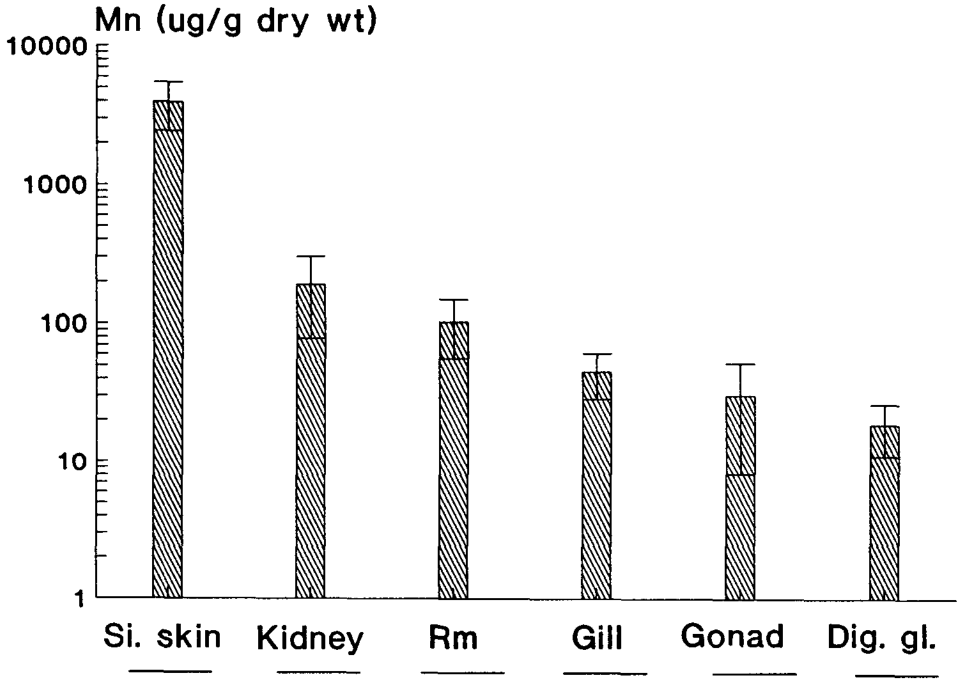

Fig. 2. Mn concentrations in the different organs of *Laternula elliptica*. The metal levels of the organs on the same line are not significantly different. For the details of the statistics, see Appendix D.

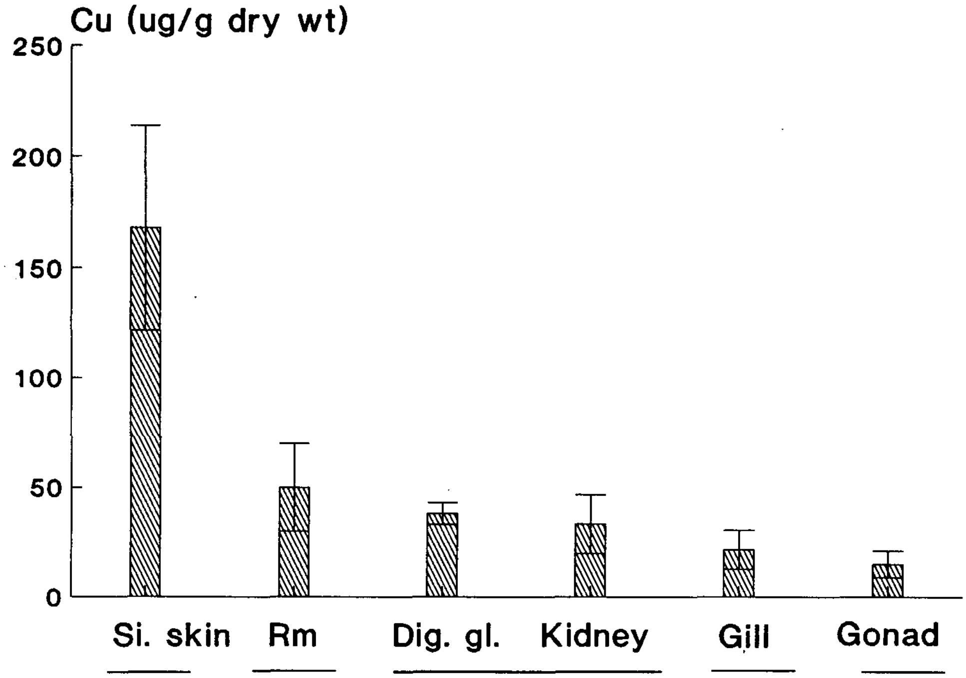

Fig. 3. Cu concentrations in the different organs of *Laternula elliptica*. The metal levels of the organs on the same line are not significantly different.

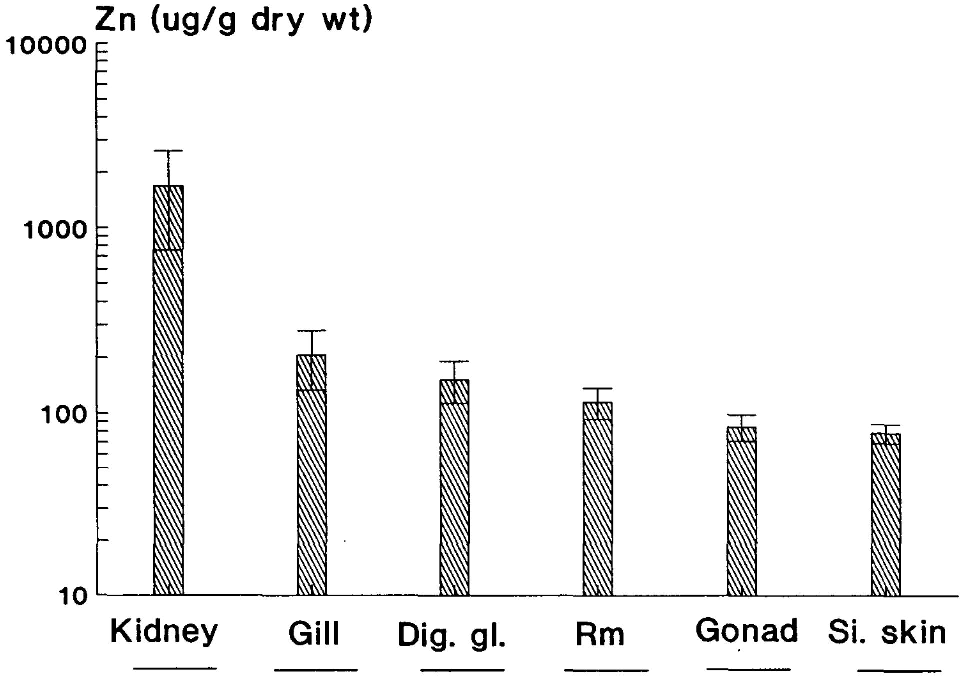

Fig. 4. Zn concentrations in the different organs of *Laternula elliptica*. The metal levels of the organs on the same line are not significantly different.

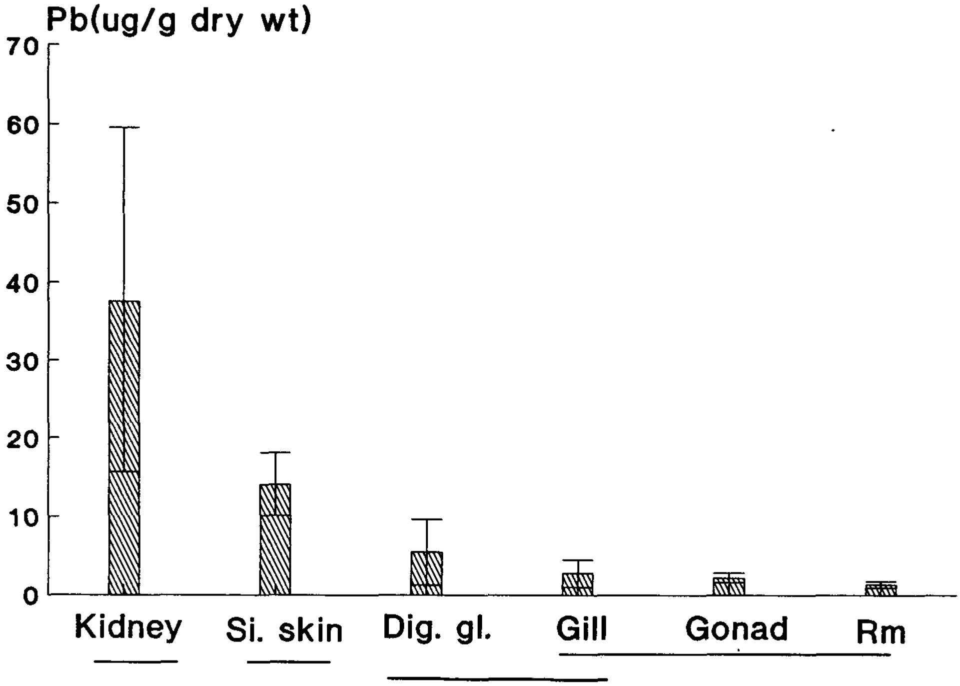

Fig. 5. Pb concentrations in the different organs of *Laternula elliptica.* The metal levels of the organs on the same line are not significantly different.

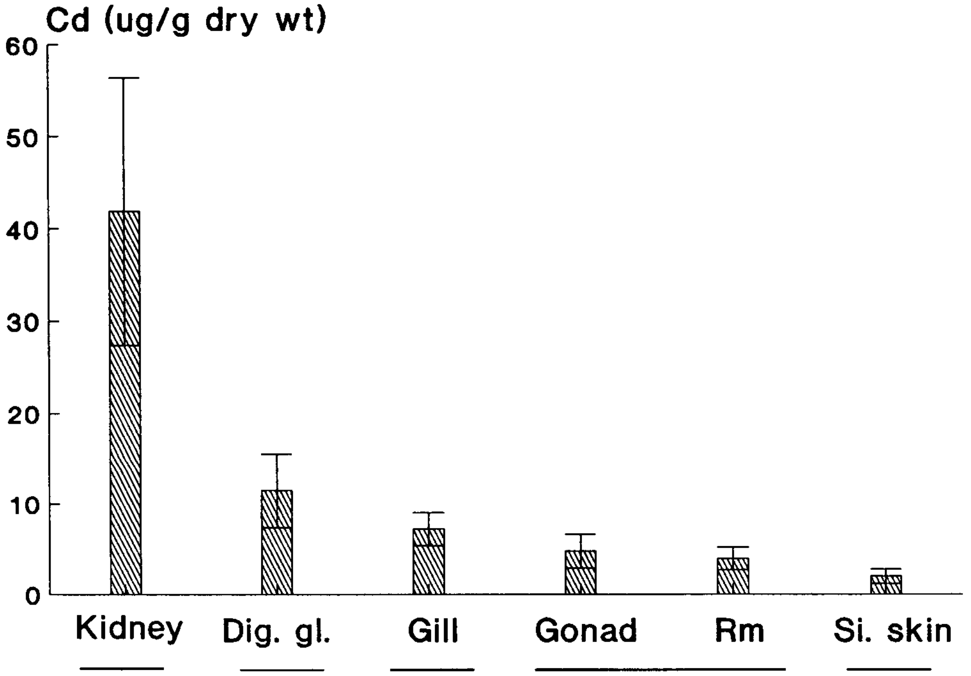

Fig. 6. Cd concentrations in the different organs of *Laternula elliptica*. The metal levels of the organs on the same line are not significantly different.

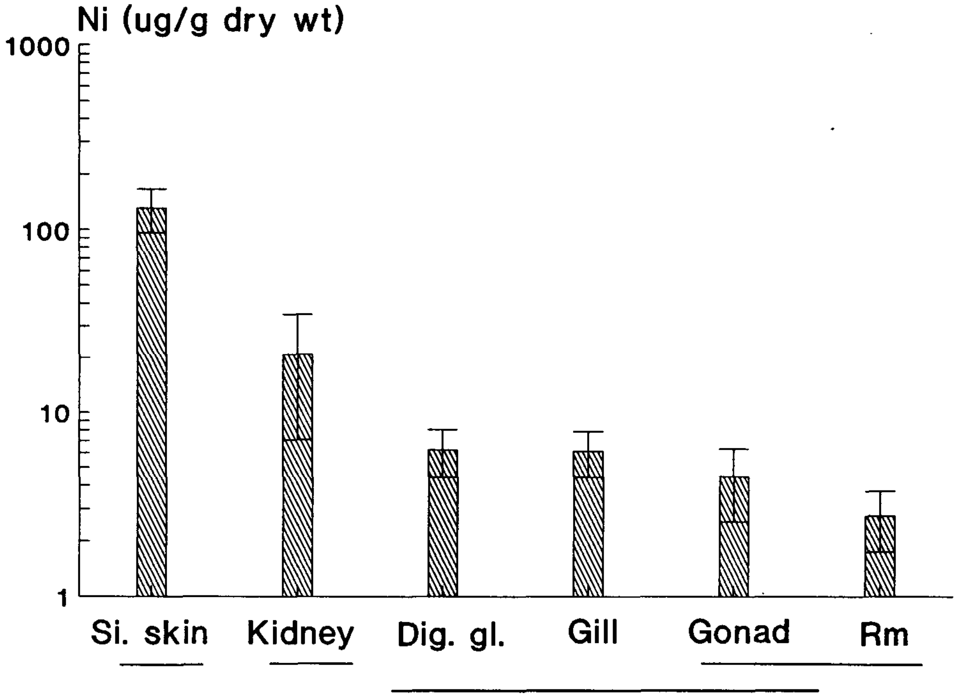

Fig. 7. Ni concentrations in the different organs of *Laternula elliptica*. The metal levels of the organs on the same line are not significantly different.

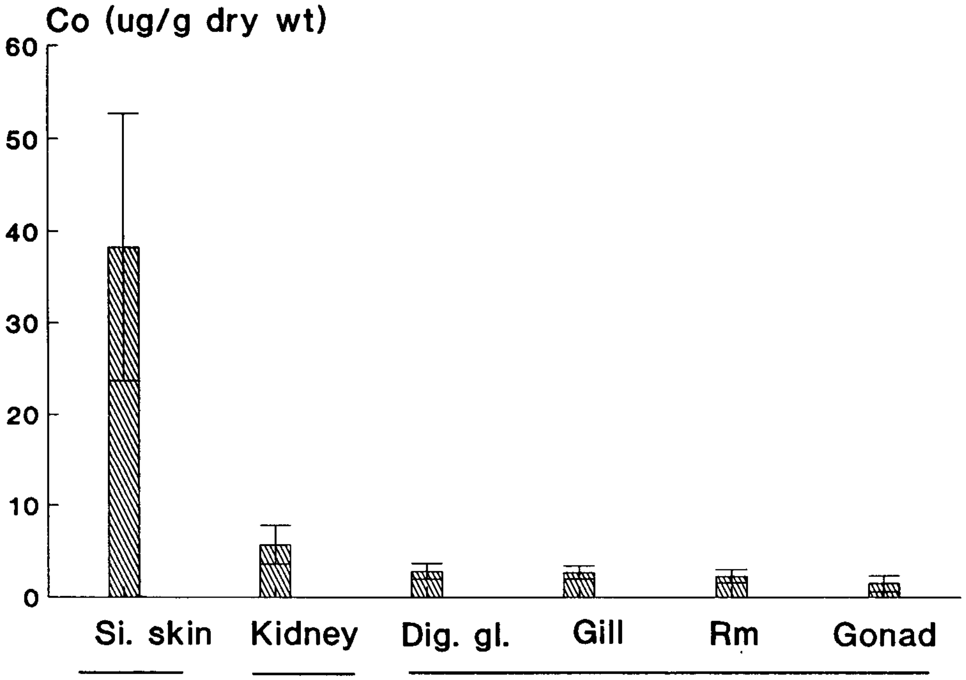

Fig. 8. Co concentrations in the different organs of *Laternula elliptica*. The metal levels of the organs on the same line are not significantly different.

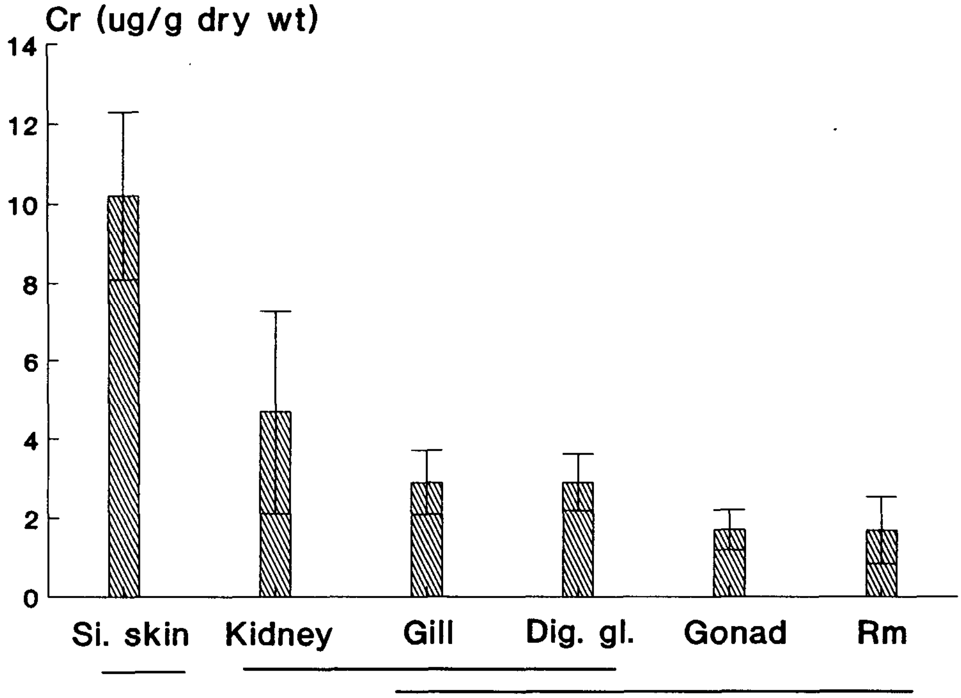

Fig. 9. Cr concentrations in the different organs of *Laternula elliptica*. The metal levels of the organs on the same line are not significantly different.

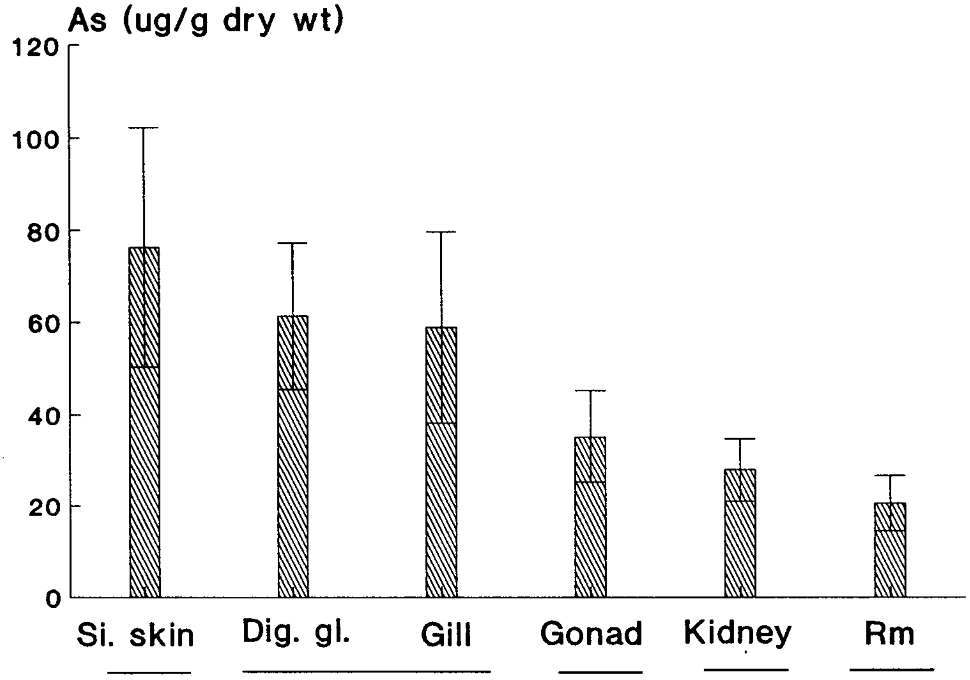

Fig. 10. As concentrations in the different organs of *Laternula elliptica*. The metal levels of the organs on the same line are not significantly different.

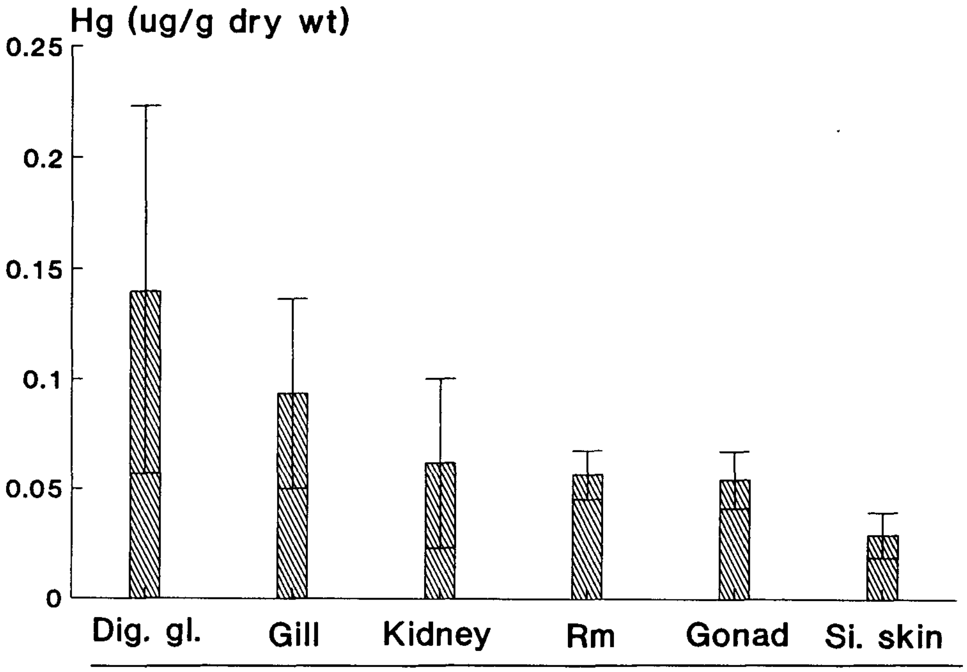

Fig. 11. Hg concentrations in the different organs of *Laternula elliptica.* The metal levels of the organs on the same line are not significantly different.

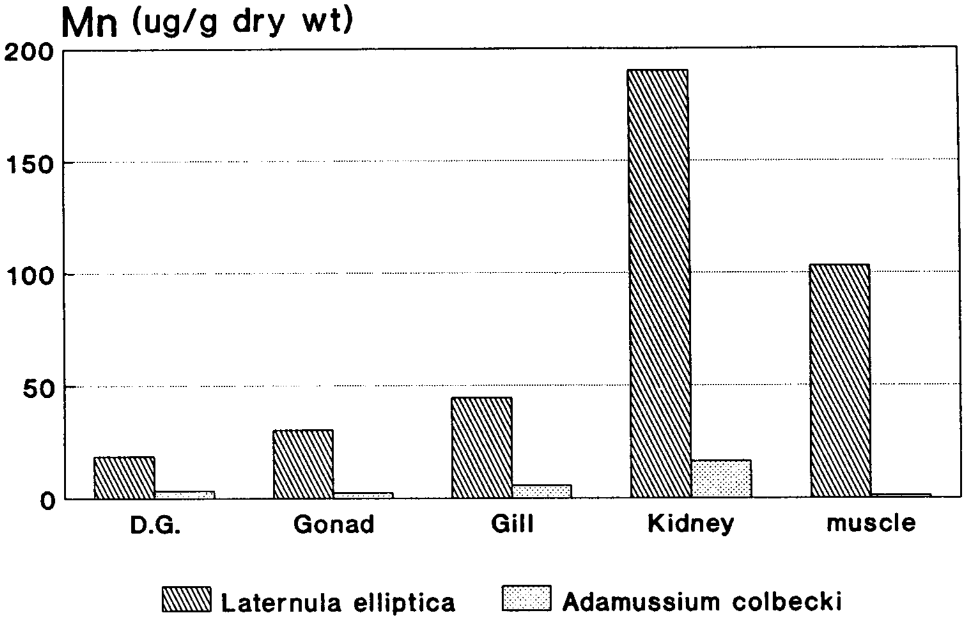

Fig. 12. Comparison of Mn levels in the organs of *Laternula elliptica* with the values of the Antarctic scallop, *Adamussium colbecki*.

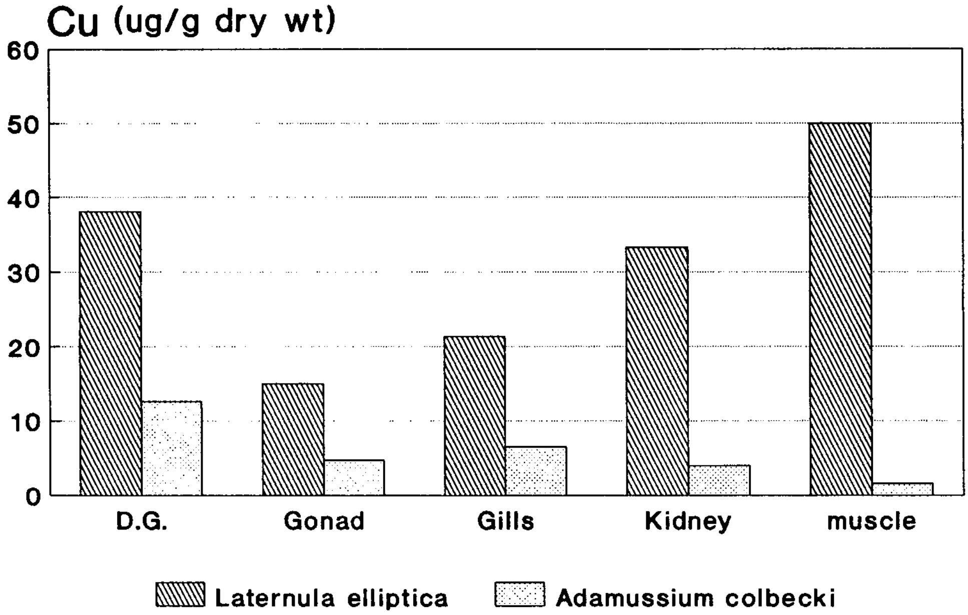

Fig. 13. Comparison of Cu levels in the organs of *Laternula elliptica* with the values of the Antarctic scallop, *Adamussium colbecki*.

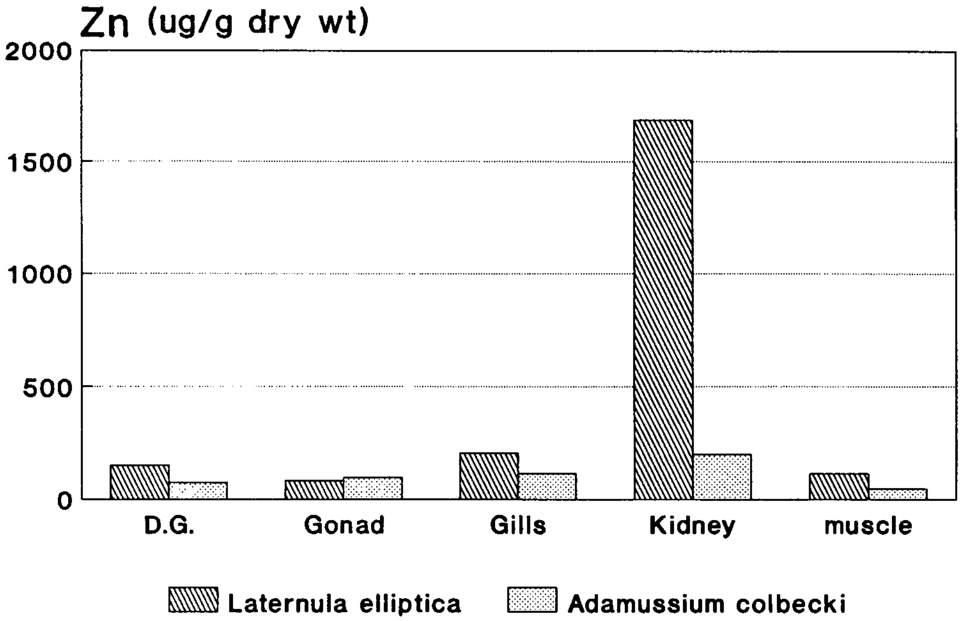

Fig. 14. Comparison of Zn levels in the organs of *Laternula elliptica* with the values of the Antarctic scallop, *Adamussium colbecki.*

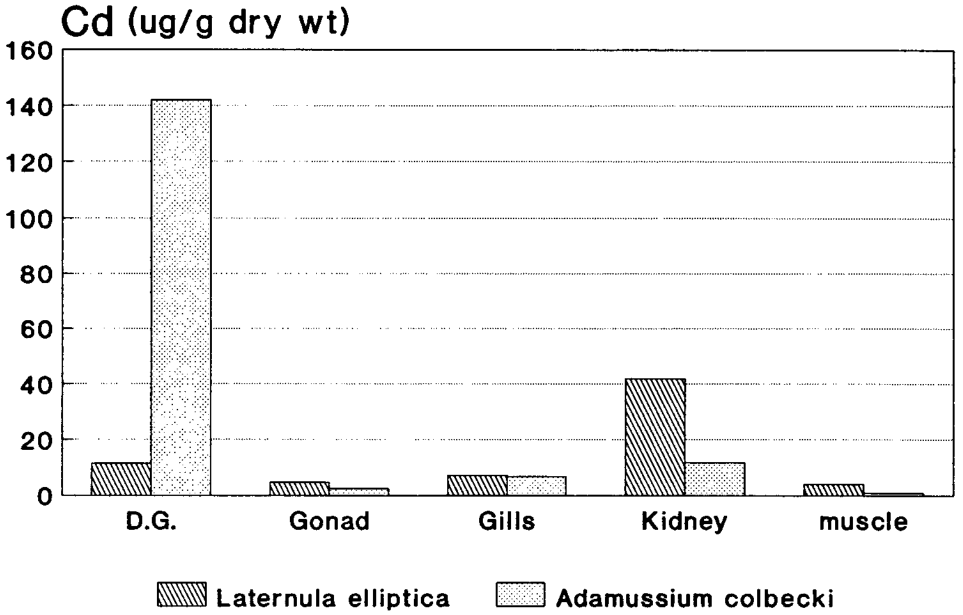

Fig. 15. Comparison of Cd levels in the organs of *Laternula elliptica* with the values of the Antarctic scallop, *Adamussium colbecki*

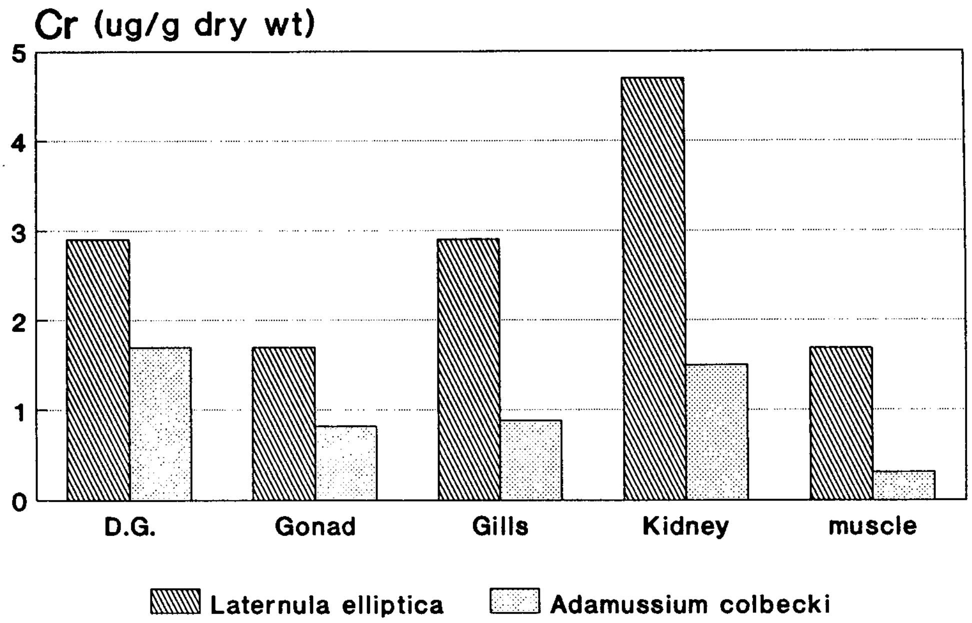

Fig. 16. Comparison of Cr levels in the organs of *Laternula elliptica* with the values of the Antarctic scallop, *Adamussium colbecki.*

Appendix A

	A	B	C	D	E	F	G	H	C-B		D-F	
Specimen#	L(mm)	W(froz)	W(corr)	Tissue	shell	Organs	Organ(FD)	G*100/F %DW	Loss 1	%	Loss 2	%
1	85.2	54.23	100.17	38.83	14.2	26.55	3.61	13.59698	45.94	45.86	12.28	31.6250
2	76	56.64	73.49	43.1	12.02	25.39	3.71	14.61205	16.85	22.92	17.71	41.0904
3	72.4	61.85	63.05	48.33	11.54	28.48	4.26	14.95786	1.2	1.903	19.85	41.0717
4	84.2	79.78	97.27	56.9	21.91	35.41	5.63	15.89946	17.49	17.98	21.49	37.7680
5	77	40.98	76.39	31.13	9.17	23.89	3.1	12.97614	35.41	46.35	7.24	23.2573
6	93.7	125.4	124.82	101.38	23.78	61.07	7.46	12.21549	-0.58	-0.46	40.31	39.7612
7	94	104.09	125.69	77.65	25.29	42.72	6.42	15.02808	21.6	17.18	34.93	44.9839
8	91.7	112.2	119.02	88.81	22.62	46.97	6.79	14.45603	6.82	5.730	41.84	47.1118
9	93.4	96.63	123.95	71.39	22.86	37.81	5.25	13.88521	27.32	22.04	33.58	47.0374
10	94.5	118.69	127.14	91.38	24.61	48.16	6.77	14.05730	8.45	6.646	43.22	47.2970
11	80.4	58.51	86.25	40.66	16.77	31.23	4.24	13.57668	27.74	32.16	9.43	23.1923
12	88.4	89.52	109.45	66.45	19.79	32.05	4.8	14.97659	19.93	18.20	34.4	51.7682
13	85	75.52	99.59	60.62	14.43	37.91			24.07	24.16	22.71	37.4628
14	85	83.71	99.59	58.46	23.39	34.6			15.88	15.94	23.86	40.8142
15	81.2	74.66	88.57	57.06	16.86	35.74			13.91	15.70	21.32	37.3641
n=12												
Mean	85.9	83.21	102.224	63.000	18.713	36.644	5.17	14.18649	19.01	19.71	26.35	39.6637
SD	7.918	27.29837	21.9847	22.340	5.4696	10.739	1.381092	0.970061	13.27	14.90	12.58	8.92400
n=15												
Mean	85.47	82.16066	100.962	62.143	18.616	36.532			18.80	19.49	25.61	39.4403
SD	7.124	24.57422	19.9606	20.065	5.1802	9.6275			12.04	13.45	11.36	8.02646

A: Shell length in mm
B: Total wet wt after frozen and then defrosted in gram
C: Total wet wt (g) corrected for the loss due to freezing & defrosting (W = -146.91 + 2.9 L)
D: B minus shell weight (E)
E: Shell weight (g)
F: Total wet wt (g) of the organs dissected
G: Total freeze-dried wt (g) of the organs dissected
H: Percentage freeze-dried wt of the wet wt of the organs dissected

Appendix B

Heavy metal concentrations in *Laternula elliptica* collected in Collins Harbor on the 25th of January of 1993.

Specimen# /Organ#	Cr	Mn	Ni	Co	Cu	Zn	As	Cd	Pb	Hg
				(μg/g dry weight)						
1-1	11.3	4260	94.6	50.4	202	84	44	2.5	21.7	0.054
2	2.2	13	5.0	2.3	40	161	54	9.0	4.6	0.124
3	1.3	23	4.1	0.9	13	93	27	4.8	2.9	0.062
4	2.6	24	4.9	2.9	34	283	43	9.8	5.3	0.071
5	5.6	217	33.1	7.3	45	1210	29	37.0	34.2	0.066
6	1.6	47	2.9	2.1	51	140	16	4.0	1.1	0.042
2-1	12.3	3480	151.0	42.7	146	79	64	1.2	20.6	0.015
2	3.1	28	5.3	2.9	39	250	51	8.3	14.9	0.083
3	1.5	16	2.6	1.1	14	96	25	3.5	1.5	0.072
4	3.6	51	8.8	3.8	22	371	57	7.9	3.3	0.045
5	4.3	125	11.1	4.5	15	2680	18	44.3	59.3	0.040
6	1.5	54	1.9	2.2	50	142	16	3.5	1.6	0.050
3-1	11.4	1910	149.0	17.0	115	73	77	1.1	11.8	0.033
2	3.0	19	6.8	2.3	42	154	46	8.4	13.6	0.107
3	2.3	50	9.0	1.9	19	94	32	3.4	2.2	0.063
4	2.8	43	7.7	2.3	15	181	49	6.0	2.4	0.029
5	1.8	119	10.1	3.9	17	1410	31	52.2	20.4	0.039
6	1.0	88	2.5	1.3	27	82	17	2.3	1.4	0.065
4-1	11.8	4720	154.0	37.1	134	87	89	2.0	13.5	0.039
2	4.4	14	8.5	3.4	37	139	74	20.5	3.3	0.248
3	1.6	24	4.7	1.3	14	91	40	5.4	1.9	0.057
4	3.4	65	7.8	3.3	19	273	85	7.7	2.3	0.175
5	4.5	208	20.3	6.0	27	1360	30	32.2	18.6	0.066
6	1.9	129	3.0	2.6	35	154	27	4.7	2.0	0.053
5-1	7.6	1560	48.4	20.5	127	63	31	1.3	9.2	0.031
2	2.1	13	4.4	1.8	29	181	45	5.4	4.5	0.054
3	0.9	7	1.5	0.7	10	97	26	2.1	1.9	0.046
4	2.1	62	7.9	2.4	20	231	46	4.6	7.1	0.112
5	10.6	176	14.4	4.6	24	2960	21	52.5	83.5	0.055
6	1.2	114	1.6	1.9	25	99	12	2.0	1.5	0.049
6-1	7.2	5870	106.0	52.3	234	91	76	3.1	17.4	0.036
2	3.2	19	6.4	3.5	50	135	89	14.2	3.8	0.238
3	1.9	30	4.9	1.6	14	80	42	5.3	1.5	0.060
4	2.6	54	5.5	2.9	14	149	77	5.9	2.0	0.124
5	2.9	112	8.3	4.0	19	1350	37	26.4	26.9	0.084
6	2.0	211	3.3	4.1	63	118	30	4.3	1.8	0.059

Specimen# /Organ#	Cr	Mn	Ni	Co	Cu	Zn	As	Cd	Pb	Hg
				(μg/g dry weight)						
7-1	7.4	4280	166.0	40.7	186	79	127	2.5	12.4	0.022
2	3.5	15	7.9	3.2	36	139	82	13.8	4.2	0.169
3	2.1	40	6.7	1.7	13	76	40	5.1	2.3	0.069
4	3.4	32	5.9	3.2	16	197	79	7.7	1.8	0.147
5	3.7	196	22.3	5.8	28	1480	32	45.9	37.6	0.067
6	1.5	85	2.5	2.3	48	109	23	4.7	2.0	0.058
8-1	8.6	2470	147.0	19.2	108	64	99	1.1	12.0	0.025
2	1.8	12	3.8	1.6	36	119	52	9.3	2.5	0.162
3	1.1	28	4.6	0.9	11	54	26	2.7	2.1	0.053
4	4.5	43	6.3	1.7	12	153	45	8.3	2.7	0.083
5	8.8	441	52.5	9.9	54	1050	19	52.1	25.0	0.008
6	1.0	90	2.0	1.4	25	89	18	3.5	0.8	0.054
9-1	11.9	6350	150.0	49.1	210	85	87	2.5	14.9	0.024
2	2.5	12	6.0	2.4	36	129	54	15.3	2.8	0.144
3	1.3	20	3.2	0.8	12	72	25	4.9	2.3	0.045
4	2.6	73	6.0	2.8	31	190	49	9.1	2.0	0.092
5	3.5	155	19.3	4.9	47	956	28	34.2	33.0	0.009
6	4.2	106	5.5	2.1	79	98	22	5.3	1.3	0.061
10-1	10.4	4460	165.0	36.7	182	69	88	1.4	9.4	0.026
2	2.8	16	6.3	3.1	36	121	67	10.9	2.9	0.036
3	1.7	20	3.9	1.3	13	81	36	3.9	1.2	0.061
4	2.4	29	4.0	2.8	23	166	66	7.4	1.1	0.120
5	2.1	101	9.6	4.2	44	998	36	35.7	28.0	0.058
6	1.5	84	2.1	2.3	76	105	23	3.4	1.1	0.042
11-1	9.1	2780	124.0	29.9	134	87	82	1.7	12.2	0.019
2	2.5	28	4.8	3.1	35	194	43	8.7	5.1	0.036
3	2.6	90	4.7	3.9	33	365	54	7.0	2.4	0.040
4	1.3	25	2.9	1.1	13	109	21	3.7	1.8	0.069
5	4.9	371	39.4	9.6	48	3780	19	72.6	71.1	0.148
6	1.4	155	3.1	2.8	44	129	14	2.9	1.1	0.068
12-1	13.0	4890	123.0	63.2	233	79	51	3.2	14.3	0.031
2	3.6	34	10.1	4.7	41	114	78	13.8	3.5	0.281
3	2.0	14	3.9	1.8	15	99	50	9.0	3.6	0.027
4	3.0	37	6.4	3.4	39	175	91	8.5	1.5	0.057
5	3.7	63	11.3	4.4	32	1020	35	18.3	14.4	0.104
6	1.6	62	2.5	2.5	78	113	29	6.4	0.8	0.081

#Part

1 : Siphon skin
2.: Digestive gland
3.: Gonad
4.: Gill
5.: Kidney
6.: Remainder

Appendix C

A. Freeze-dried weights (g) of the organs of 12 Laternula elliptica

Organ#	1		2		3		4		5		6		
Specimen#	siphon	(%)	D. G.	(%)	Gonad	(%)	Gill	(%)	kidney	(%)	Rm	(%)	Total
1	0.98	27.14	0.42	11.63	0.47	13.01	0.23	6.37	0.07	1.93	1.44	39.88	3.61
2	1.3	35.04	0.28	7.547	0.49	13.20	0.14	3.77	0.05	1.34	1.45	39.08	3.71
3	1.69	39.67	0.35	8.215	0.3	7.042	0.14	3.28	0.07	1.64	1.71	40.14	4.26
4	2.14	38.01	0.67	11.90	0.73	12.96	0.31	5.50	0.11	1.95	1.67	29.66	5.63
5	0.64	20.64	0.22	7.096	0.45	14.51	0.14	4.51	0.02	0.64	1.63	52.58	3.1
6	2.02	27.07	0.81	10.85	1.09	14.61	0.43	5.76	0.17	2.27	2.94	39.41	7.46
7	2.02	31.46	0.78	12.14	0.59	9.190	0.4	6.23	0.09	1.40	2.54	39.56	6.42
8	1.94	28.57	0.58	8.541	0.85	12.51	0.29	4.27	0.06	0.88	3.07	45.21	6.79
9	1.5	28.57	0.79	15.04	0.92	17.52	0.25	4.76	0.1	1.90	1.69	32.19	5.25
10	2.49	36.77	0.74	10.93	1.07	15.80	0.38	5.61	0.1	1.47	1.99	29.39	6.77
12	2.28	47.5	0.54	11.25	0.13	2.708	0.22	4.58	0.06	1.25	1.57	32.70	4.8
(11)	1.29	30.42	0.32	7.547	0.2	4.716	0.77	18.1*	0.06	1.41	1.6	37.73	4.24

* : outlier

***Siphon skin (organ #1) was excluded in the following calculations.**

B. Mean % contribution of each organ to the total freeze-dried tissue weight

Organ#	1	2	3	4	5	6
mean		15.227	18.95	7.309	2.283	56.21
SD		3.5611	4.025	1.450	0.728	7.557

(Specimens #11 & #12 were not included in the statistics.)

C. Mean concentrations of metals in the organs (n=12) (micro gram/g dry wt)

Organ#	Cr	Mn	Ni	Co	Cu	Zn	As	Cd	Pb	Hg
2	2.9	18.6	6.27	2.84	38.11	153.0	61.41	11.4	5.49	0.14
3	1.68	30.07	4.47	1.48	14.99	84.93	35.23	4.75	2.15	0.05
4	2.85	44.66	6.16	2.71	21.44	206.4	58.91	7.21	2.77	0.09
5	4.7	190.3	20.97	5.74	33.27	1687.	27.84	41.9	37.65	0.06
6	1.69	102.0	2.74	2.28	49.96	114.7	20.5	3.9	1.35	0.05

D. Products of mean % of each organ to total organ weight (B) and mean metal concentrations of the organs (C) (micro grams)

Organ#	Cr	Mn	Ni	Co	Cu	Zn	As	Cd	Pb	Hg
2	0.44158	2.832	0.9547	0.432	5.803	23.30	9.350	1.74	0.835	0.02
3	0.31836	5.698	0.8470	0.280	2.840	16.09	6.676	0.90	0.407	0.01
4	0.20830	3.264	0.4502	0.198	1.567	15.08	4.305	0.52	0.202	0.00
5	0.10730	4.346	0.4787	0.131	0.759	38.51	0.635	0.95	0.859	0.00
6	0.94994	57.37	1.5401	1.281	28.08	64.48	11.52	2.19	0.758	0.03

E. Mean values of metal concentrations in the soft tissues (micro gram/g dry weight)

Cr	Mn	Ni	Co	Cu	Zn	As	Cd	Pb	Hg
2.02549	73.51	4.2709	2.323	39.05	157.4	32.49	6.32	3.064	0.07

F. Mean % contribution of the organs to the total tissue metal (D/E*100)

Organ#	Cr	Mn	Ni	Co	Cu	Zn	As	Cd	Pb	Hg
2	21.8012	3.852	22.354	18.61	14.86	14.80	28.78	27.5	27.28	30.4
3	15.7176	7.751	19.833	12.07	7.274	10.22	20.54	14.2	13.29	14.7
4	10.2842	4.440	10.541	8.526	4.012	9.585	13.25	8.33	6.607	9.77
5	5.29753	5.912	11.209	5.641	1.945	24.47	1.956	15.1	28.05	2.02
6	46.8997	78.04	36.061	55.16	71.91	40.97	35.46	34.6	24.76	45.6
sum	100.000	100.0	100.00	100.0	100.0	100.0	100.0	100.	100.0	102.

***Siphon skin (organ #1) was included in the following calculations.**

B. Mean % contribution of each organ to the total freeze-dried tissue weight

Organ#	1	2	3	4	5	6
mean	32.77	10.470	12.10	4.970	1.520	38.16
SD	7.49	2.38	4.25	1	0.49	6.95

(Specimen# 11 was not included in the statistics.)

C. Mean concentrations of metals in the organs (n=12) (micro gram/g dry wt)

Organ#	Cr	Mn	Ni	Co	Cu	Zn	As	Cd	Pb	Hg
1	10.17	3920	131.46	38.23	167.7	78.3	76.27	1.96	14.11	0.02
2	2.9	18.6	6.27	2.84	38.11	153.0	61.41	11.4	5.49	0.14
3	1.68	30.07	4.47	1.48	14.99	84.93	35.23	4.75	2.15	0.05
4	2.85	44.66	6.16	2.71	21.44	206.4	58.91	7.21	2.77	0.09
5	4.7	190.3	20.97	5.74	33.27	1687.	27.84	41.9	37.65	0.06
6	1.69	102.0	2.74	2.28	49.96	114.7	20.5	3.9	1.35	0.05

D. Products of mean % of each organ to total organ weight (B) and mean metal concentrations of the organs (C) (micro grams)

Organ#	Cr	Mn	Ni	Co	Cu	Zn	As	Cd	Pb	Hg
1	3.33270	1284.	43.079	12.52	54.95	25.65	24.99	0.64	4.623	0.00
2	0.30363	1.947	0.6564	0.297	3.990	16.02	6.429	1.19	0.574	0.00
3	0.20328	3.638	0.5408	0.179	1.813	10.27	4.262	0.57	0.260	0.00
4	0.14164	2.219	0.3061	0.134	1.065	10.25	2.927	0.35	0.137	0.00
5	0.07144	2.893	0.3187	0.087	0.505	25.64	0.423	0.63	0.572	0.00
6	0.64389	38.88	1.0439	0.868	19.03	43.71	7.810	1.48	0.514	0.02

E. Mean values of metal concentrations in the soft tissues (micro gram/g dry weight)

Cr	Mn	Ni	Co	Cu	Zn	As	Cd	Pb	Hg
4.69659	1334.	45.945	14.09	81.36	131.5	46.84	4.89	6.683	0.04

F. Mean % contribution of the organs to the total tissue metal (D/E*100)

Organ#	Cr	Mn	Ni	Co	Cu	Zn	As	Cd	Pb	Hg
1	70.9691	96.28	93.763	88.91	67.54	19.50	53.35	13.1	69.18	21.2
2	6.46571	0.145	1.4288	2.110	4.904	12.17	13.72	24.4	8.600	4.52
3	4.32879	0.272	1.1772	1.270	2.229	7.810	9.100	11.7	3.892	14.4
4	3.01629	0.166	0.6663	0.955	1.309	7.797	6.250	7.31	2.059	10.2
5	1.52129	0.216	0.6937	0.619	0.621	19.49	0.903	13.0	8.563	2.06
6	13.7114	2.914	2.2721	6.165	23.39	33.22	16.67	30.3	7.696	47.5
sum	100.012	100.0	100.00	100.0	100.0	100.0	100.0	100.	100.0	100.

Metals	Organs	Mean	SD	%
Mn	Siphon skin	3920	1500	96.3
	Dig. gland	18.6	7.5	0.15
	Gonad	30.1	22	0.27
	Gill	44.7	16.3	0.17
	Kidney	190	112	0.22
	Remainder	102	46	2.91
Cu	Siphon skin	168	46	67.5
	Dig. gland	38.1	5.0	4.9
	Gonad	15.0	6.0	2.2
	Gill	21.4	8.9	1.3
	Kidney	33.3	13.6	0.62
	Remainder	50	20.2	23.4
Zn	Siphon skin	78.3	9.4	19.5
	Dig. gland	153	39	12.2
	Gonad	84.9	13.9	7.8
	Gill	206	72	7.8
	Kidney	1687	926	19.5
	Remainder	115	22	33.2
Pb	Siphon skin	14.1	4.0	69.2
	Dig. gland	5.49	4.18	8.6
	Gonad	2.15	0.65	3.9
	Gill	2.77	1.74	2.1
	Kidney	37.7	21.9	8.6
	Remainder	1.35	0.42	7.7
Cd	Siphon skin	1.96	0.78	13.1
	Dig. gland	11.5	4.1	24.5
	Gonad	4.75	1.88	11.7
	Gill	7.21	1.82	7.3
	Kidney	41.9	14.5	13.0
	Remainder	3.9	1.25	30.3
Ni	Siphon skin	131	35	93.8
	Dig. gland	6.27	1.83	1.4
	Gonad	4.47	1.91	1.2
	Gill	6.16	1.71	0.67
	Kidney	21	13.9	0.69
	Remainder	2.74	1.00	2.27
Co	Siphon skin	38.2	14.5	88.9
	Dig. gland	2.84	0.85	2.1
	Gonad	1.48	0.85	1.3
	Gill	2.71	0.75	0.96
	Kidney	5.74	2.11	0.62
	Remainder	2.28	0.72	6.2
Cr	Siphon skin	10.2	2.1	71.0
	Dig. gland	2.9	0.72	6.5
	Gonad	1.7	0.51	4.3
	Gill	2.9	0.81	3.0
	Kidney	4.7	2.6	1.5
	Remainder	1.69	0.85	13.7
As	Siphon skin	76.3	26.0	53.4
	Dig. gland	61.4	15.9	13.7
	Gonad	35.2	10.1	9.1
	Gill	58.9	20.7	6.3
	Kidney	27.8	6.9	0.90
	Remainder	20.5	5.97	16.7
Hg	Siphon skin	0.030	0.010	21.2
	Dig. gland	0.140	0.083	4.5
	Gonad	0.055	0.013	14.5
	Gill	0.094	0.043	10.2
	Kidney	0.062	0.039	2.1
	Remainder	0.057	0.011	47.5

Appendix D

```
MCPAIR
ID =As in L. elliptica in 93, C.H.

      6 GROUPS, INPUT CODE =  1, TRANSFORMATION CODE =  0
                                 POWER =    1.00000

MEANS SORTED FROM LOW TO HIGH

GROUP     N(I)     YBAR(I)
   |6      12      20.5000
   |5      12      27.8400
   |3      12      35.2300
   |4      12      58.9100
   |2      12      61.4100
   |1      12      76.2100

MS(WITHIN) =       14.260000 WITH   66 DEGREES OF FREEDOM
K* =     15


--------------- TESTS AMONG ALL PAIRS OF MEANS ---------------

                 k=a=6   ν=66

GROUP

 6 VERSUS:

   GROUPS        5.          3.           4.           2.           1.
   DIFF :      7.34000    14.73000     38.41000     40.91000     55.71000
   T,T-K:       6.733 ***   13.512 ***   35.235 ***   37.528 ***   51.105 ***
   GT2   :      4.761        9.555       24.915       26.537       36.137
   T'    :      6.733       13.512       35.235       37.528       51.105

 5 VERSUS:

   GROUPS        3.          4.           2.           1.
   DIFF :      7.39000    31.07000     33.57000     48.37000
   T,T-K:       6.779***    28.502 ***   30.795 ***   44.372 ***
   GT2   :      4.794       20.154       21.775       31.376
   T'    :      6.779       28.502       30.795       44.372

 3 VERSUS:

   GROUPS        4.          2.           1.
   DIFF :     23.68000    26.18000     40.98000
   T,T-K:      21.723 ***   24.016 ***   37.593 ***
   GT2   :     15.360       16.982       26.582
   T'    :     21.723       24.016       37.593

 4 VERSUS:

   GROUPS        2.          1.
   DIFF :      2.50000    17.30000
   T,T-K:       2.293       15.870 ***
   GT2   :      1.622       11.222
   T'    :      2.293       15.870

 2 VERSUS:         GROUPS       1.
                   DIFF :    14.80000
                   T,T-K:     13.577 ***
                   GT2   :     9.600
                   T'    :    13.577

                --end--
```

```
MCHETV
ID =Cd in L. elliptica in 1993, C.H.

      6 GROUPS, INPUT CODE =  1, TRANSFORMATION CODE =  0
                                 POWER =    1.00000

MEANS SORTED FROM LOW TO HIGH

GROUP    N(I)     YBAR(I)     VAR(I)
  |1       12       1.9600       .7800
  |6       12       3.9000      1.2500
  |3       12       4.7500      1.8800
  |4       12       7.2100      1.8200
  |2       12      11.4500      4.1400
  |5       12      41.9400     14.4500

--------------- TESTS AMONG ALL PAIRS OF MEANS ---------------


GROUP

 1 VERSUS:

   GROUPS        6.          3.          4.          2.          5.
   DIFF :     1.94000     2.79000     5.25000     9.49000    39.98000
   G & H:      4.717 *     5.926 **   11.279 ***  14.821 ***   35.488 ***
   DF*   :    20.88       18.79       18.97       15.00       12.18

 6 VERSUS:

   GROUPS        3.          4.          2.          5.
   DIFF :      .85000     3.31000     7.55000    38.04000
   G & H:      1.664       6.544 **   11.265 ***  33.257 ***
   DF*   :    21.14       21.27       17.09       12.89

 3 VERSUS:

   GROUPS        4.          2.          5.
   DIFF :     2.46000     6.70000    37.19000
   G & H:      4.430 *     9.459 ***  31.880 ***
   DF*   :    21.99       19.28       13.81

 4 VERSUS:

   GROUPS        2.          5.
   DIFF :     4.24000    34.73000
   G & H:      6.016 **   29.826 ***
   DF*   :    19.11       13.73

 2 VERSUS:

   GROUPS        5.
   DIFF :    30.49000
   G & H:     24.497 ***
   DF*   :    16.82

--end--
```

```
MCHETV
ID =Co in L. elliptica in 1993, C.H.

      6 GROUPS, INPUT CODE =  1, TRANSFORMATION CODE =  0
                                 POWER =    1.00000

MEANS SORTED FROM LOW TO HIGH

GROUP    N(I)     YBAR(I)      VAR(I)
  |3       12       1.4800        .8500
  |6       12       2.2800        .7200
  |4       12       2.7100        .7500
  |2       12       2.8400        .8500
  |5       12       5.7400       2.1100
  |1       12      38.2300      14.5100


--------------- TESTS AMONG ALL PAIRS OF MEANS ---------------


GROUP

 3 VERSUS:

   GROUPS        6.          4.          2.          5.          1.
   DIFF :      .80000     1.23000     1.36000     4.26000    36.75000
   G & H:      2.212       3.368       3.613       8.577***   32.483 ***
   DF*  :     21.85       21.91       22.00       18.63       12.28

 6 VERSUS:

   GROUPS        4.          2.          5.          1.
   DIFF :      .43000      .56000     3.46000    35.95000
   G & H:      1.229       1.548       7.125 **    31.911 ***
   DF*  :     21.99       21.85       17.72       12.09

 4 VERSUS:

   GROUPS        2.          5.          1.
   DIFF :      .13000     3.03000    35.52000
   G & H:       .356       6.207 **    31.498 ***
   DF*  :     21.91       17.94       12.13

 2 VERSUS:

   GROUPS        5.          1.
   DIFF :     2.90000    35.39000
   G & H:      5.839 **   31.281 ***
   DF*  :     18.63       12.28

 5 VERSUS:

   GROUPS        1.
   DIFF :    32.49000
   G & H:     27.607 ***
   DF*  :     14.13

 --end--
```

```
MCHETV
ID =Cr in L. elliptica in 1993, C.H.

      6 GROUPS, INPUT CODE =  1, TRANSFORMATION CODE =  0
                                 POWER =   1.00000

MEANS SORTED FROM LOW TO HIGH

GROUP     N(I)     YBAR(I)      VAR(I)
   |3       12       1.6800        .5100
   |6       12       1.6900        .8500
  ||4       12       2.8500        .8100
  ||2       12       2.9000        .7200
  | 5       12       4.7000       2.6100
  | 1       12      10.1700       2.0600

--------------- TESTS AMONG ALL PAIRS OF MEANS ---------------


GROUP

 3 VERSUS:

   GROUPS        6.          4.          2.          5.          1.
   DIFF :      .01000     1.17000     1.22000     3.02000     8.49000
   G & H:       .030       3.528       3.811       5.923 **   18.346 ***
   DF*  :     20.71       20.92       21.38       15.14       16.13

 6 VERSUS:

   GROUPS        4.          2.          5.          1.
   DIFF :     1.16000     1.21000     3.01000     8.48000
   G & H:      3.119       3.345       5.606 *    17.220 ***
   DF*  :     21.99       21.85       17.48       18.76

 4 VERSUS:

   GROUPS        2.          5.          1.
   DIFF :      .05000     1.85000     7.32000
   G & H:       .140       3.465      14.968 ***
   DF*  :     21.92       17.23       18.49

 2 VERSUS:

   GROUPS        5.          1.
   DIFF :     1.80000     7.27000
   G & H:      3.417      15.104 ***
   DF*  :     16.64       17.85

 5 VERSUS:

   GROUPS        1.
   DIFF :     5.47000
   G & H:      8.768 ***
   DF*  :     21.70

--end--
```

```
MCHETV
ID =Cu in L. elliptica in 1993, C.H.

      6 GROUPS, INPUT CODE =  1, TRANSFORMATION CODE =  0
                                 POWER =    1.00000

MEANS SORTED FROM LOW TO HIGH

GROUP     N(I)     YBAR(I)      VAR(I)
  |3        12      14.9900       6.0300
  |4        12      21.4400       8.9300
  |5        12      33.2700      13.5600
  |2        12      38.1100       4.9800
  |6        12      49.9600      20.2700
  |1        12     167.7000      45.5500

--------------- TESTS AMONG ALL PAIRS OF MEANS ---------------


GROUP

 3 VERSUS:

   GROUPS        4.          5.          2.          6.          1.
   DIFF :     6.45000    18.28000    23.12000    34.97000   152.71000
   G & H:      5.777 **   14.307 ***  24.137 ***  23.622 ***  73.658 ***
   DF*  :     21.20       19.17       21.80       17.01       13.86

 4 VERSUS:

   GROUPS        5.          2.          6.          1.
   DIFF :    11.83000    16.67000    28.52000   146.26000
   G & H:      8.641 ***  15.483 ***  18.283 ***  68.643 ***
   DF*  :     21.11       20.36       19.12       15.15

 5 VERSUS:

   GROUPS        2.          6.          1.
   DIFF :     4.84000    16.69000   134.43000
   G & H:      3.894       9.940 ***  60.570 ***
   DF*  :     18.12       21.17       17.02

 2 VERSUS:

   GROUPS        6.          1.
   DIFF :    11.85000   129.59000
   G & H:      8.169 ***  63.152 ***
   DF*  :     16.10       13.38

 6 VERSUS:

   GROUPS        1.
   DIFF :   117.74000
   G & H:     50.273 ***
   DF*  :     19.17

--end--
```

```
MCHETV
ID =Hg in L. elliptica in 1993, C.H.

      6 GROUPS, INPUT CODE =  1, TRANSFORMATION CODE =  0
                                 POWER =    1.00000

MEANS SORTED FROM LOW TO HIGH

GROUP     N(I)      YBAR(I)      VAR(I)
   |1        12         .0295        .0103
   |3        12         .0545        .0129
   |6        12         .0568        .0111
   |5        12         .0620        .0387
   |4        12         .0936        .0432
   |2        12         .1401        .0830

--------------- TESTS AMONG ALL PAIRS OF MEANS ---------------
```

all are not significantly different.

```
GROUP

 1 VERSUS:

   GROUPS         3.          6.          5.          4.          2.
   DIFF :      .02500      .02730      .03250      .06410      .11060
   G & H:        .569        .646        .509        .960       1.254
   DF*  :     21.73       21.97       16.47       15.96       13.69

 3 VERSUS:

   GROUPS         6.          5.          4.          2.
   DIFF :      .00230      .00750      .03910      .08560
   G & H:        .051        .114        .572        .958
   DF*  :     21.88       17.60       17.03       14.34

 6 VERSUS:

   GROUPS         5.          4.          2.
   DIFF :      .00520      .03680      .08330
   G & H:        .081        .547        .941
   DF*  :     16.83       16.30       13.89

 5 VERSUS:

   GROUPS         4.          2.
   DIFF :      .03160      .07810
   G & H:        .383        .776
   DF*  :     21.93       19.43

 4 VERSUS:

   GROUPS         2.
   DIFF :      .04650
   G & H:        .453
   DF*  :     20.01

--end--
```

```
MCHETV
ID =Mn in L. elliptica in 1993, C.H.

      6 GROUPS, INPUT CODE =  1, TRANSFORMATION CODE =  0
                                 POWER =    1.00000

MEANS SORTED FROM LOW TO HIGH

GROUP     N(I)     YBAR(I)      VAR(I)
  |2        12      18.6000       7.4600
  |3        12      30.0700      22.0000
  |4        12      44.6600      16.3200
  |6        12     102.0700      46.2100
  |5        12     190.3700     111.8000
  |1        12    3920.0000    1508.0000

--------------- TESTS AMONG ALL PAIRS OF MEANS ---------------


GROUP

 2 VERSUS:

   GROUPS        3.          4.           6.          5.          1.
   DIFF :    11.47000    26.06000    83.47000   171.77000  3901.40000
   G & H:      7.320***   18.512***   39.469***   54.487*** 347.167***
   DF*  :     17.69       19.32       14.46       12.46       11.11

 3 VERSUS:

   GROUPS        4.          6.          5.          1.
   DIFF :    14.59000    72.00000   160.30000  3889.93000
   G & H:      8.165***   30.199***   48.006***  344.498***
   DF*  :     21.53       19.54       15.17       11.32

 4 VERSUS:

   GROUPS        6.          5.          1.
   DIFF :    57.41000   145.71000  3875.34000
   G & H:     25.150***   44.593***  343.845***
   DF*  :     17.91       14.14       11.24

 6 VERSUS:

   GROUPS        5.          1.
   DIFF :    88.30000  3817.93000
   G & H:     24.334***  335.478***
   DF*  :     18.77       11.67

 5 VERSUS:

   GROUPS        1.
   DIFF :  3729.63000
   G & H:    321.015***
   DF*  :     12.62

 --end--
```

```
MCHETV
ID =Ni in L. elliptica in 1993, C.H.

      6 GROUPS, INPUT CODE =  1, TRANSFORMATION CODE =  0
                                 POWER =    1.00000

MEANS SORTED FROM LOW TO HIGH

GROUP     N(I)     YBAR(I)      VAR(I)
  |6        12       2.7400       1.0000
 ||3        12       4.4700       1.9100
 | 4        12       6.1600       1.7100
 | 2        12       6.2700       1.8300
 | 5        12      20.9700      13.9000
 | 1        12     131.4600      34.5500

--------------- TESTS AMONG ALL PAIRS OF MEANS ---------------


GROUP

 6 VERSUS:

   GROUPS        3.          4.          2.          5.          1.
   DIFF :     1.73000     3.42000     3.53000    18.23000   128.72000
   G & H:      3.513       7.197***    7.269***   16.360***   74.785***
   DF*   :    20.04       20.59       20.26       12.57       11.64

 3 VERSUS:

   GROUPS        4.          2.          5.          1.
   DIFF :     1.69000     1.80000    16.50000   126.99000
   G & H:      3.077       3.224      14.375***   72.854 ***
   DF*   :    21.93       21.99       13.97       12.21

 4 VERSUS:

   GROUPS        2.          5.          1.
   DIFF :      .11000    14.81000   125.30000
   G & H:       .203      12.985***   72.082 ***
   DF*   :    21.97       13.67       12.09

 2 VERSUS:

   GROUPS        5.          1.
   DIFF :    14.70000   125.19000
   G & H:     12.839 ***  71.900 ***
   DF*   :    13.85       12.16

 5 VERSUS:

   GROUPS        1.
   DIFF :   110.49000
   G & H:     54.988 ***
   DF*   :    18.62

--end--
```

```
MCHETV
ID =Pb in L. elliptica in 1993, C.H.

      6 GROUPS, INPUT CODE =  1, TRANSFORMATION CODE =  0
                                 POWER =    1.00000

MEANS SORTED FROM LOW TO HIGH

GROUP     N(I)      YBAR(I)      VAR(I)
  |6        12        1.3500        .4150
  |3        12        2.1500        .6500
 ||4        12        2.7700       1.7400
 |2         12        5.4900       4.1800
 |1         12       14.1100       3.9600
 |5         12       37.6500      21.9300

--------------- TESTS AMONG ALL PAIRS OF MEANS ---------------


GROUP

 6 VERSUS:

   GROUPS        3.          4.          2.          1.          5.
   DIFF :      .80000     1.42000     4.14000    12.76000    36.30000
   G & H:      2.685       3.351       6.690**    21.133***   26.602***
   DF*  :     20.98       15.96       13.16       13.28       11.42

 3 VERSUS:

   GROUPS        4.          2.          1.          5.
   DIFF :      .62000     3.34000    11.96000    35.50000
   G & H:      1.389       5.265*     19.296***   25.880***
   DF*  :     18.21       14.34       14.52       11.65

 4 VERSUS:

   GROUPS        2.          1.          5.
   DIFF :     2.72000    11.34000    34.88000
   G & H:      3.873      16.454***   24.835***
   DF*  :     18.81       19.10       12.73

 2 VERSUS:

   GROUPS        1.          5.
   DIFF :     8.62000    32.16000
   G & H:     10.466***   21.802***
   DF*  :     21.98       15.05

 1 VERSUS:

   GROUPS        5.
   DIFF :    23.54000
   G & H:     16.026***
   DF*  :     14.85

--end--
```

```
MCHETV
ID =Zn in L. elliptica in 1993, C.H.

      6 GROUPS, INPUT CODE =  1, TRANSFORMATION CODE =  0
                                 POWER =    1.00000

MEANS SORTED FROM LOW TO HIGH

GROUP     N(I)     YBAR(I)      VAR(I)
   |1       12      78.3000       9.4000
   |3       11      84.9300      13.8700
   |6       12     114.7300      22.4100
   |2       12     153.0400      39.2800
   |4       12     206.4300      72.1100
   |5       12    1687.1500     926.0500


--------------- TESTS AMONG ALL PAIRS OF MEANS ---------------


GROUP

 1 VERSUS:

   GROUPS        3.          6.           2.           4.           5.
   DIFF :     6.63000    36.43000    74.73999    128.13000   1608.85000
   G & H:      4.637*      22.375***   37.108***   49.163***  182.220***
   DF*  :     19.46        18.85        15.98        13.82        11.22

 3 VERSUS:

   GROUPS        6.          2.           4.           5.
   DIFF :    29.80000    68.10999    121.50000   1602.22000
   G & H:     16.848***   31.986***    45.062***  180.916***
   DF*  :     20.56        18.15        15.36        11.36

 6 VERSUS:

   GROUPS        2.          4.           5.
   DIFF :    38.30999    91.69999   1572.42000
   G & H:     16.848***   32.674***  176.868***
   DF*  :     20.47        17.23        11.53

 2 VERSUS:

   GROUPS        4.          5.
   DIFF :    53.39000  1534.11000
   G & H:     17.524***  171.045***
   DF*  :     20.24        11.93

 4 VERSUS:

   GROUPS        5.
   DIFF :  1480.72000
   G & H:    162.354***
   DF*  :     12.70

--end--
```