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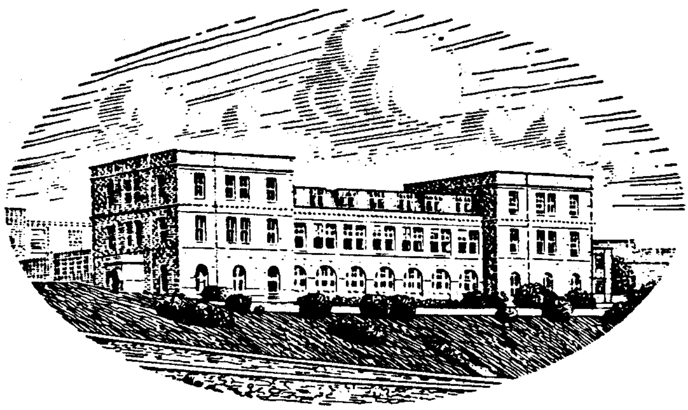

THE USE OF BIOLOGICAL INDICATORS OF HEAVY METAL CONTAMINATION IN ESTUARIES

WITH SPECIAL REFERENCE TO AN ASSESSMENT OF THE BIOLOGICAL AVAILABILITY OF METALS IN ESTUARINE SEDIMENTS FROM SOUTH-WEST BRITAIN

by

G.W. Bryan, W.J. Langston and L.G. Hummerstone

OCCASIONAL PUBLICATION NUMBER 1

The Laboratory,
Citadel Hill,
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ABSTRACT

The use of the deposit-feeding molluscs *Scrobicularia plana* and *Macoma balthica* and the burrowing polychaete *Nereis diversicolor* as indicators of the biological availability of heavy metals in sediments has been evaluated. Concentrations of Ag, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Sn and Zn have been measured in organisms and sediments from more than 30 estuaries in south-west England and South Wales and indicate that the biological availability of most metals varies by orders of magnitude between uncontaminated and contaminated sites. The results have been compared with those obtained with the use of other species of indicator organisms in estuaries.

This work was carried out under contract DGR 480/51 for the Department of the Environment. The views expressed are those of the authors and not necessarily those of the Department.

CONTENTS

SUMMARY

The concentrations of 13 metals (Ag, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Sn, Zn) have been measured in biological indicator species and surface sediments from more than 100 sites in over 30 estuaries in south-west England and South Wales. Although the concentrations of metals in sediments reflect their input and retention by estuaries, they do not necessarily reflect the biological availability of sediment-bound metals as indicated by the concentrations in sediment-dwelling species.

Three burrowing species, the polychaete _Nereis diversicolor_ and the deposit-feeding bivalves _Scrobicularia plana_ and _Macoma balthica_, have been evaluated as indicators of the availability of metals in estuarine sediments. _Scrobicularia_ has been studied in most detail and is the best accumulator of metals. It exchanges metals slowly and appears to be a good indicator of changes in chronic contamination. Studies on the influence of size and season on metal levels in _Scrobicularia_ show that sampling animals of 4 cm shell length in the autumn or early spring is the most reliable method of comparing different sites. Most of the metals lie in the digestive gland and some surveys have been conducted with the use of both this organ and the whole soft parts. The disadvantage of having to dissect the digestive gland is balanced to some extent by its ease of analysis and for most metals both tissues give comparable results. When _Scrobicularia_ was absent, _Macoma balthica_ (1.5 cm) was used wherever possible. The polychaete _Nereis diversicolor_ was analysed at almost every site and proved a useful indicator for Ag, Cd, Cu and Hg although not Zn which it regulates.

Surveys with these species indicate that the biological availability of most metals differs by orders of magnitude between the sediments from uncontaminated and contaminated sites. The results for these organisms have been combined to make a preliminary classification of the estuaries for each metal. On this basis, the most contaminated are: Ag, East Looe and upper Severn; As, Restronguet Creek and Hayle; Cd, Severn and Plym; Cr, Loughor; Cu, Restronguet Creek and Hayle; Hg, Severn and Neath; Pb, Gannel; Sn, Loughor and Truro; Zn, Gannel.

Results for the burrowing indicator species are compared with those for other benthic species which have been used as indicators of the availability of metals in estuarine waters.

INTRODUCTION

One of the main causes for concern about heavy metals is their accumulation by living systems; first, because the absorption of high concentrations by commercial species might prove harmful to man and, second, because the productivity of marine or estuarine organisms may be affected. Although at suitable concentrations, some heavy metals such as Cu and Zn are essential for life, they also form an important group of enzyme inhibitors when natural levels are exceeded. In human foodstuffs Hg, Cd and Pb are regarded as the most hazardous metals, but to marine organisms the toxicity of Cu or Ag often approaches that of Hg and, by virtue of their abundance in some areas, less toxic metals such as Zn and As are also important.

In British waters the most obvious metallic contamination occurs in estuaries, where incoming heavy metals of natural and anthropogenic origin tend to become trapped. As a river enters an estuary, its rate of flow is reduced and suspended particles of freshwater origin are deposited. At the same time, the changes in salinity and sometimes pH, as fresh water and sea water are mixed, cause the flocculation of iron oxides together with humic substances and other colloidal materials such as clays. By association with these processes, heavy metals may be removed from solution and deposited in the sediments at concentrations many orders of magnitude greater than those in the overlying water.

Since most of the metals in an estuary lie in the sediments, analyses of these deposits are very useful in assessing the input and retention of heavy metals in an estuary. However, as will be shown later, such analyses are generally an unreliable indication of the biological availability of sediment-bound metals. For example, it was found that although similar concentrations of Ag were present in the sediments of the West and East Looe estuaries, levels in the burrowing bivalve Scrobicularia plana from the East Looe branch were more than an order of magnitude higher than in animals from the other branch[1]. One reason for this type of observation is that measurements of metal concentrations in water or sediment do not usually take into account the presence of different chemical forms having different biological availabilities. Since biological availability is one of the pre-requisites for heavy-metal pollution, analysis of biological material seems to be an appropriate way of assessing contamination.

Information on the use of biological indicators of metal contamination has been reviewed by Phillips[2] and Jones[3]. For example, brown seaweeds concentrate metals from sea water by a factor of about 10^4 (concentration in dry weed/concentration in water) and have proved to be useful as indicators and integrators of contamination in estuarine waters[4,5,6]. Similarly, filter-feeding molluscs such as mussels have been used as indicators of heavy metals in water and suspended particles[1,7]. However, relatively little work has been done on the use of indicators in sediments where most of the metals lie.

The purpose of this report is (i) to illustrate some of the problems of using biological indicators and to compare different types, (ii) to produce a broad classification of estuaries in terms of the biologically available metals in sediments.

1 BIOLOGICAL INDICATORS OF METALS IN ESTUARINE SEDIMENTS

1.1 PROPERTIES REQUIRED OF AN INDICATOR ORGANISM

It is important that indicator organisms should not only be good accumulators of metals and of reasonable size (for easy analysis) but should reflect the changing availability of metals in some phase of the environment - in this case the sediments. The ability of some organisms to maintain relatively constant metal concentrations in their tissues clearly makes them unsuitable as indicators. Ideal indicator organisms should in addition be easily recognized, common, accessible, relatively stationary, long lived, available at all times of year and, in this case, sufficiently tolerant of low salinities to be distributed along a reasonable length of an estuary.

The number of sediment-dwelling species which satisfy these criteria and penetrate into the upper reaches of estuaries where the worst metallic contamination often occurs is very limited and detailed studies have been confined to the bivalve molluscs *Scrobicularia plana* (da Costa) and *Macoma balthica* (L.), and the ragworm *Nereis* (*Hediste*) *diversicolor* O.F. Müller.

1.2 PROBLEMS IN THE USE OF INDICATORS

Studies with *Scrobicularia plana* will serve to illustrate some of the factors which require consideration when using biological indicators.

This bivalve lives at a depth of 10-25 cm in intertidal sediments and feeds mainly on surface deposits via its inhalent siphon. Its salinity tolerance is such that in the Tamar Estuary it is distributed from

1.5 km from the mouth where the salinity of the interstitial water is 33-35‰, to 18 km where in winter the salinity falls to about 10‰ at a depth of 10-20 cm in the sediment.

1.2.1 Sampling sites, collection, pretreatment and analysis

In most estuaries, metal concentrations in the sediments decrease downstream as material of freshwater origin is diluted with that from the sea. Preliminary sampling of Scrobicularia in small estuaries was usually carried out at sites near the upper and lower limits of its distribution along the estuary. Sites were positioned at about mid-tide level where the species is usually most abundant, but position along the estuary was also governed by accessibility and the need to collect other indicator species. Most sites were sampled at least twice and, particularly where there was evidence of contamination, the number of sites was increased (e.g. to 9 in the Tamar and Looe estuaries). Experience has shown that because of the spread of contaminated particles through the action of tides and currents, it is not necessary to sample a large number of sites to obtain a reasonable picture of metal contamination in small or moderately sized estuaries.

Scrobicularia were collected by digging and returned to the laboratory in sediment in insulated containers. To remove ingested sediment the animals were kept for a week in 50% sea water which was changed at intervals. Exposure to constant salinity ensured that concentrations calculated on a dry weight basis were not affected by variations in the weight of salt included in the dry weight. Tissues, other than those for the analysis of As, Hg and Sn, were dissected from the shell, dried at 80°C, digested with nitric acid (low in Cr) and, following evaporation, dissolved in 1N hydrochloric acid. Analyses for Ag, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn were carried out by flame atomic absorption with the use of background correction when necessary. A graphite furnace atomizer was used to measure the lowest concentrations of Ag, Cd and Cr.

Additional animals were homogenised and subsampled for Hg, As and Sn analyses. Samples for Hg determinations were digested with a mixture of nitric and sulphuric acids and oxidised with hydrogen peroxide before being analysed by cold-vapour atomic absorption. Samples for As and Sn analyses were mixed with a magnesium oxide/magnesium nitrate ashing aid, dry ashed at 500°C and dissolved in 6N HCl. After reduction of the sample with sodium borohydride, the volatile hydrides of As and Sn were collected in a liquid nitrogen trap. The hydrides were then volatilized and passed into the inert gas supply to a graphite furnace atomizer.

1.2.2 Factors affecting concentrations in Scrobicularia

Particularly in contaminated estuaries, concentrations of Cd, Co, Cr, Ni, Pb and Zn in Scrobicularia tend to increase as the animal grows (Figures 1 & 2). As a result, comparisons between sites have been made with the use of animals of about 4 cm shell length (0.3 - 0.4g dry weight soft tissues). Because individual animals do not always provide enough material for all analyses and to improve the replication of samples, analyses were usually carried out on the pooled soft parts of 5-6 similar-sized individuals. The variability of analyses between samples is considered in Appendix 1. Tests with pooled samples collected along the Plym Estuary, where the gradient of contamination is fairly shallow, suggest that sampling at a single site is reasonably representative of a fairly level area of about 18,000 m^2 and that therefore the positioning of the site is not critical (Appendix 1). On the other hand, studies on sloping shores in the Tamar and Torridge estuaries showed that concentrations of some metals in animals from the upper shore may be higher than those from the lower shore. Thus when repeatedly sampling Scrobicularia it is important to position the site fairly accurately with regard to shore level. Our samples have been collected from about mid-tide level where the species is generally most abundant.

1.2.3 Factors affecting changes in concentration and sampling frequency

In Scrobicularia, the digestive gland (liver) accounts for about 25% of the dry weight of the soft parts and is probably the most important site for the absorption of metals from ingested sediment. Results for animals from the Tamar Estuary show that the mean contribution of the digestive gland to the total metal content of the soft parts is Ag 15%, As 36%, Cd 95%, Co 94%, Cr 80%, Cu 38%, Fe 10%, Hg 65%, Mn 73%, Ni 83%, Pb 85%, Sn 58% and Zn 87%. Experiments in which animals were exchanged between the uncontaminated Camel Estuary and the contaminated Gannel Estuary show that, particularly for Pb, Cd, Co and Zn, changes in concentration with time in the digestive gland are extremely slow (Figure 3). Although changes in the other tissues occur more rapidly[8], the results show that Scrobicularia is unlikely to reflect short-term fluctuations in the environment and should be regarded as a long-term integrator of the chronic type of contamination which is particularly characteristic of sediments. For this reason there seems to be no need to sample animals frequently (i.e. more than twice a year).

Results for the control animals in Figure 3 show that in the Camel and

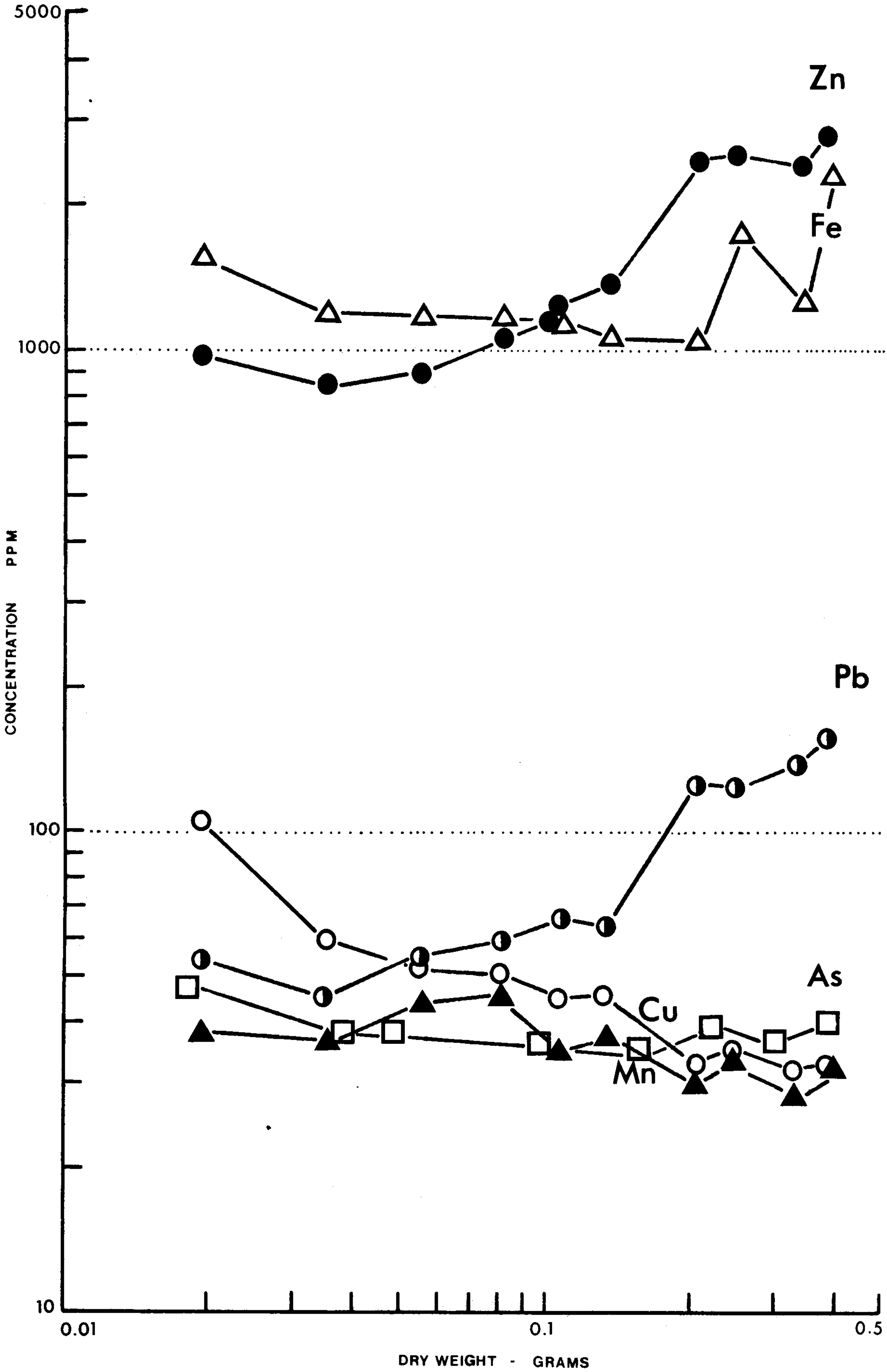

Figure 1 INFLUENCE OF SIZE ON METAL CONCENTRATIONS IN SCROBICULARIA FROM THE TAMAR ESTUARY (POOLED SAMPLES)

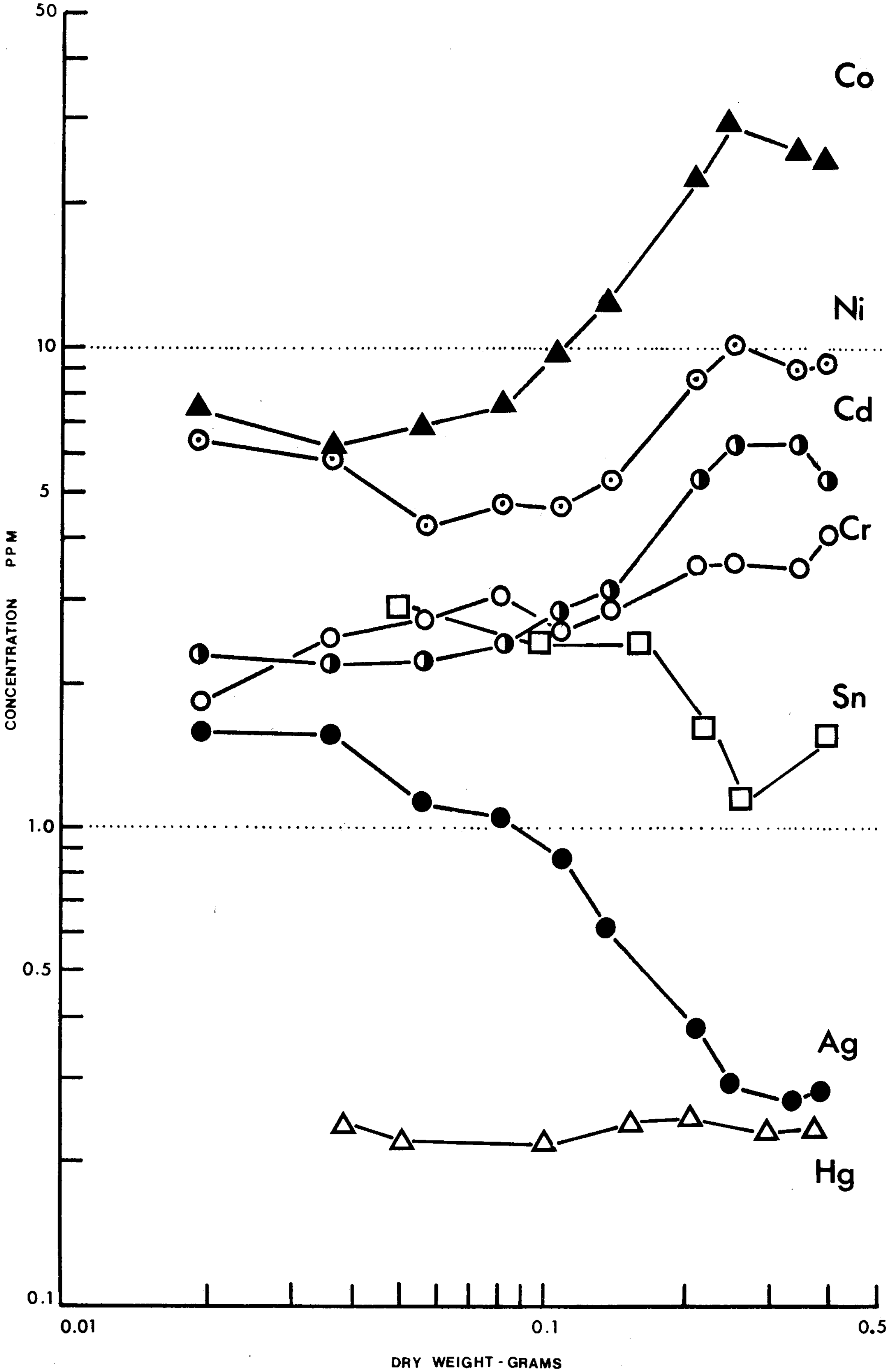

Figure 2 INFLUENCE OF SIZE ON METAL CONCENTRATIONS IN SCROBICULARIA FROM THE TAMAR ESTUARY (POOLED SAMPLES)

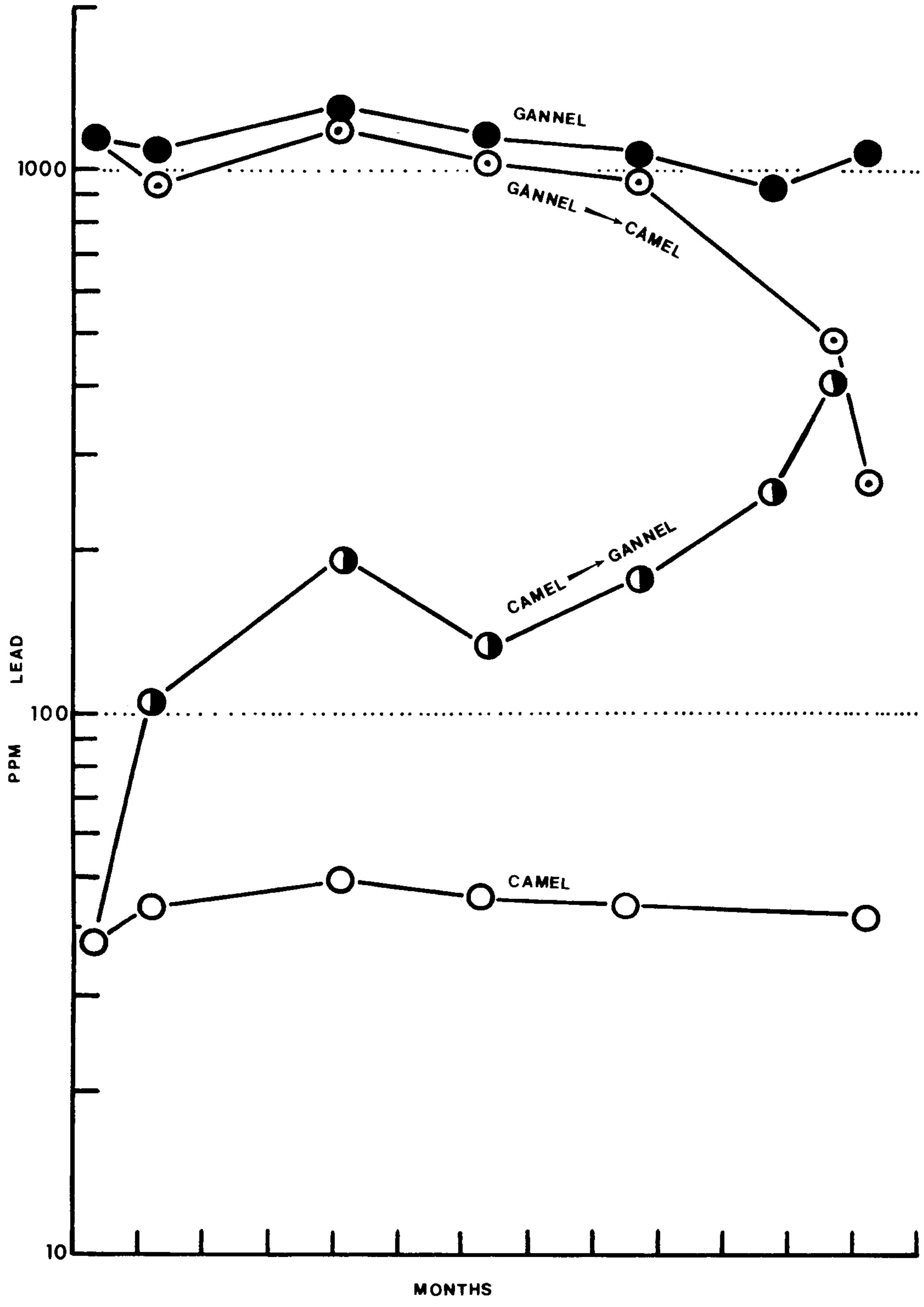

Figure 3 LEAD CONCENTRATIONS IN THE DIGESTIVE GLAND OF SCROBICULARIA EXCHANGED BETWEEN TWO ESTUARIES, STARTING IN OCTOBER. CONCENTRATIONS IN NATIVE ANIMALS ALSO SHOWN (POOLED SAMPLES)

Gannel estuaries there are no major changes in the Pb concentration of the digestive gland over a period of a year. This suggests that the availability of the metal remains fairly constant during the year and that the level in the digestive gland is not seriously affected by seasonal metabolic changes within the animal. However, when whole animals are used for analysis, dilution of the soft parts through the development of gonads during the summer (June - August) can reduce the concentration. As a result, sampling is best carried out in the early spring and autumn when the gonads are largely undeveloped (see also Appendix 1).

1.2.4 Digestive gland in Scrobicularia

It is evident from the foregoing sections that analysis of the digestive gland alone has some advantages over analysis of the whole soft parts; its higher metal concentrations are more easily measured, it seems less likely to be influenced by gonad development and, since it is an important site for the digestion and absorption of ingested material, it is the tissue most likely to reflect the availability of metals in the sediments. In order to evaluate this tissue, samples pooled from 5-6 animals of about 4 cm shell length were analysed at many sites for comparison with the whole animal results.

1.2.5 Analysis of sediment associated with Scrobicularia

Scrobicularia appears to feed mainly on the oxidized surface sediments and is known to accept particles of at least 40 µm[9]. Surface sediment was sampled by careful scraping and sieved through 100 µm plastic mesh as soon as possible after collection. For most metals the air-dried sediment was digested with nitric acid (1g + 20ml) and analysed in the same way as the tissues. This digestion dissolves the major fractions of most heavy metals and should extract any that could possibly become biologically available. Wet sediments were used in As and Hg determinations. Samples weighing approximately 3g were refluxed for two hours with 20 ml of nitric acid. Separate subsamples were dried for wet/dry weight conversions. An ammonium iodide fusion followed by dissolution in 1N HCl was used to release tin from cassiterite since this is not attacked by the nitric acid digestion. Samples were analysed in the same way as the tissues.

1.2.6 Summary of sampling policy and methods

Preliminary assessments of the biological availability of metals in the sediments of an estuary are based on analyses of three species (Scrobicularia plana, Macoma balthica and Nereis diversicolor) from a small number of sites. For comparison, other benthic species and sediments are also analysed. The number of sites is increased in subsequent surveys, particularly in contaminated areas. Some of the problems associated with the use of indicators have been illustrated by reference to Scrobicularia. At individual sites this bivalve is collected from the sediments at mid-tide level during the spring or autumn and cleaned by exposure to 50% sea water for a week. Analyses of Ag, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Sn and Zn are carried out on samples consisting of the pooled soft parts from 5-6 animals of 4 cm shell length. Normally, at least 3 samples, one for As, Hg and Sn and two for the other metals, are analysed from each site and most sites are sampled on at least two occasions.

At some sites pooled samples covering a range of sizes are analysed and from these results values for 4 cm animals (0.3 - 0.4g dry weight soft parts) can be interpolated. Samples of digestive gland pooled from 5-6 animals have been analysed for comparison with the whole soft parts and for most metals both tissues show similar trends. With atomic absorption equipment fitted with background correction analysis of the whole soft parts is easiest and we have concentrated on this method. In the absence of background correction, however, analysis of the digestive gland is more reliable at low concentrations.

1.3 REGIONAL SURVEYS WITH THE USE OF SCROBICULARIA PLANA

Typical analyses of the whole soft parts and digestive gland of Scrobicularia from selected sites in different estuaries are given in Appendices 2 & 3. Extreme concentrations in the whole soft parts are summarised in Table 1 and indicate that the biological availability of metals in sediments from different sites may vary over ranges of 1-2 orders of magnitude for As, Co, Cr, Cu, Fe, Hg, Mn, Ni, and Sn, more than 2 orders for Cd and Pb and more than 3 orders for Ag. In order to condense the type of information contained in Appendices 2 & 3 and to compare different estuaries, the results for the metals which are regarded as being potentially most toxic have been reduced to the concentration ranges (based on orders or half orders of magnitude) within which most of the values from a particular estuary lie (Tables 2 & 3). The classification resulting from the use of whole soft parts is similar to that obtained with the digestive gland although exact equality is not to be expected: the concentration ranges for the two types of sample are not exactly equivalent and concentrations

Table 1. MAXIMUM AND MINIMUM METAL LEVELS IN SCROBICULARIA PLANA

Results compiled from all samples

		Concentration (ppm dry weight)												
		Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	As	Hg	Sn
Cornwall and Devon														
	Maximum	259	42.7	106	7.1	752	9770	339	22.4	1080	4920	191	1.3	8.5
Whole	Estuary	E. Looe	Plym	Gannel	E. Looe	Erme	Tamar	Gannel	E. Looe	Gannel	Gannel	Restronguet	W. Looe	Truro
soft parts	Minimum	< 0.1	0.3	2.6	0.6	11	375	10	1.1	8	309	12	0.04	0.23
	Estuary	Lynher	Camel	Plym	Hayle	Fowey	Plym	Helford	Hayle	Camel	Camel	Exe	Restronguet	Taw
South Wales, Bristol Channel and Severn														
	Maximum	11.7	39.7	14.1	23.8	75	1550	112	14.2	103	2440	26	0.75	14.0
Whole	Estuary	Shepperdine	Rhymney	Neath	Loughor	Shepperdine	Loughor	Loughor	Tywi	Rhymney	Rhymney	Usk/Severn	Neath	Loughor
soft parts	Minimum	0.1	0.2	2.0	0.5	9	248	18	1.2	5	256	5	0.02	< 0.1
	Estuary	Loughor	W. Cleddau	E. Cleddau	W. Cleddau	Loughor	Tywi	W. Cleddau	W. Cleddau	Loughor	Taf	W. Cleddau	Loughor	Severn
Maximum/Minimum ratios - all estuaries														
	Whole soft parts	> 2590	213	53	48	84	39	34	20	216	19	38	65	> 140

Table 2. METAL CONTAMINATION IN SOFT PARTS OF SCROBICULARIA PLANA

Summary compiled from results in Appendix 2 and from additional surveys at same and other sites. Estuary or site numbers refer to positions in Figure 4.

No.	Estuary	No of sites	Ag	Cd	Cr	Cu	Pb	Zn	As	Hg	Sn
				Cornwall and Devon							
1	Taw	1	–	–	–	–	–	–	–	–	–
2	Torridge	3	+	–	–	–	–	–	–	+	–
3	Camel	2	–	–	–	+	–	–	–	–	–
4	Gannel	3	+	+	–	+	+++	++	+	+	–
5	Hayle	3	–	–	–	+	–	+	++	–	+
6	Helford	2	–	–	–	–	–	+	–	–	+
7	Restronguet	3	–	+	–	++	+	+	++	–	+
8	Truro	3	–	+	–	+	+	++	+	–	++
9	Tresillian	1	–	+	–	+	+	+	+	–	+
9X	Fal	1	–	–	–	–	–	+	–	–	–
10	Fowey	5	–	–	–	+	–	+	–	–	+
11	W. Looe	4	+	–	+	++	++	+	+	+	+
12	E. Looe	6	+++	–	+	++	++	+	+	+	–
13	Lynher	2	–	–	–	–	+	+	+	–	+
14	Low Tamar	3	–	–	–	+	+	+	–	–	–
15	Upper Tamar	5	–	+	–	+	+	+	+	–	+
16	Tavy	1	–	+	–	++	+	+	+	–	–
17	Plym	3	–	++	+	+	–	+	–	–	+
18	Yealm	3	–	–	–	–	+	+	–	+	–
19	Erme	3	–	–	–	+	+	+	+	+	–
20	Avon	5	–	–	–	+	–	–	–	+	–
21	Kingsbridge	2	–	–	–	–	–	–	+	+	–
22	Dart	1	–	–	–	–	–	–	–	–	–
23	Teign	5	–	–	–	–	+	+	–	–	
24	Exe	2	+	–	+	–	–	+	–	+	+
25	Otter	1	–	–	–	+	–	+	–	+	–
26	Axe	3	+	–	–	+	–	+	–	+	+

Table 2 continued

No.	Estuary	No of sites	Ag	Cd	Cr	Cu	Pb	Zn	As	Hg	Sn
					South Wales and Severn						
1a	Usk/Severn	1	+	++	–	–	+	+	–	+	–
2a	Rhymney/Severn	1	+	+++	+	–	+	+	–	–	–
3a	Cardiff H.	1	+	+	–	–	–	–	–	+	–
4a	Barry H.	1	+	+	+	+	+	–	–	+	–
5a	Neath	2	–	–	–	–	+	–	–	+	–
6a	Swansea Bay (West)	2	+	–	–	+	–	–	–	+	–
7a	Loughor	9	–	–	++	–	–	–	–	–	++
8a	Gwendraeth	1	–	–	–	–	–	–	–	–	–
9a	Tywi	3	–	–	–	–	–	–	–	–	–
10a	Taf	3	–	–	–	–	–	–	–	–	–
11a	W. Cleddau	2	+	–	–	–	–	–	–	–	–
	E. Cleddau	2	–	–	–	–	–	–			
				Severn and Southern Bristol Channel							
2b	Shepperdine	1	++	++		+	–	–			–
8b	Watchet H.	1	+	+	+	+	+	+	–	+	–
9b	Dunster	1	+	++	–	–	–	–			
10b	Minehead H.	1	+	–	–	+	–	–	–	+	–

					Concentration (ppm dry weight)				
	Ag	Cd	Cr	Cu	Pb	Zn	As	Hg	Sn
Key									
–	< 1	< 3.3	< 3.3	< 33	< 33	< 1000	< 33	< 0.3	< 1.0
+	1–10	3.3–10	3.3–10	33–100	33–100	1000–3300	33–100	0.3–1.0	1.0–3.3
++	10–100	10–33	> 10 at some sites	100–330	100–330	> 3300 at some sites	> 100	> 1.0	> 3.3
+++	> 100 at some sites	> 33		> 330	> 330				

Table 3. METAL CONTAMINATION IN THE DIGESTIVE GLAND OF SCROBICULARIA PLANA

Summary compiled from results in Appendix 3 and from additional surveys at same and other sites. Estuary or site numbers refer to positions in Figure 4.

No.	Estuary	No of sites	Ag	Cd	Cr	Cu	Pb	Zn
					Cornwall and Devon			
1	Taw	1	+	–	–	–	–	–
2	Torridge	2	+	–	–	–	–	–
3	Camel	2	–	–	–	+	–	–
4	Gannel	2	+	+	–	+	+++	++
5	Hayle	3	–	–	–	++	–	+
6	Helford	2	–	–	–	+	–	+
7	Restronguet	1	–	+	–	++	+	++
8	Truro	1	+	+	–	+	++	++
9	Tresillian	1	–	+	–	+	+	++
10	Fowey	1	–	–	–	+	+	+
11	W. Looe	1	++	–	–	+	++	–
12	E. Looe	1	+++	–	–	++	+	–
13	Lynher	2	–	+	–	+	+	+
14	Lower Tamar	3	–	–	–	+	+	+
15	Upper Tamar	6	–	+	–	+	++	++
16	Tavy	1	–	+	–	++	+	+
17	Plym	2	–	++	+	+	+	+
18	Yealm	2	–	–	–	+	+	–
19	Erme	2	+	–	–	++	+	–
20	Avon	1	–	–	–	++	–	–
21	Kingsbridge	2	+	–	–	–	+	–
22	Dart	1	–	–	–	–	–	–
23	Teign	2	+	–	–	–	+	+
24	Exe	2	+	–	+	–	+	+
25	Otter	1	–	–	–	–	–	+
26	Axe	3	+	–	–	–	–	–

Table 3 continued

No.	Estuary	No. of sites	Ag	Cd	Cr	Cu	Pb	Zn
				South Wales and Severn				
1a	Usk/Severn	1	+	++	+	+	+	+
2a	Rhymney/Severn	1	+	+++	+	+	++	+
3a	Cardiff H.	1	+	++	–	+	+	+
4a	Barry H.	1	++	+	–	+	+	–
5a	Neath	1	+	–	–	+	–	–
7a	Loughor	4	–	–	+	+	–	–
8a	Gwendraeth	1	–	–	–	–	–	–
9a	Tywi	1	+	+	–	+	–	–
10a	Taf	1	–	–	–	–	–	–
11a	W. Cleddau	2	+	–	–	++	–	–
				Southern Bristol Channel				
8b	Watchet H.	1	+	+	–	+	+	+
10b	Minehead H.	1	++	+	–	++	+	–
				Concentration (ppm dry weight)				
	Key	–	< 1	< 10	< 10	< 33	< 100	< 3300
		+	1–10	10–33	> 10	33–100	100–330	3300–10000
		++	10–100	33–100		100–330	330–1000	> 10000 at some sites
		+++	> 100	> 100		> 330	> 1000	

in tissues other than the digestive gland do have some influence on the whole animal results.

1.4 REGIONAL SURVEYS WITH THE USE OF MACOMA BALTHICA

Scrobicularia are rare in a few areas and appear to have been replaced by Macoma balthica a much smaller deposit-feeding bivalve. The two species seem to accumulate metals from similar sources[1] and so an attempt has been made to use Macoma as a substitute indicator. Pooled samples containing about 10 animals of 1.2 - 1.8 cm are used, since the concentrations of some metals are influenced by size (Table 4). Concentrations in the two species are not equal and Table 5 shows the concentration ratios from a few sites where both species were collected. There is no exact relation between the species, although Scrobicularia is a better accumulator of some metals, especially Cd and Pb.

Typical analyses of Macoma from some of the sampling sites are shown in Appendix 4 and maximum and minimum concentrations from all sources are summarised in Table 6. Since the rarity of Scrobicularia is a problem in the Severn Estuary, the Scrobicularia/Macoma ratios from the Rhymney/Severn site have been used to calculate the concentration ranges for Macoma which are equivalent to those for Scrobicularia. The classification resulting from the use of Macoma is shown in Table 7. A comparison of Tables 2 and 7 shows that at sites where both species were collected comparable results are obtained, particularly where contamination is evident.

1.5 REGIONAL SURVEYS WITH THE USE OF NEREIS DIVERSICOLOR

Although Nereis is able to penetrate into less saline areas than the molluscs, sampling was largely confined to the sites where Scrobicularia and Macoma were collected (Appendices 2 & 4). Work already published[10,11,12,13] shows that Nereis reflects changes in the availability of Ag, Cd, Cu and Pb in sediments, but appears to regulate the concentration of Zn in its body. Concentrations of Zn in Nereis fall as the animal grows and much of the variation shown in Table 8 results from size differences. For other metals no consistent effect of size is observed and it seems to be less important than in Scrobicularia. However, it is impossible to collect animals of equal size from different estuaries and this may have increased the variability of the results. Variability caused by the gut contents is

TABLE 4. EFFECT OF SIZE ON METAL CONCENTRATIONS IN SOFT PARTS OF MACOMA BALTHICA

Animals from Rhymney/Severn site (2a)

Shell length (cm)	Dry weight (g)	No. of animals pooled	Concentration (ppm dry weight)											
			Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	As	Hg
1.80	0.036	7	5.0	6.4	4.3	3.2	88	1950	29	2.8	29	1690	21	0.14
1.66	0.028	6	4.5	6.7	2.6	2.6	75	2310	32	2.1	25	1900	20	0.25
1.57	0.027	9	5.1	5.7	3.6	2.5	67	1510	31	1.9	18	1620	-	-
1.40	0.018	7	5.1	4.7	3.6	2.1	68	1760	18	1.8	28	1360	17	0.15
1.23	0.014	7	4.3	4.7	2.7	2.2	70	1540	33	-	-	1120	-	-
0.9	0.007	3	2.3	4.3	3.0	-	71	785	143	-	-	904	-	-

TABLE 5. *SCROBICULARIA/MACOMA* RATIOS

*From Table 10

No.	Estuary	Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	As	Hg	Sn
12	E. Looe*	0.69	5.8	3.1	1.0	0.89	0.76	1.0	2.1	3.1	1.1	1.4	1.2	-
2a	Rhymney/Severn	0.59	6.2	3.1	1.7	0.43	0.52	0.75	1.7	3.6	1.4	0.86	1.5	-
4a	Barry	0.66	2.9	1.7	1.7	0.46	0.48	1.2	2.3	5.6	0.76	1.1	2.4	-
6a	Swansea Bay	1.0	3.8	2.3	0.7	0.48	1.1	0.57	1.2	2.1	1.3	0.77	1.3	0.42
7a	Loughor	1.0	4.1	1.5	2.0	1.3	2.1	1.5	0.89	1.8	1.5	1.4	1.6	3.9

Table 6. MAXIMUM AND MINIMUM METAL LEVELS IN <u>MACOMA BALTHICA</u>

Results compiled from all samples

	Concentration (ppm dry weight)												
	Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	As	Hg	Sn
Maximum	122	9.4	7.4	16.3	224	1950	356	12.7	36.5	1790	46	1.3	1.69
Estuary	E. Looe	Sharpness	Swansea Bay	E. Looe	Sharpness	Rhymney	Sharpness	Sharpness	E. Looe	New Passage	E. Looe	New Passage	Weston
Minimum	0.3	0.1	1.0	0.8	21	210	8	1.0	2.3	396	11	0.12	< 0.1
Estuary	Loughor	E. Cleddau	Blue Anchor	E. Cleddau	Swansea Bay	Loughor	Loughor	E. Cleddau	Blue Anchor	Loughor	Loughor	Loughor	Barry H.
	Maximum/Minimum ratio												
	406	94	7.4	20	10.7	9.3	44	13	16	4.5	4.2	11	> 17

Table 7. METAL CONTAMINATION IN SOFT PARTS OF *MACOMA BALTHICA*

Summary compiled from results in Appendix 4 and from additional surveys at same and other sites. Estuary or site numbers refer to positions in Figure 4.

No.	Estuary	No. of sites	Ag	Cd	Cr	Cu	Pb	Zn	As	Hg	Sn
	Cornwall and Devon										
12	E. Looe	3	++	+	+	++	++	+	+	+	-
17	Plym	1	-	+	-	-	-	-	-	+	+
	South Wales and Severn										
4c	Redwick	1	+	++	+	-	+	+			
1a	Usk/Severn	1	+	++	+	-	+	+			
2a	Rhymney/Severn	1	+	+++	+	-	+	+	-	-	-
4a	Barry H.	1	+	+	+	+	+	+	-	-	-
6a	Swansea Bay	1	-	+	-	-	+	-	-	+	-
7a	Loughor	1	-	-	+	-	-	-	-	-	+
11a	W. Cleddau	2	+	-	-	-	-	-			
	E. Cleddau	1	+	-	-	-	-	-			
	Severn and Southern Bristol Channel										
1b	Sharpness	1	++	+++	+	+	+	+			
2b	Shepperdine	1	++	++	+	-	-	+			
3b	New Passage	1	++	+++	+	+	-	+	-	++	-
4b	Portishead	1	+	++	+	-	+	+			
5b	Sand Bay	1	+	++	+	-	+	+			
6b	Weston	1	+	++	+	-	-	+	-	+	+
7b	Burnham	1	+	++	+	-	-	+			
9b	Blue Anchor	1	+	++	+	-	-	+	-	+	-
	Concentration (ppm dry weight)										
	Key	-	< 1.7	< 0.53	< 1.9	< 77	< 9.2	< 694	< 33	< 0.33	< 1.0
		+	1.7-17	0.53-1.6	> 1.9	77-234	9.2-28	> 694	> 33	0.33-1.0	> 1.0
		++	> 17	1.6-5.3		> 234	> 28			> 1.0	
		+++		> 5.3							

Table 8. MAXIMUM AND MINIMUM METAL LEVELS IN *NEREIS DIVERSICOLOR*

Results compiled from all samples

	Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	As	Hg	Sn
	Concentration (ppm dry weight)												
	Cornwall and Devon												
Maximum	12.2	3.2	24.5	6.5	1430	871	51.9	15.6	1190	510	87	0.47	2.6
Estuary	Gannel	Plym	Tavy	Fal	Restronguet	Tamar	Tamar	W. Looe	Gannel	Gannel	Restronguet	Tavy	Fowey
Minimum	0.05	0.03	0.7	< 0.3	10	212	4.1	0.6	0.2	91	5.3	0.05	0.06
Estuary	Plym	Yealm	Dart	Torridge	Camel	E. Looe	Plym	Fowey	Torridge	Dart	Taw	Restronguet	Taw
	South Wales, Bristol Channel and Severn												
Maximum	24.0	10.1	10.4	10.4	90	711	34.3	10.3	7.1	504	24	2.5	3.9
Estuary	Sharpness	Sharpness	Cardiff	Loughor	Portishead	W. Cleddau	Parrett	Loughor	Watchet	New Passage	Usk/Severn	Sharpness	Loughor
Minimum	0.13	0.04	2.5	0.1	10	181	7.0	1.7	0.5	103	4	0.01	< 0.1
Estuary	Taf	W. Cleddau	Loughor	Taf	Tywi	Loughor	New Passage	Watchet	Rhymney	E. Cleddau	Neath	Loughor	Wye
	Maximum/Minimum ratios - all estuaries												
	480	336	35	104	143	4.8	13	26	5950	5.6	22	250	65

Table 9. METAL CONTAMINATION IN NEREIS DIVERSICOLOR

Summary compiled from results in Appendix 5 and from additional surveys at same and other sites. Estuary or site numbers refer to positions in Figure 6.

*All sites not identical with those for Scrobicularia

No.	Estuary	No. of sites	Ag	Cd	Cr	Cu	Pb	As	Hg	Sn
					Cornwall and Devon					
1	Taw	1	-	-	-	-	-	-	-	-
2	Torridge	3	-	-	-	-	-	-	-	-
3	Camel	2	-	-	-	-	+	-	-	-
4	Gannel	4*	++	-	-	++	+++	-	-	+
5	Hayle	5*	+	-	-	+++	-	+	-	-
6	Helford	2	-	-	-	+	-	-	-	+
7	Restronguet	5*	++	-	-	+++	+	+	-	-
8	Truro	2	++	-	-	++	-			
9	Tresillian	1	+	-	-	+	-	-	-	+
9X	Fal	1	-	-	+	+	-			
10	Fowey	6*	-	-	-	+	+	-	-	+
11	W. Looe	5	+	-	-	+	++	-	-	-
12	E. Looe	6	++	-	-	+	+	-	-	-
13	Lynher	2	+	-	-	++	+	-	-	-
14	Low. Tamar	3	-	-	-	+	+	-	-	-
15	Up. Tamar	6	-	-	-	++	+	-	-	-
16	Tavy	1	+	+	-	++	+	-	+	-
17	Plym	3	-	+	+	-	+	-	+	+
18	Yealm	3	-	-	-	-	+	-	-	-
19	Erme	3	-	-	-	-	+	-	-	-
20	Avon	3	-	-	-	-	+	-	-	-
21	Kingsbridge	2	-	-	-	-	+	-	-	+
22	Dart	4*	-	-	-	-	-	-	-	-
23	Teign	5	-	-	-	-	+	-	-	
24	Exe	2	-	-	-	-	+	-	-	-
25	Otter	1	-	-	-	-	-	-	-	-
26	Axe	3	-	-	-	-	-	-	-	-

Table 9 continued

No.	Estuary	No. of sites	Ag	Cd	Cr	Cu	Pb	As	Hg	Sn
					South Wales and Severn					
1c	Wye	1	++	++	-	+	+	-	++	-
2c	Beachley/Severn	1	+++	+	-	+	-	-	++	-
3c	Black Rock/Severn	1	+++	+	-	-	-	-	++	-
4c	Redwick/Severn	1	++	++	-	+	-	-	++	-
1a	Usk/Severn	1	++	++	-	+	+	-	++	-
2a	Rhymney/Severn	1	+	+	-	-	-	-	+	-
3a	Cardiff H.	1	+	++	-	+	+	-	+	-
4a	Barry H.	1	+	-	-	+	-	-	+	-
5a	Neath	2	+	-	-	+	-	-	++	-
6a	Swansea Bay	2	+	-	-	+	+	-	+	-
7a	Loughor	10*	-	-	+	-	-	-	-	+
8a	Gwendraeth	1	-	-	-	-	-	-	-	-
9a	Tywi	3	-	-	-	-	-	-	-	-
10a	Taf	3	-	-	-	-	-	-	-	-
11a	W. Cleddau	2	-	-	-	-	-	-	-	-
	E. Cleddau	2	-	-	-	-	-	-	-	-
					Severn and Southern Bristol Channel					
1b	Sharpness	1	+++	++	-	+	+	-	++	+
2b	Shepperdine	1	++	++	-	+	+	-	++	-
3b	New Passage	1	++	++	-	+	+	-	++	-
5c	Avon	2	++	+	-	+	-	-	++	-
4b	Portishead	1	++	++	-	+	-	-	++	-
5b	Sand Bay	1	++	++	-	+	+			
6b	Weston	1	++	+	-	+	-	-	+	-
7b	Burnham	1	++	+	-	+	+			
6c	Parrett	2	++	++	-	+	-			
8b	Watchet H.	1	+	-	-	+	+	-	+	-
10b	Minehead H.	1	+	-	-	+	-	-	+	-

		Ag	Cd	Cr	Cu	Pb	As	Hg	Sn
					Concentration (ppm dry weight)				
Key	-	< 1.0	< 1.0	< 1.0	< 33	< 3.3	< 33	< 0.33	< 1.0
	+	1.0-3.3	1.0-3.3	> 1.0	33-100	3.3-10	> 33	0.33-1.0	> 1.0
	++	3.3-10	> 3.3		100-330	10-33		> 1.0	
	+++	> 10			> 330	> 33			

avoided by cleaning the worms in acid-washed sand covered with 50% sea water for 6 days and water only for 1 day.

Some typical analyses of samples consisting of about 20 pooled animals are shown in Appendix 5 and the maximum and minimum values from all sources are given in Table 8. The results are shown in a simplified form in Table 9 and Zn has been excluded because the concentration in the body responds only slightly to changes in the environment.

1.6 METALS IN SEDIMENTS

Typical analyses of oxidized surface sediments on which the burrowing species appear to feed are shown in Appendix 6. The results are given in a simplified form in Table 12 and are considered in section 1.9.2.

1.7 SUMMARY OF REGIONAL SURVEY RESULTS

Numbers in brackets following the names of estuaries refer to their positions on the maps in Figures 4-9.

1.7.1 Silver

Concentrations in the sediments range from around 0.2 ppm in several estuaries in South Devon and West Wales to more than 1 ppm in estuaries which are or were associated with metalliferous mining; these include the Gannel (4), Hayle (5), Restronguet Creek (7), West Looe (11), Tamar (15) and Teign (23). Some contamination of *Nereis* is evident in most of these estuaries and also in the East Looe (12) and Severn (1b-1c) estuaries where the source of Ag seems less likely to be mining. Although in these two estuaries concentrations of Ag in the sediments are not exceptional, they stand out clearly from the others when concentrations in *Scrobicularia* and *Macoma* are considered (Figure 4). Sediment concentrations in the East Looe Estuary only rarely approach the level of 4-5 ppm found in Restronguet Creek and yet a maximum of 269 ppm of Ag has been found in *Scrobicularia* from the East Looe Estuary compared with less than 0.5 ppm in animals from Restronguet Creek. This example clearly demonstrates the need to consider contamination in terms of biological availability and not simply in terms of concentrations in water or sediments.

1.7.2 Cadmium

In the sediments concentrations vary from about 0.2 ppm in uncontaminated

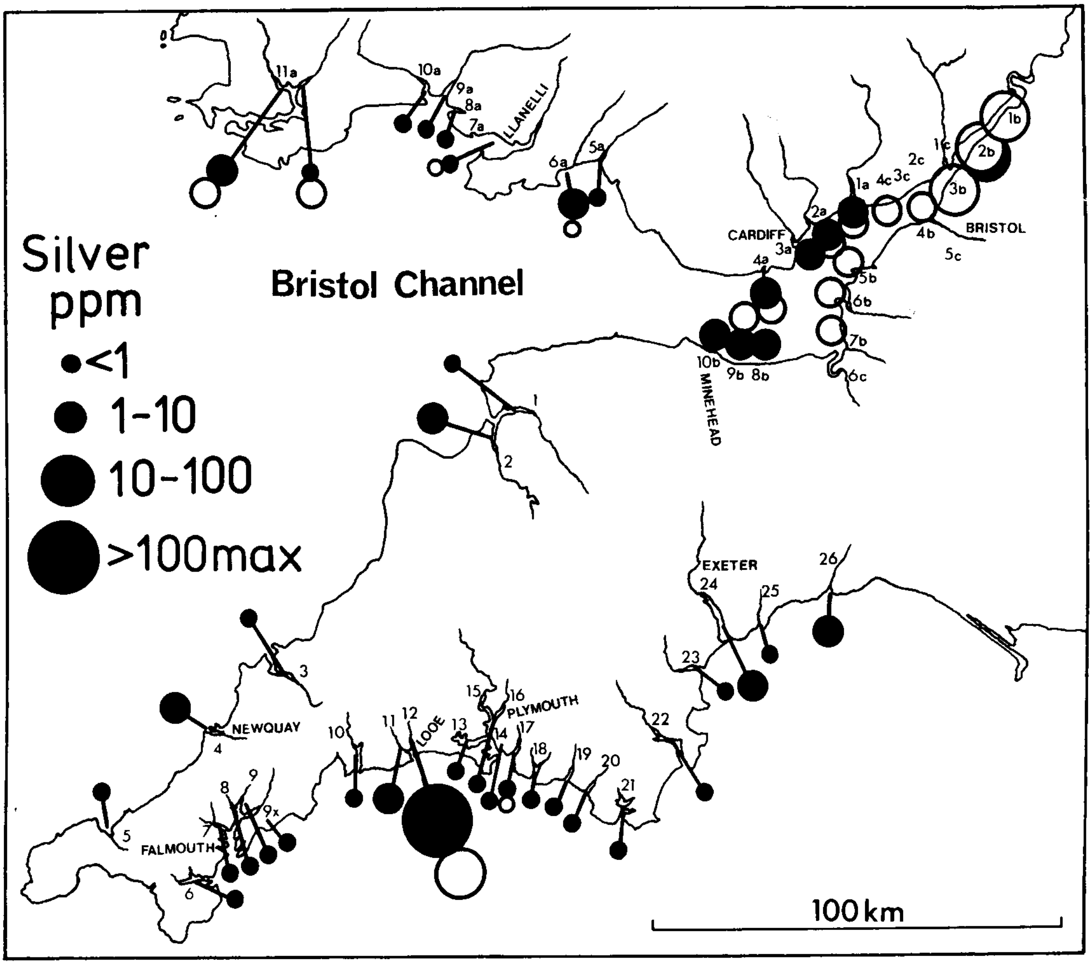

Figure 4 GEOGRAPHICAL DISTRIBUTION OF SILVER IN WHOLE SOFT PARTS OF SCROBICULARIA

Open circles are equivalent levels in Macoma, the concentration ranges above being divided by 0.59. Results are for individual sites in Severn (1a-4a, 1b-10b) but for other estuaries are the ranges within which most of the values for different sites occur.

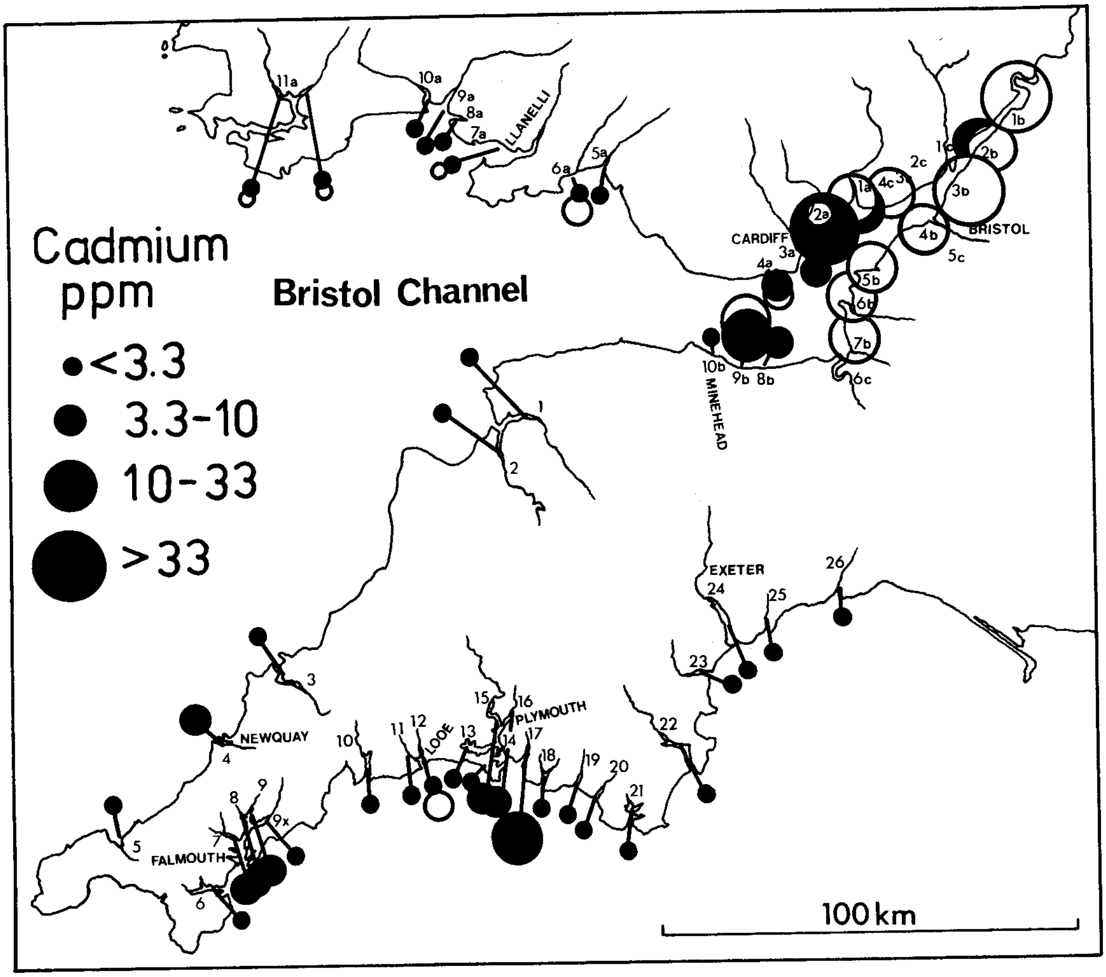

Figure 5 GEOGRAPHICAL DISTRIBUTION OF CADMIUM IN WHOLE SOFT PARTS OF SCROBICULARIA

Open circles are equivalent levels in Macoma, the concentration ranges above being divided by 6.2. Results are for individual sites in Severn (1a-4a, 1b-10b) but for other estuaries are the ranges within which most of the values for different sites occur.

areas to more than 1 ppm in some of the estuaries which receive mining wastes, including the Hayle (5), Helford (6), Restronguet Creek (7) and upper Tamar (15). More than 1 ppm is also found in some sediments from the South Wales/Severn area (2a-3a) and in the Plym (17) where up to 2.5 ppm can be found. Results for Scrobicularia and Macoma are summarised in Figure 5 and show that the availability of Cd is greatest in the Plym (17) and in the Severn (1a-2a, 1b-9b) where contamination with Cd is well documented[14,15,16,17]. Evidence of lesser contamination is observed in Scrobicularia from some of the Cornish estuaries (4, 9, 15), but, unlike the Plym and Severn animals, Cd tends to be associated with high levels of Zn. The results for Nereis (Table 9) generally support those for the molluscs, particularly in the Severn Estuary.

1.7.3 Chromium

Sediment concentrations range from about 30 ppm in uncontaminated areas to almost 800 ppm at a site in the Loughor Estuary (7a). This estuary receives effluent from the manufacture of tinplate[18] and is the only area where contamination of both Scrobicularia and Nereis with Cr is obvious.

1.7.4 Copper

Sediment concentrations exceeding 60 ppm are largely confined to estuaries in Cornwall and West Devon where copper mining was an important industry in the past. In Nereis the highest Cu levels are found in Restronguet Creek (7) and the Hayle Estuary (5) (Figure 6) and there is a fairly clear relation between concentrations in the worms and in the sediments (Figure 7). In contrast, there is virtually no relation between Cu concentrations in Scrobicularia and the sediment. For example, in 1974 concentrations of 619 and 238 ppm were observed respectively in animals from the Erme (20) and East Looe (12) estuaries where the sediments contained less than 50 ppm of Cu, but only 102 ppm was found in animals from sediments containing nearly 3000 ppm in Restronguet Creek (7). This illustrates how availability to the organism may be patently unrelated to the concentration in the environment and also suggests that the availability of Cu to Scrobicularia differs radically from its availability to Nereis.

1.7.5 Lead

In uncontaminated areas the sediments contain about 50 ppm, but in the

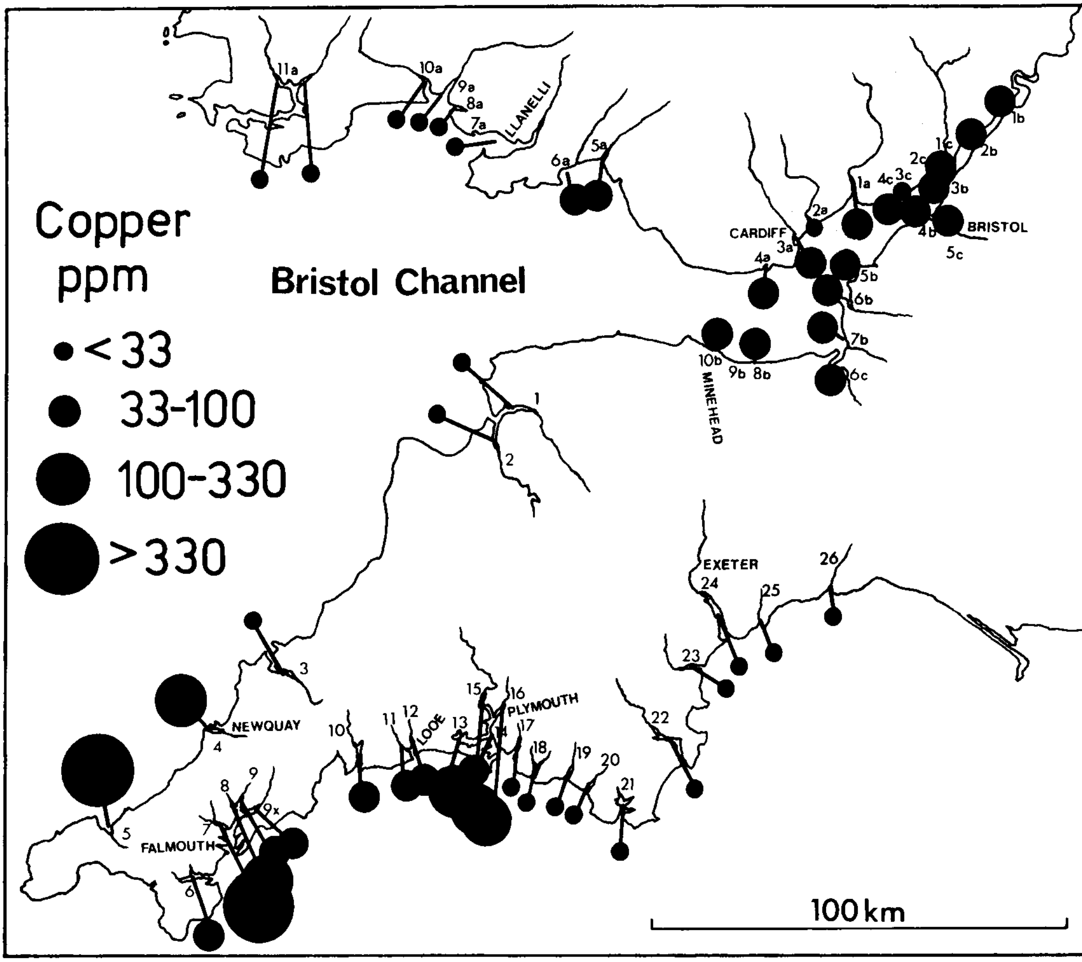

Figure 6 GEOGRAPHICAL DISTRIBUTION OF COPPER IN NEREIS

Results are for individual sites in Severn (1a-4a, 1b-10b) but for other estuaries are ranges within which most of the values for different sites occur.

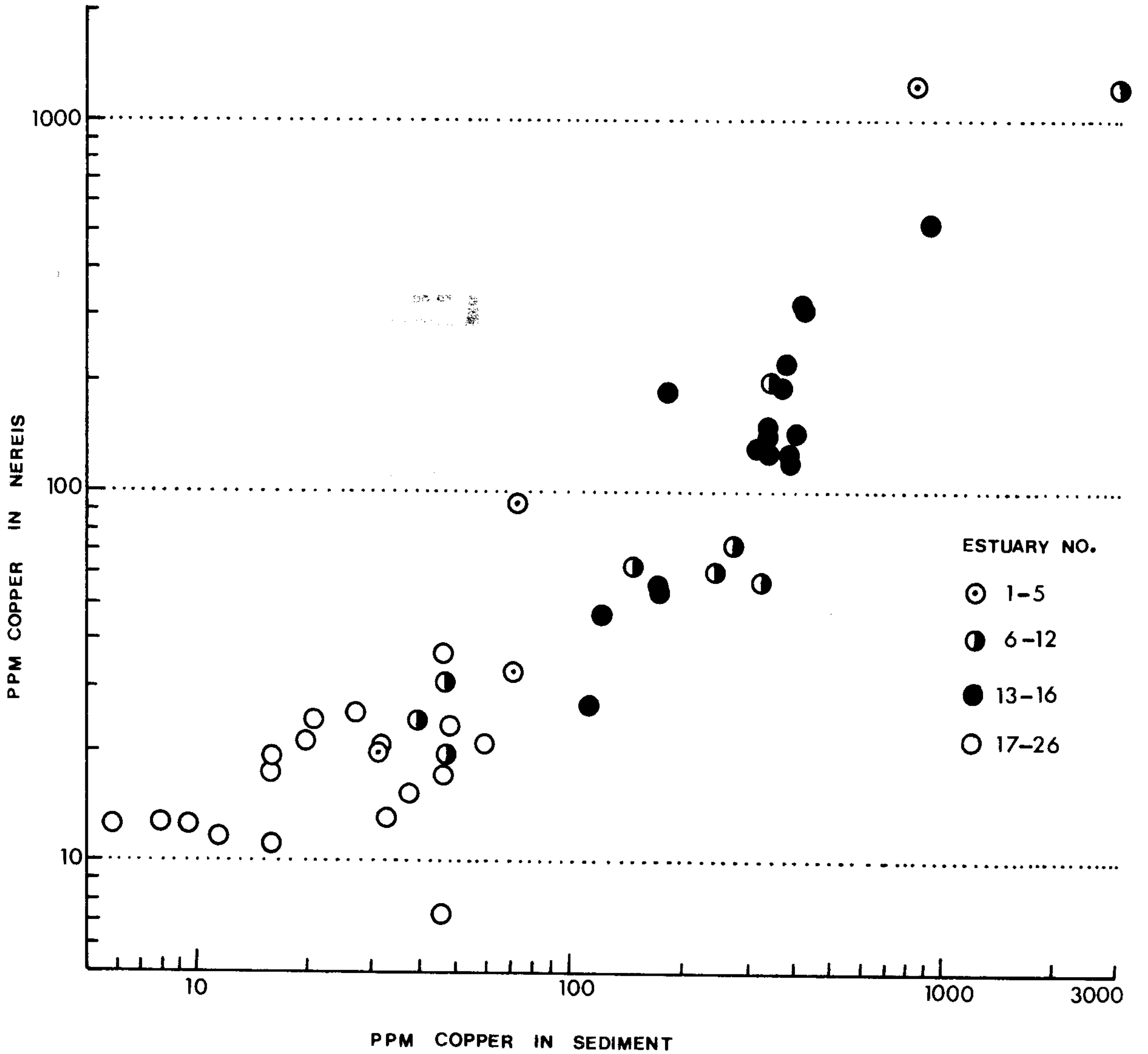

Figure 7 RELATION BETWEEN COPPER IN NEREIS AND SEDIMENTS FROM ESTUARIES IN CORNWALL AND DEVON

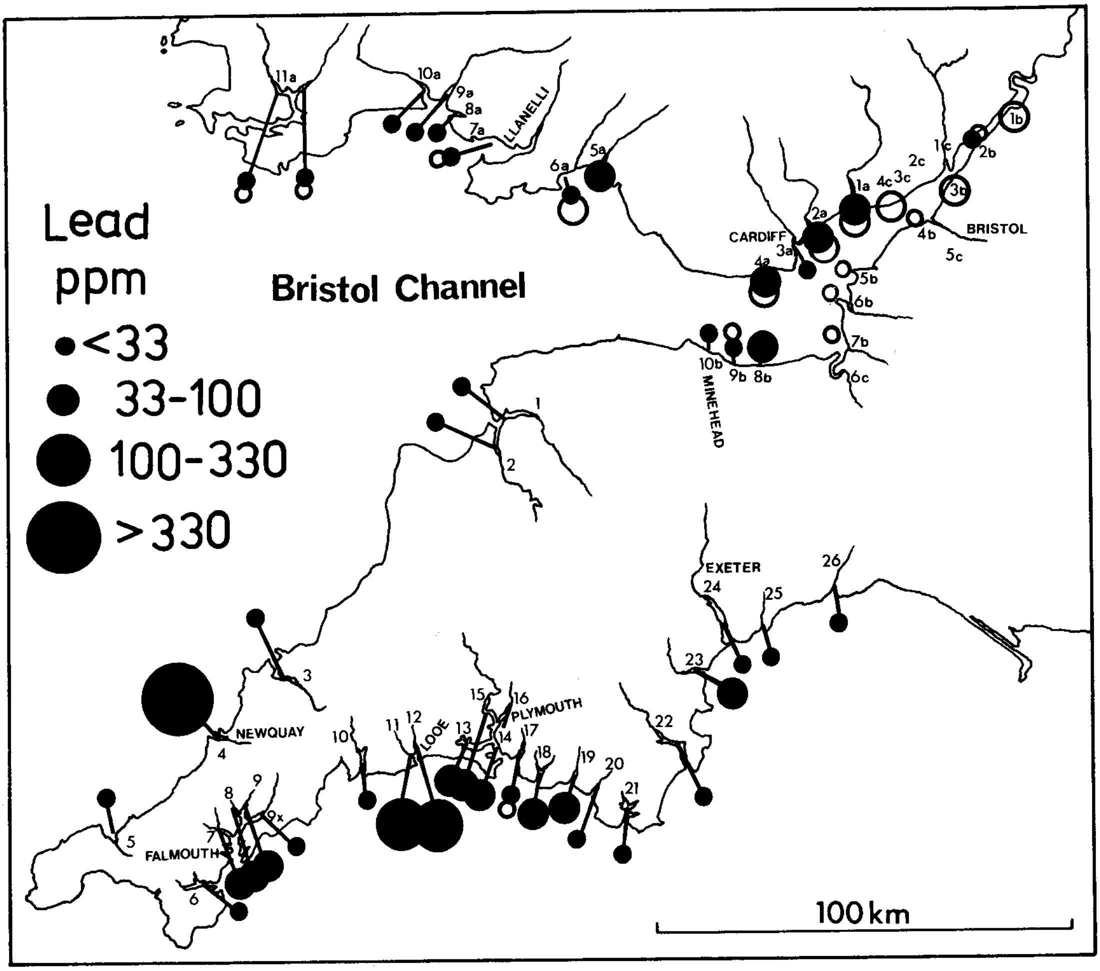

Figure 8 GEOGRAPHICAL DISTRIBUTION OF LEAD IN WHOLE SOFT PARTS OF SCROBICULARIA

Open circles are equivalent levels in Macoma, the concentration ranges above being divided by 3.6. Results are for individual sites in Severn (1a-4a, 1b-10b) but for other estuaries are the ranges within which most of the values for different sites occur.

upper parts of the Gannel Estuary Scrobicularia and Nereis are associated with sediment concentrations of the order of 2000ppm. The geographical distribution of Pb concentrations in Scrobicularia and Macoma is shown in Figure 8. Although several areas show signs of contamination, the most heavily contaminated are the Gannel (4) and the Looe (11, 12) which receive drainage from old lead mines. In Nereis, Pb concentrations are much lower than in Scrobicularia but the results show similar trends (Table 9).

1.7.6 Zinc

Less than 200 ppm is found in sediments from the majority of South Devon and West Wales estuaries, but higher levels are found in the South Wales/ Severn sediments and in estuaries draining the old mining areas of Cornwall and Devon; over 3000 ppm is observed in Restronguet Creek. Nereis is not considered as an indicator, but concentrations in Scrobicularia range from around 500 ppm in some of the West Wales estuaries to more than 3300 ppm at some sites in estuaries associated with mining such as the Gannel (4).

1.7.7 Arsenic

Arsenic concentrations are highest in estuaries in south-west England receiving drainage from metalliferous mines. Sediment levels in excess of 1,000 ppm are found in the Hayle estuary (5) and Restronguet Creek (7), whilst sediments in moderately contaminated estuaries including the Gannel (4), upper Lynher (13), upper Tamar (15) and Tavy (16) contain 100-200 ppm. Levels below 10 ppm are typical of most Severn and West Wales sediments. Concentrations in burrowing organisms, especially Scrobicularia, reflect contamination of the sediments, and the results are summarised in Figure 9. Scrobicularia from Restronguet Creek and Hayle contain 100-200 ppm As, about twenty times the concentrations in animals from the uncontaminated West Cleddau (11a). The results for Scrobicularia are supported by those for Nereis although the latter does not accumulate such high levels of As (Table 9).

1.7.8 Mercury

In uncontaminated estuaries, particularly those in West Wales (7a-11a), sediment concentrations are less than 0.2 ppm. Higher levels, 0.4 - 0.6 ppm, are found in the Severn sediments and in the River Neath (5a) they may be as high as 1.2 ppm. Among the estuaries in south-west England the highest sediment values, 0.8 - 1.0 ppm, are found in the Dart (22), upper Tamar (15),

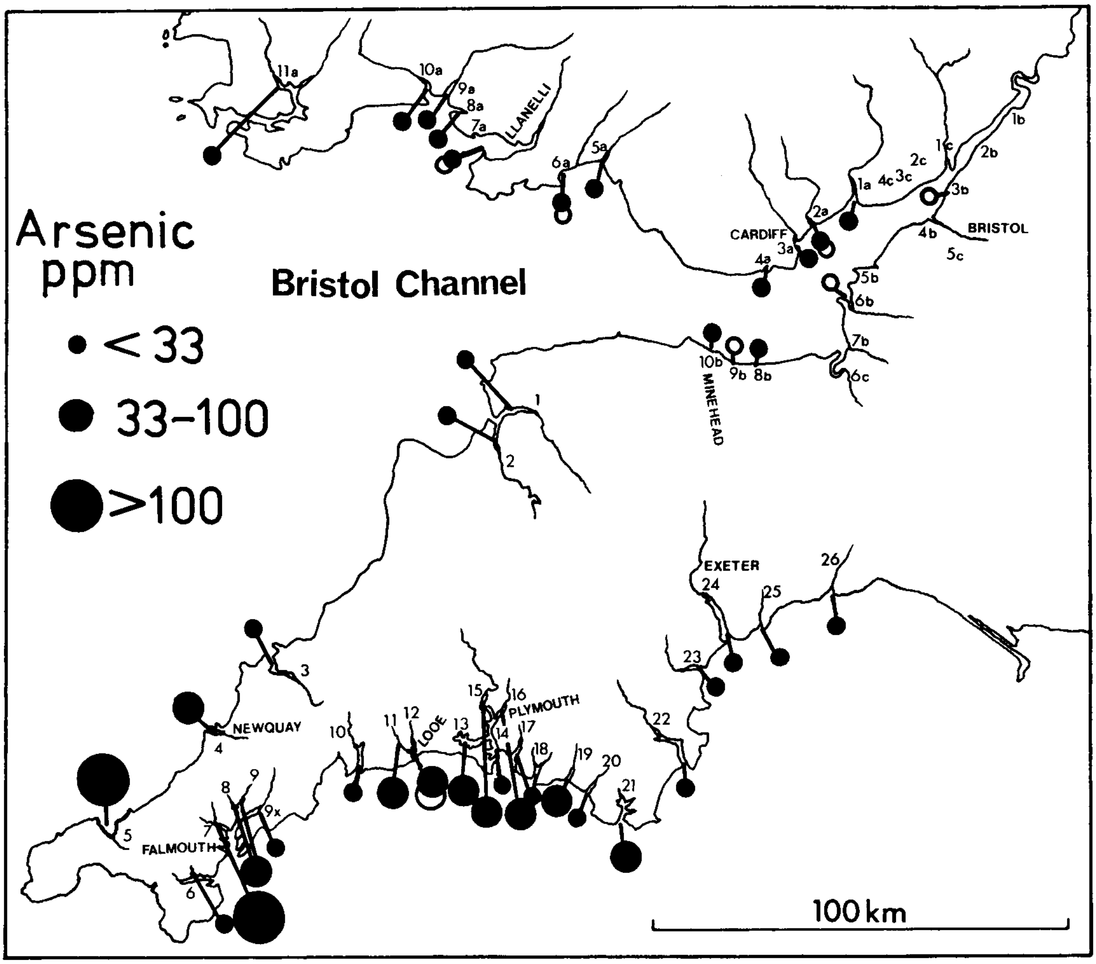

Figure 9 GEOGRAPHICAL DISTRIBUTION OF ARSENIC IN SCROBICULARIA AND MACOMA

Open circles are for Macoma. Results are for individual sites in Severn (1a-4a, 1b-10b) but for other estuaries are the ranges within which most of the values for different sites occur.

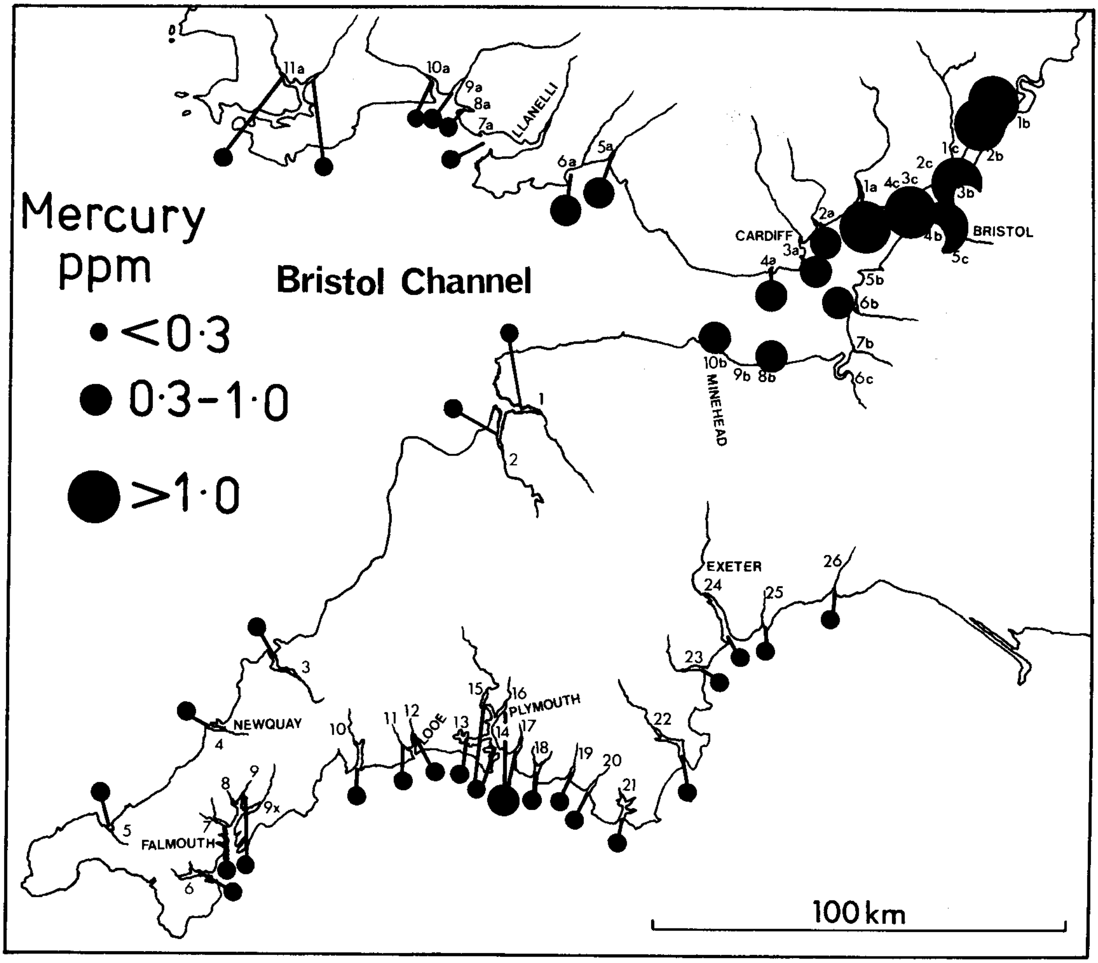

Figure 10 GEOGRAPHICAL DISTRIBUTION OF MERCURY IN <u>NEREIS</u>

Results are for individual sites in Severn (1a-4a, 1b-10b) but for other estuaries are the ranges within which most of the values for different sites occur.

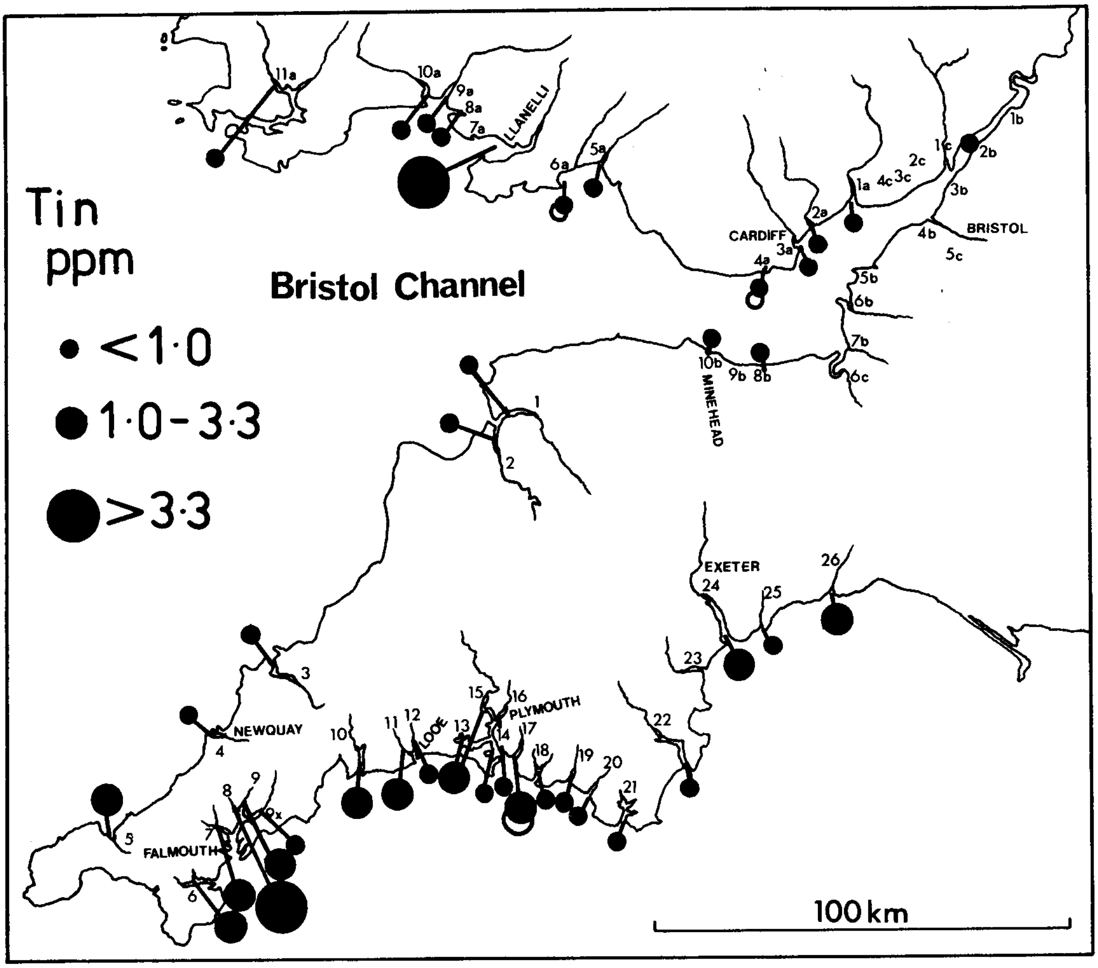

Figure 11 GEOGRAPHICAL DISTRIBUTION OF TIN IN WHOLE SOFT PARTS OF <u>SCROBICULARIA</u> AND <u>MACOMA</u>

Open circles are for <u>Macoma</u>. Results are for individual sites in Severn (1a-4a, 1b-10b) but for other estuaries are the ranges within which most of the values for different sites occur.

Tavy (16) and Lynher (13) estuaries. Mercury concentrations frequently exceed 1 ppm in Scrobicularia and Nereis from the relatively contaminated Neath and Severn estuaries. Similar concentrations are found in Scrobicularia from some sites in the West Looe (11) and Axe (26) where Hg concentrations in the sediment are only 0.2 - 0.3 ppm. It seems unlikely, therefore, that biological availability is determined by the total sediment concentration. The lowest concentrations in Nereis and Scrobicularia are from the West Wales estuaries (7a-11a) particularly the Loughor (7a). The geographical distribution of Hg in Nereis is shown in Figure 10 and indicates that the most contaminated areas are the Severn and industrialised South Wales estuaries.

1.7.9 Tin

Tin concentrations in sediments range from about 30 ppm in several estuaries in south-west England to over 1000 ppm in some of the Cornish estuaries such as the Hayle (5), Helford (6) and Restronguet Creek (7) which receive mining wastes. Some contamination of Nereis and Scrobicularia is evident in this latter group of estuaries and tissue concentrations approach 3 ppm. A concentration of 9 ppm is present in Scrobicularia from Truro (8) where past tin smelting operations may have enhanced contamination. Nereis and Scrobicularia from the Severn and South Wales estuaries usually contain low levels of Sn, often less than 0.1 ppm. The Loughor (7a) estuary is a significant exception and concentrations in Scrobicularia may be as high as 14 ppm. The source of this Sn contamination, is thought to be the manufacture of tinplate[18]. The geographical distribution of Sn in Scrobicularia is shown in Figure 11.

1.8 COMPARISON OF ESTUARINE BIOLOGICAL INDICATORS

In addition to those already discussed, organisms which have been used as indicators of metallic contamination include brown seaweeds[19], bivalve molluscs such as oysters[20], mussels[21] and cockles[22] and gastropod molluscs including limpets[14] and winkles[23]. Since the weed absorbs metals from the water, the gastropods are herbivorous and the bivalves feed on suspended material including phytoplankton, these indicators are more likely to reflect the availability of metals in the overlying water than in the sediments. However, there is always some overlap in the sources from which metals are obtained. The herbivorous gastropods and filter-feeding bivalves will probably ingest some particles of sediment and the deposit feeders used in this work will ingest some phytoplankton and absorb some metals from solution in the water.

1.8.1 Comparison of species at single sites

In Table 10 a comparison is made between different species from the East Looe Estuary which is contaminated with Ag and Pb, and the Severn Estuary which is contaminated with Cd and Ag. Although the availability of metals from water and food to different species undoubtedly varies, some such as Patella (Cd) and Cerastoderma (Ni) appear to possess an inherent ability to concentrate certain metals. Of the burrowing species, Nereis has the least affinity for metals, Macoma is a somewhat better accumulator and Scrobicularia is arguably the best all-round accumulator among the species listed in Table 10.

1.8.2 Comparison of species along estuaries

East Looe Estuary

A detailed comparison between the indicators in Table 10 has been published for the East and West Looe estuaries where there is contamination with Ag and Pb[1]. Results for Ag in organisms and sediments from the E. Looe estuary are illustrated in Figure 12 and show a marked contrast between the responses of different species. Whereas concentrations in the sediments increase upstream by about an order of magnitude, those in Scrobicularia increase by more than 2 orders and levels in Macoma are also high. On the other hand, Fucus which would be expected to reflect concentration changes in solution shows less than an order of magnitude increase and Mytilus, sometimes suggested as a universal indicator, shows no response. One of the conclusions drawn from these results is that, although there is some evidence for contamination with Ag in solution, Scrobicularia and Macoma probably accumulate the metal from a readily available sediment-bound source[1].

By comparison with Ag, the behaviour of Pb in the Looe Estuary is comparatively simple since, although different levels of Pb are found in different species, the patterns of change along the estuary are very similar[1].

Severn Estuary

Contamination of this estuary with Cd is well known[14,15,16,17,24] but there is also evidence for contamination with Ag and Hg[26]. In Figure 13 levels of Ag in Macoma and Nereis are compared with concentrations in the sediment, Fucus and Littorina obtusata. Concentrations in the sediments remain at a consistently low level along the estuary and are appreciably lower than in the East Looe Estuary (Figure 12). On the other hand, concentrations in Fucus increase upstream in the Severn to levels exceeding those in the East

Table 10. COMPARISON BETWEEN METAL INDICATOR SPECIES FROM TWO SITES

Highest concentrations in organisms are in boxes

Species	Mean dry weight soft parts (g)	Concentration (ppm dry tissue) Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	As	Hg	Sn
East Looe estuary (2 km from mouth)														
Scrobicularia plana (bivalve)	0.148	56.4	1.2	**11.5**	**3.3**	300	603	25	14.5	**189**	**1120**	**94**	0.47	**0.87**
Macoma balthica (bivalve)	0.037	**81.9**	0.2	3.7	3.3	**338**	788	24	6.9	61	1010	46	**0.97**	-
Nereis diversicolor (ragworm)	0.019	4.2	0.4	3.9	0.3	60	415	8	3.5	25	258	23	0.11	0.18
Mytilus edulis (mussel)	0.240	0.2	2.3	0.6	2.5	9	401	6	2.6	45	113	21	0.39	0.81
Cerastoderma edule (cockle)	0.278	2.4	0.7	1.6	1.9	10	565	6	**54**	5.3	54	21	0.26	0.44
Littorina littorea (winkle)	0.180	30.0	1.6	1.1	0.5	154	361	25	2.8	17	232	37	0.21	0.13
Patella vulgata (limpet)	0.530	5.6	**5.6**	0.6	0.5	18	**1160**	6	2.3	30	145	33	0.26	-
Fucus vesiculosus (seaweed)	-	0.7	1.1	4.7	1.9	12	946	**315**	11.3	17	190	38	0.09	0.63
Surface sediment	-	1.3	0.2	9.8	37	43	2.61%	382	35	104	133	8.7	0.16	63
Severn estuary (Weston)														
Macoma balthica	0.023	6.8	2.2	3.1	3.6	54	1810	73	3.8	8.7	**899**	22	0.44	1.7
Nereis diversicolor	0.021	4.6	2.5	**7.3**	0.2	49	468	12	7.1	2.6	256	13	**0.88**	$<$ 0.1
Littorina saxatilis	0.028	4.7	27.1	0.1	0.5	73	273	61	4.7	3.6	134	11	0.32	1.7
Littorina obtusata	0.064	12.1	69.7	1.3	0.4	**235**	281	62	5.9	4.2	194	**24**	0.29	**3.94**
Patella vulgata	0.64	2.5	**239**	2.4	**3.6**	41	**1740**	47	4.5	**10.3**	279	15	0.12	3.14
Fucus vesiculosus	-	0.7	8.8	1.2	1.2	15	379	**123**	**16.5**	3.0	198	16	0.04	0.74
Surface sediment	-	0.5	0.7	14.2	41.4	33	2.92%	560	33.3	87.7	252	7.8	0.42	53

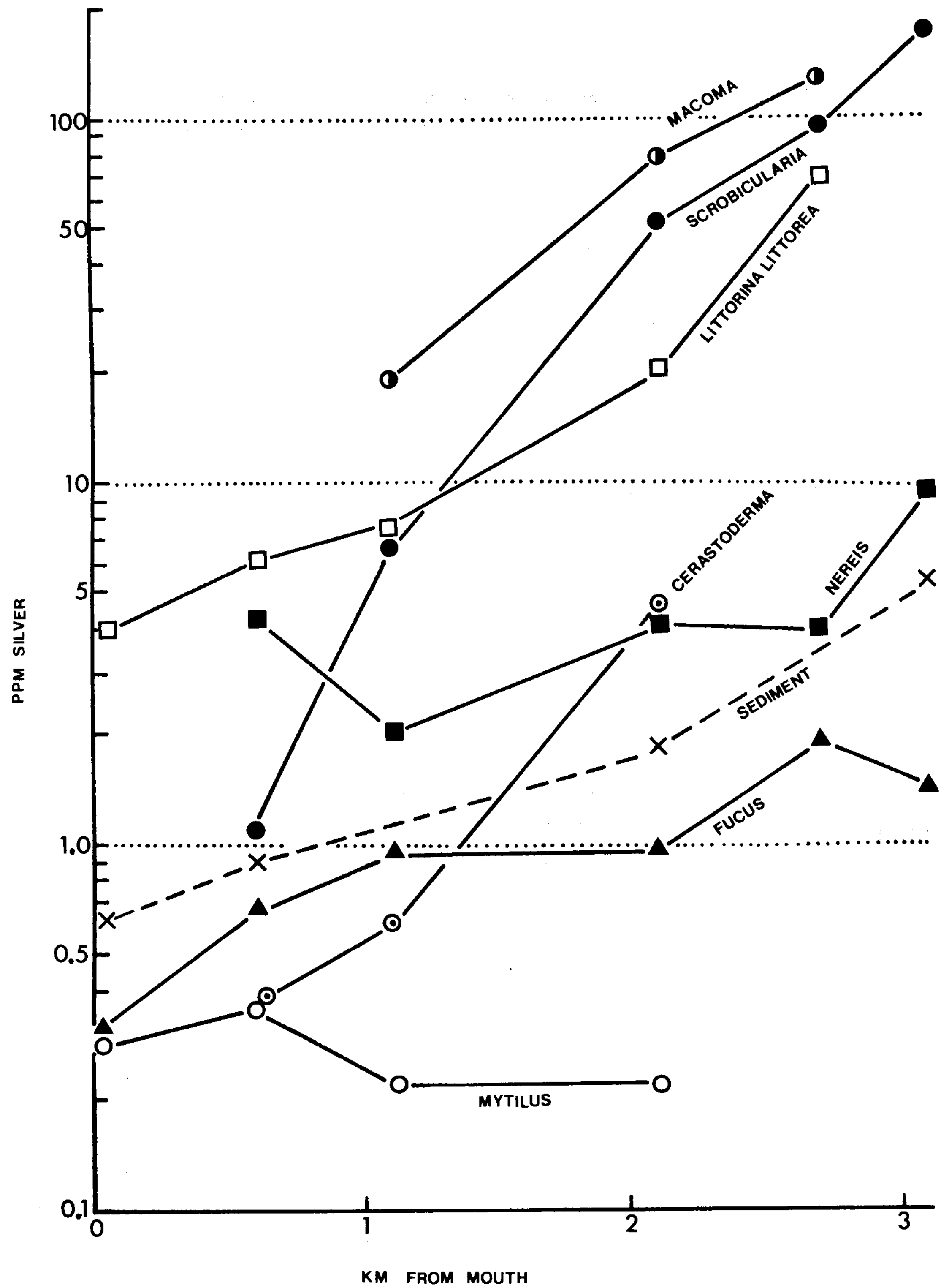

Figure 12 CONCENTRATIONS OF SILVER IN SEDIMENT AND ORGANISMS FROM THE EAST LOOE ESTUARY

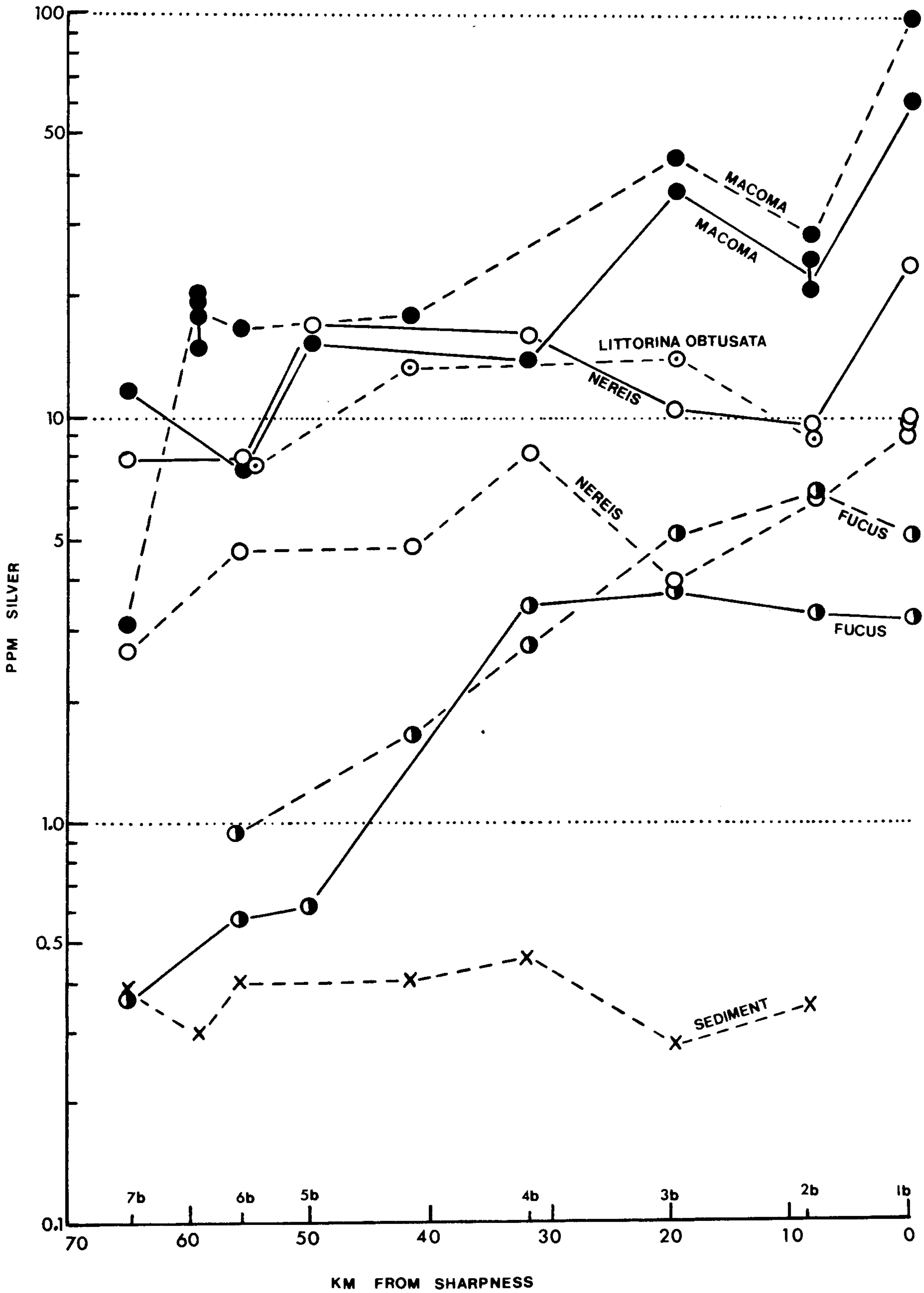

Figure 13 CONCENTRATIONS OF SILVER IN SEDIMENT AND ORGANISMS FROM THE SEVERN ESTUARY
Broken line is Nov. 1976 and continuous line April 1977.
Multiple points show that replicates of different-sized organisms were analysed.

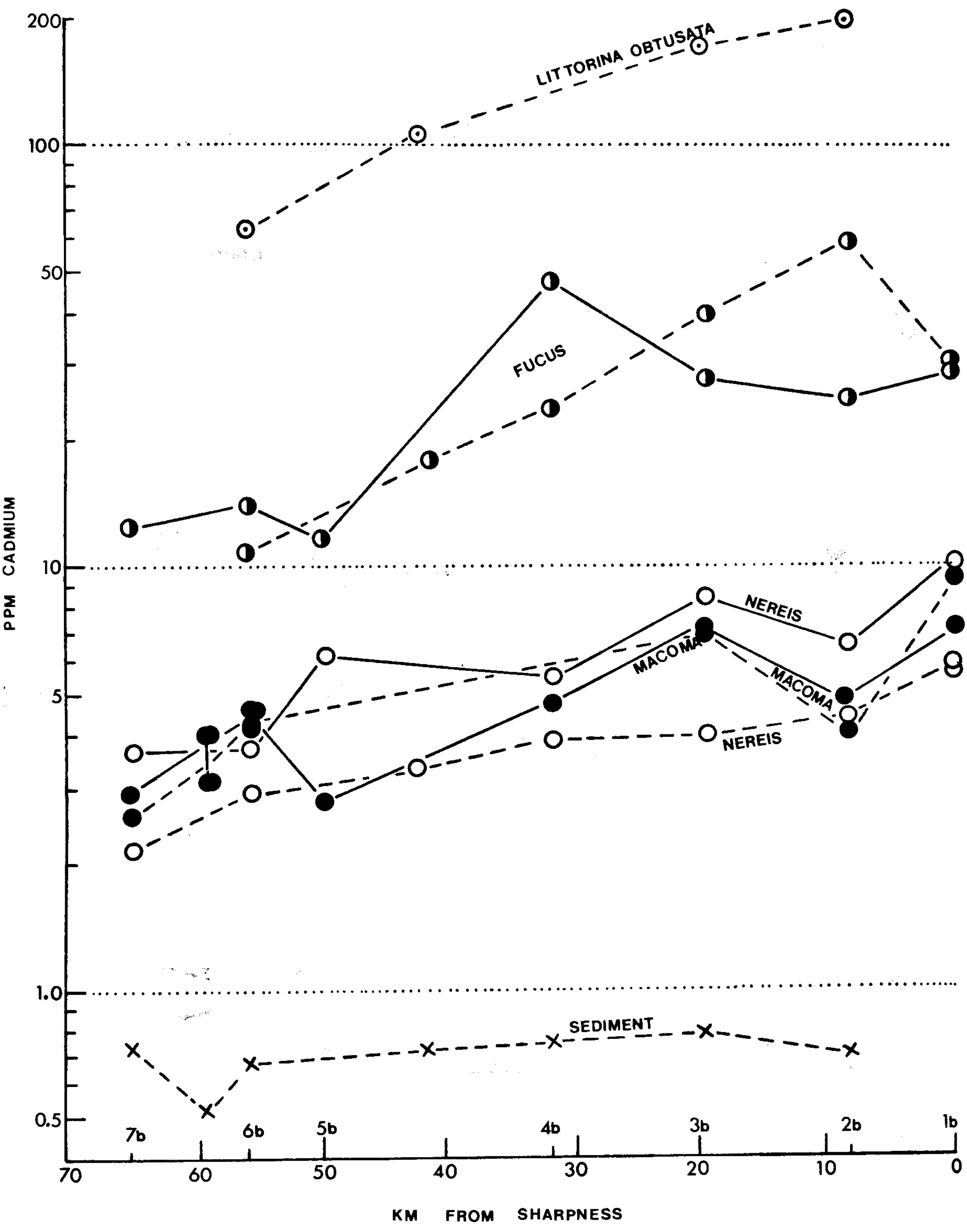

Figure 14 CONCENTRATIONS OF CADMIUM IN SEDIMENT AND ORGANISMS FROM THE SEVERN ESTUARY

Broken line is Nov. 1976 and continuous line April 1977.
Multiple points show that replicates of different-sized organisms were analysed.

Looe, thus implying that dissolved Ag is more important in the Severn. Results for Macoma and Nereis also increase upstream and show a closer relationship to the seaweed than to the sediment results. The highest concentrations in Macoma and Nereis from the Severn are 100 and 24 ppm respectively and thus of the same order as maxima from the Looe Estuary. Although these burrowing species undoubtedly absorb some Ag from solution, the influence of the water seems most likely to be mediated through the ingestion of surface sediment to which the readily available Ag is adsorbed. This adsorbed fraction may be so small that changes along the estuary would not be detected in a 'total' analysis of the sediment. There is, in addition, the possibility that the increased availability of Ag upstream is in some way related to salinity changes.

Results for Cd in Figure 14 show that concentrations in the sediments remain comparatively constant by comparison with those in the biota. In contrast to Ag, concentrations of Cd in Macoma and Nereis are much lower than those in Fucus or Littorina, although all the values are appreciably higher than normal. Since the concentration of Cd in Fucus is known to be related to high concentrations in the water[5], the higher levels in the burrowing species upstream suggest a similar source. This apparent relation may be caused by the absorption of Cd adsorbed on to ingested surface sediment. In Nereis, for example, the direct absorption of Cd from solution is so slow that uptake from ingested material seems the most likely route[11].

1.8.3 Summary

Because different species have different affinities for metals and absorb them from different sources, it seems unlikely that any organism will come to be regarded as a universal indicator of metallic contamination. Any reasonable monitoring programme should involve analyses of several species (e.g. seaweed, filter-feeding bivalve and a deposit-feeding bivalve) to try to assess contamination in different forms.

An important limitation on the use of some suggested indicators in estuaries is their inability to penetrate into the less saline areas where contamination is often greatest. In the lower reaches of an estuary, the seaweed Fucus vesiculosus, the filter-feeders Mytilus edulis and Cerastoderma edule, and the deposit-feeders Scrobicularia plana and Macoma balthica may all be present, together with species of the herbivores Patella and Littorina. Of these species, Scrobicularia is probably the best all-round accumulator although it is superseded for Cd by Patella and Littorina and for Ni by Cerastoderma. In the less saline parts of an estuary the choice of species becomes more limited. In the present area of study, we have found the most widely available to be Fucus, Scrobicularia or Macoma, Nereis and, to a lesser extent, Littorina littorea or L. obtusata. With all these species, various factors including the size of the organism, level on the shore and time of year need to be considered when comparisons between different sites or estuaries are made.

1.9 CLASSIFICATION OF ESTUARIES

1.9.1 Classification based on metal availability to burrowing species

The biological availability of sediment-bound metals in different estuaries is compared by adding the positive signs from the simplified tables of results for Nereis and Scrobicularia or Macoma (Table 11). Because efforts were generally directed towards the more contaminated estuaries, coverage of different areas has been uneven and in a few of the south-west England estuaries single sites only were sampled, albeit in the upper reaches where the highest levels of contamination would be expected. However, with the exception of the Otter Estuary which is very small and the Dart where previous work had indicated that contamination is low[4,10,11], the single sites are in branches of estuary systems; for example, the Tavy forms part of the Tamar system. Sites in the Severn Estuary and Bristol Channel are considered singly because of the size of the area. Since the results in the original tables (2, 7 & 9) are based on differences between concentration ranges covering half or whole orders of magnitude, Table 11 is considered to be a reliable guide, particularly with regard to areas of greatest metal availability. Briefly these are: Ag, E. Looe and upper Severn; As, Restronguet Creek and Hayle; Cd, Severn and Plym; Cr, Loughor; Cu, Restronguet Creek and Hayle; Hg, Neath and Severn; Pb, Gannel; Sn, Loughor and Truro; Zn, Gannel.

1.9.2 Comparison of biological classification with sediment results

The classification in Table 11 is comparable with the simplified results for sediments in Table 12. Because sediment analyses of this type do not necessarily reflect biological availability, the results in the tables show similar trends in some cases but not in others. For six of the metals, the highest sediment concentrations occur in estuaries where the organisms are clearly also contaminated, namely: As, Restronguet Creek; Cd, Plym;

Cr, Loughor; Cu, Restronguet Creek; Pb, Gannel; Zn, Restronguet Creek. However, contaminated organisms have been found in areas where the sediments are not so obviously contaminated. For example, although the sediments in Restronguet Creek contain more Ag and Cd than those of the Severn, contamination of the burrowing species is higher in the Severn.

1.10 FUTURE DEVELOPMENTS

It has been found that the biological availability of a metal in two sediments containing equal concentrations may differ appreciably in different estuaries. It should be possible to take advantage of such contrasts to discover the conditions which control the uptake of sediment-bound metals by organisms. Some factors are likely to be biological. For instance, the ability of the feeding system of the organism to accept a certain size of particle would be very important if particles of that size were very metallic. Other factors are chemical, because availability depends both on the binding of metals in the sediments and, following ingestion, on the ability of the digestive and absorptive systems of the animal to break these bonds and accumulate the metal.

If it is assumed that the chemical factors are usually most important, then by studying the chemistry of sediments from different estuaries it should be possible to establish which conditions (e.g. high Fe or high organics) promote or inhibit biological availability. This information will be useful because (i) it may help to predict whether the properties of sediments in a particular estuary are favourable or not for the introduction of metallic wastes and (ii) it may indicate ways of controlling the composition of wastes so that the availability of metallic components is inhibited rather than promoted. It has, for example, been shown that the biological availabilities of sediment-bound Pb and As to Scrobicularia are strongly influenced by the level of readily extractable Fe in the sediment, lower concentrations of Pb and As being found in animals from sediments high in Fe[25,27].

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Table 11. A CLASSIFICATION OF ESTUARIES IN TERMS OF METAL LEVELS IN BURROWING ORGANISMS.

Results compiled by adding positive signs from Table 2 (whole Scrobicularia), Table 7 (Macoma if Scrobicularia absent) and Table 9 (Nereis excluding Zn). Some sites where Nereis but no bivalves were collected are not included. Exceptional values are enclosed in boxes.

No.	Estuary	Ag	Cd	Cr	Cu	Pb	Zn	As	Hg	Sn
1	Taw	0	0	0	0	0	0	0	0	0
2	Torridge	1	0	0	0	0	0	0	1	0
3	Camel	0	0	0	1	1	0	0	0	0
4	Gannel	3	1	0	3	[6]	[2]	1	1	1
5	Hayle	1	0	0	4	0	1	[3]	0	1
6	Helford	0	0	0	1	0	1	0	0	2
7	Restronguet	2	1	0	[5]	2	1	[3]	0	1
8	Truro	2	1	0	3	1	2	-	-	-
9	Tresillian	1	1	0	2	1	1	1	0	2
9X	Fal	0	0	1	1	0	1	-	-	-
10	Fowey	0	0	0	2	1	1	0	0	2
11	W. Looe	2	0	1	3	4	1	1	1	1
12	E. Looe	[5]	0	1	3	3	1	1	1	0
13	Lynher	1	0	0	2	2	1	1	0	1
14	Low. Tamar	0	0	0	2	2	1	0	0	0
15	Up. Tamar	0	1	0	3	2	1	1	0	1
16	Tavy	1	2	0	4	2	1	1	1	0
17	Plym	0	3	2	1	1	1	0	1	2
18	Yealm	0	0	0	0	2	1	0	1	0
19	Erme	0	0	0	1	2	1	1	1	0
20	Avon	0	0	0	1	1	0	0	1	0
21	Kingsbridge	0	0	0	0	1	0	1	1	1
22	Dart	0	0	0	0	0	0	0	0	0
23	Teign	0	0	0	0	2	1	0	0	-
24	Exe	1	0	1	0	1	1	0	1	1
25	Otter	0	0	0	1	0	1	0	1	0
26	Axe	1	0	0	1	0	1	0	1	1

Table 11 continued

No.	Estuary	Ag	Cd	Cr	Cu	Pb	Zn	As	Hg	Sn
				South Wales and Severn						
4c	Redwick	3	4	1	1	1	1	-	-	-
1a	Usk/Severn	3	4	0	1	2	1	0	3	0
2a	Rhymney/ Severn	2	4	1	0	1	1	0	1	0
3a	Cardiff H	2	3	0	1	1	0	0	2	0
4a	Barry H	2	1	1	2	1	0	0	2	0
5a	Neath	1	0	0	1	1	0	0	3	0
6a	W. Swansea Bay	2	0	0	2	1	0	0	2	0
7a	Loughor	0	0	3	0	0	0	0	0	3
8a	Gwendraeth	0	0	0	0	0	0	0	0	0
9a	Tywi	0	0	0	0	0	0	0	0	0
10a	Taf	0	0	0	0	0	0	0	0	0
11a	W. Cleddau	1	0	0	0	0	0	0	0	0
	E. Cleddau	0	0	0	0	0	0	-	-	-
			Severn and Southern Bristol Channel							
1b	Sharpness	5	5	1	2	2	1	-	-	-
2b	Shepperdine	4	4	1	1	1	1	-	-	-
3b	New Passage	4	5	1	2	1	1	0	4	0
4b	Portishead	3	4	1	1	1	1	-	-	-
5b	Sand Bay	3	4	1	1	2	1	-	-	-
6b	Weston	3	3	1	1	0	1	0	2	1
7b	Burnham	3	3	1	1	1	1	-	-	-
8b	Watchet	2	1	1	2	2	1	0	2	0
10b	Minehead	2	0	0	2	0	0	0	2	0

Table 12. METAL CONTAMINATION IN SURFACE SEDIMENT FROM SAME SITES AS INDICATOR ORGANISMS.

Summary showing ranges within which most values occurred compiled from results in Appendix 4 and additional surveys at same and other sites.

No.	Estuary	Ag	Cd	Cr	Cu	Pb	Zn	As	Hg	Sn
					Cornwall and Devon					
1	Taw	-	-	-	-	-	-	-	+	-
2	Torridge	-	-	-	-	-	-	-	+	-
3	Camel	+	-	-	+	-	-	+	-	++
4	Gannel	+	-	-	+	++	+	++	-	++
5	Hayle	+	+	-	+++	+	++	+++	-	+++
6	Helford	+	+	-	++	-	+	-	+	+++
7	Restronguet	++	+	-	+++	++	+++	+++	+	+++
8	Truro	++	+	-	++	+	++	++	+	++
9	Tresillian	+	+	-	++	+	+	+	+	++
9X	Fal	-	-	-	+	-	+	+	-	+
10	Fowey	-	-	-	+	-	-	+	+	++
11	W. Looe	+	-	-	+	+	-	-	-	-
12	E. Looe	+	-	-	-	-	-	-	-	-
13	Lynher	+	-	-	++	+	+	++	+	+
14	Low. Tamar	+	-	-	++	+	+	+	+	-
15	Up. Tamar	+	+	-	++	+	+	++	+	+
16	Tavy	+	-	-	++	+	+	++	+	+
17	Plym	+	++	-	+	-	-	+	+	
18	Yealm	-	-	-	-	-	-	+	+	+
19	Erme	-	-	-	-	-	-	-	+	-
20	Avon	-	-	-	-	-	-	-	-	-
21	Kingsbridge	-	-	-	-	-	-	-	+	-
22	Dart	-	-	-	-	-	-	-	+	-
23	Teign	+	+	-	-	+	+	-	-	-
24	Exe	-	-	-	-	-	-	-	-	-
25	Otter	-	-	-	-	-	-	-	+	-
26	Axe	-	-	-	-	-	-	-	-	-

Table 12 continued

No.	Estuary	Ag	Cd	Cr	Cu	Pb	Zn	As	Hg	Sn
						South Wales and Severn				
1c	Wye	-	+	-	+	-	+	-	+	-
2c	Severn/Beachley	+	+	-	+	+	+	-	+	-
3c	Severn/Black Rock	-	+	-	+	-	+	-	+	-
4c	Severn/Redwick	+	+	-	+	-	+	-	+	-
1a	Usk/Severn	+	+	-	+	-	+	-	+	-
2a	Rhymney/Severn	+	+	-	+	+	+	-	+	-
3a	Cardiff H.	+	+	-	+	+	+	-	+	-
4a	Barry H.	-	-	-	+	-	+	-	+	-
5a	Neath	+	+	-	+	-	+	-	+	-
6a	Swansea Bay (West)	-	-	-	-	-	+	-	+	-
7a	Loughor	-	-	+	-	-	-	-	-	+
8a	Gwendraeth	-	-	-	-	-	-	-	-	-
9a	Tywi	-	-	-	-	-	-	-	-	-
10a	Taf	-	-	-	-	-	-	-	-	-
11a	W. Cleddau	-	-	-	-	-	-	-	-	-
	E. Cleddau	-	-	-	-	-	-	-	-	-
						Severn and Southern Bristol Channel				
1b	Sharpness	-	-	-	-	-	+	-	+	-
2b	Shepperdine	-	-	-	-	-	+	-	+	-
3b	New Passage	-	-	-	-	-	+	-	+	-
5c	Avon	-	-	-	-	+	+	-	+	-
4b	Portishead	-	-	-	-	-	+	-	+	-
5b	Sand Bay	-	-	-	-	-	+			
6b	Weston	+	-	-	-	-	+	-	+	-
7b	Burnham	-	-	-	-	+	+	-	+	-
6c	Parrett	-	-	-	-	+	+			
8b	Watchet H.	-	+	-	-	-	-	-	+	-
9b	Blue Anchor	-	-	-	-	-	-	-	-	-
10b	Minehead H.	-	-	-	-	-	+	-	+	-
						Concentration (ppm dry weight)				
Key	-	< 0.5	< 1	< 100	< 50	< 100	< 200	< 33	< 0.33	< 100
	+	0.5-1.6	1-3.3	> 100	50-165	100-330	200-600	33-100	0.33-1.0	100-330
	++	> 1.6	> 3.3		165-500	> 330	600-2000	100-330	> 1.0	330-1000
	+++				> 500		> 2000	> 330		> 1000

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APPENDICES

Appendix 1. VARIABILITY OF ANALYSES

Analyses of individual Scrobicularia from within an area of a few m^2 are given in Table 1 and show that the coefficient of variation ranges from 13% for Cr to 46% for Ag. In order to reduce the analytical effort and still retain reasonable replication of analyses, pooled samples were used and usually contained 6 animals of about 4 cm shell length. Results obtained from 5 sites at which 3 pooled samples (i.e. about 18 animals) were analysed are shown in Table 2. Comparisons between the different sites suggest that, for all except Ag and Fe, a difference of 30-40% between the mean values is likely to be detectable at the 95% level of significance.

In the Plym Estuary, a comparison between two areas 100m apart was made by analysing 6 pooled samples from each. The results are given in Table 3 and show that the coefficient of variation at the upstream site ranges from 8% for Pb to 32% for Ag. Differences of less than 20% between the mean values for manganese and zinc from the two sites are significant at the 95% level and, had they existed, differences of about 20% for As, Cu, Hg and Pb would probably be significant. However, the limits for Cd, Co and Sn would almost certainly be worse than this and the limit for Ag would be considerably worse. This level of sampling (i.e. 36 similar-sized animals from each site) is certainly feasible at many sites but was impracticable in the present survey because As, Hg and Sn were usually analysed on different samples from the other 10 metals and too much time would have been involved in collection. However, it is considered that the level of sampling of Scrobicularia ultimately employed at most sites (i.e. 1 pooled sample for As, Hg and Sn and 2 for the other metals, collected on 2 occasions = 36 animals), is adequate as a means of provisionally classifying an area of estuary within ranges of concentration covering half orders of magnitude for most metals and orders of magnitude for silver.

Relative to these very wide ranges, the differences between the two Plym sites in Table 3 are small, thus suggesting that a single site is reasonably representative of quite a large area of mud-flat. Results from samples which were collected 8 months later along a 150 m transect at right angles to the line of the original sites (Table 4) show that there are no clear concentration gradients across this shore, which is comparatively flat.

The middle site (C) is nearly coincident with the downstream site in Table 3, and a comparison of similar-sized animals from the two sites (Table 4) shows that the concentrations are very similar despite the differences (September - May) in time of collection. These results suggest that in the Plym Estuary, sampling at a single site is reasonably representative of a 150 x 120 m area of mud-flat and also support the conclusion that the best times for sampling this species are the autumn and spring.

Table 1. Analyses of single Scrobicularia plana from Restronguet Creek

Shell length (cm)	ppm dry soft parts									
	Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
4.2	0.18	4.63	8.05	1.30	154	1759	23.6	3.18	43.6	2664
4.4	0.24	4.72	8.42	1.59	104	3380	10.8	4.56	62.8	3112
4.1	0.60	3.57	8.57	1.33	250	2051	15.6	3.80	51.6	3191
4.2	0.50	2.66	9.06	1.19	160	3622	22.3	1.91	37.0	2473
4.4	0.24	4.21	12.1	1.21	137	2469	15.2	4.04	49.7	3158
4.4	0.28	5.41	12.2	1.30	105	2304	22.5	4.26	57.6	2726
4.2	0.51	5.50	16.7	1.26	228	2783	13.2	3.35	51.9	3391
4.4	0.26	5.69	20.6	1.66	105	3233	11.8	8.25	45.0	4547
Mean	0.35	4.55	12.0	1.35	156	2700	16.9	4.17	49.9	3158
± S.D	0.16	1.04	4.5	0.17	57	668	5.2	1.84	8.1	642
± %	46	23	37	13	37	25	31	44	16	20

Table 2. Analysis of three pooled samples of S. plana (usually 6 animals per sample) from each of five estuaries

	Mean shell length (cm)	ppm dry soft parts									
		Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
							Tamar				
	4.42	0.38	5.3	25	4.1	33	2230	33	9.4	155	2800
	4.18	0.33	6.3	25	3.4	32	1220	28	9.1	138	2400
	3.82	0.25	6.3	30	3.5	35	1720	34	10.0	122	2510
Mean	4.14	0.32	5.97*	27*	3.7	33	1723*	32	9.5	138	2570
							Camel				
	4.43	0.60	0.60	6.3	1.1	25	867	22	6.7	14	253
	4.10	0.38	0.55	5.0	1.3	23	724	29	4.7	12	374
	3.70	0.42	0.50	6.0	1.4	25	682	25	4.3	16	352
Mean	4.08	0.47*	0.55	5.8	1.3*	24*	758	25*	5.2	14*	326
							Helford				
	4.20	0.33	1.9	6.0	1.7	16	827	28	6.4	16	2120
	3.98	0.34	1.5	5.2	1.7	22	726	26	4.4	22	1840
	3.88	0.38	1.6	6.5	1.4	17	693	31	7.9	17	1580
Mean	4.02	0.35	1.7	5.9	1.6	18*	749	28	6.2	18*	1847*
							Gannel				
	4.55	0.89	8.8	44	1.6	76	715	67	16	264	2480
	4.12	0.82	7.2	39	1.9	68	857	78	16	317	2630
	3.78	0.73	8.3	44	2.1	57	1080	62	17	335	2920
Mean	4.15	0.81*	8.1*	42*	1.9*	67	884*	69	16*	305	2677
							East Looe (4 cm animals rarely found)				
	3.66	34	1.6	15	3.0	243	733	32	13.0	133	1360
	3.27	50	1.7	13	3.5	189	933	32	11.0	126	1350
	3.13	28	2.1	14	3.2	144	967	32	10.0	125	1360
Mean	3.35	37	1.8	14	3.2	192	878	32*	11.3*	128	1353*
							Percentage difference between marked values (•)				
		72	36	55	44	33	95	28	44	31	36
							Significance of difference in 't' test (values of p)				
		< 0.05	< 0.05	< 0.01	< 0.05	< 0.05	~0.05	< 0.05	< 0.01	~0.1	< 0.05

Table 3. Analyses of pooled samples of S. plana (6 animals in each) from six positions, 10 metres apart around a 10 x 20 metre area in Plym Estuary (September)

		ppm dry soft parts										
	(cm)	Ag	As	Cd	Co	Cu	Fe	Hg	Mn	Pb	Sn	Zn
1	4.6	0.42	23.8	11.6	5.80	21.0	852	0.29	13.0	32.2	1.99	1566
2	4.5	0.32	23.0	6.53	3.55	19.7	739	0.23	13.8	22.0	1.80	915
3	4.6	0.15	24.9	7.57	4.75	13.9	518	0.23	10.0	21.2	1.51	1295
4	4.6	0.36	26.3	9.87	6.04	19.9	714	0.25	11.9	30.5	1.88	1432
5	4.5	0.38	32.5	12.0	6.07	20.7	844	0.23	12.8	30.1	1.67	1556
6	4.6	0.27	23.8	10.9	4.73	19.6	774	0.19	12.3	27.3	2.38	1416
	Mean	0.32	25.7	9.74	5.16	19.1	740	0.24	12.3	27.2	1.87	1363
	± S.D.	0.095	3.5	2.23	0.99	2.6	121	0.03	1.3	4.6	0.3	241
	± %	30	14	23	19	14	16	12	11	17	16	18
	Analyses from similar area 100 metres upstream at same tide level											
7	4.7	0.32	27.6	9.07	4.45	17.3	510	0.21	8.9	27.9	1.24	1326
8	4.7	0.54	32.7	13.1	5.71	22.0	868	0.24	11.6	32.2	2.19	1641
9	4.7	0.31	23.5	12.7	5.40	20.4	798	0.20	12.0	26.8	2.02	1733
10	4.6	0.59	23.7	12.0	6.73	22.0	675	0.26	9.9	26.9	3.01	1824
11	4.6	0.47	31.4	10.6	6.90	19.4	673	0.23	11.0	26.2	2.54	1615
12	4.5	0.28	26.4	12.1	6.17	16.3	778	0.22	10.5	26.4	2.46	1597
	Mean	0.42	27.5	11.6	5.89	19.6	716	0.23	10.6	27.7	2.24	1623
	± S.D.	0.13	3.8	1.5	0.91	2.4	126	0.02	1.1	2.3	0.6	168
	± %	32	14	13	15	12	18	9	10	8	27	10
Percentage difference between sites		31	7	19	14	3	3	4	16*	2	20	19*

* Results significantly different between two areas, p ~ 0.05

Table 4. Analyses of pooled samples of S. plana from 150 metre transect across shore of Plym Estuary in May

Site		Mean shell length (cm)	ppm dry soft parts: Ag	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sn	Zn
Upper shore	A	4 2	0.28	33	5.10	4.36	2.50	20.1	755	0.29	13.1	1.97	23.1	1.13	1109
	B	4.2	0.24	23	4.94	2.78	2.09	17.5	842	0.21	13.5	1.79	19.3	0.98	937
Mid	C	4.1	0.38	24	7.65	4.11	2.98	20.2	1060	0.22	12.1	1.89	24.1	1.30	1288
	D	4.1	0.40	27	7.99	5.12	3.21	19.7	1146	0.20	13.2	2.54	28.7	1.40	1230
Lower shore	E	4.2	0.33	25	5.28	4.34	3.29	30.1	1033	0.23	8.2	2.01	31.6	1.41	1117
Analyses at site C in previous September (mean of 6 pooled samples)															
	C	4.2	0.34	26*	7.64	4.04	2.83	22.4	1037	0.24*	17.5	2.06	25.1	1.87*	1199

* 4.6 cm animals

Appendix 2. METALS IN SOFT PARTS OF SCROBICULARIA PLANA - TYPICAL ANALYSES

Extreme values from two main areas (1-26 and remainder) are in boxes

±Analyses of As, Hg and Sn in 1978; *1979

No.	Estuary	Site	Map ref.	Date	Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	As	Hg	Sn
					Concentration (ppm dry weight)												
									Cornwall and Devon								
1	Taw	Mid	SS516:335	Jan. 80	0.6	1.2	5.6	1.2	11	620	31	3.3	13	476	14	0.24	0.23
2	Torridge	Upper	SS462:246	Jan. 80	0.7	1.1	8.0	1.7	17	1980	54	4.5	13	403	18	0.42	0.54
		Lower	SS460:285	Jan. 80	1.5	2.4	19.1	3.5	41	1360	43	14.4	37	1210	37	0.72	0.85
3	Camel	Upper	SW987:730	Jan. 80	0.2	0.4	4.4	0.9	19	989	18	2.7	8	309	27	0.24	0.65
		Lower	SW933:755	Nov. 74	0.5	0.3	5.4	1.7	70	983	27	4.5	22	457	-	-	-
4	Gannel	Upper	SW809:606	April 77	2.0	13.6	97.0	2.3	81	1910	261	15.1	991	4810	-	-	-
		Mid	SW804:607	April 77*	0.7	9.1	70.0	3.8	61	2730	333	14.9	459	4920	98	0.90	0.90
		Lower	SW798:609	April 77	1.3	1.9	27.3	2.4	332	1060	59	8.8	335	2270	-	-	-
5	Hayle	Upper	SW547:364	Nov. 74*	0.5	3.4	10.5	1.3	122	1930	38	4.7	21	1560	97	0.11	0.79
		Dock	SW558:374	June 74	0.1	0.7	6.2	0.6	27	962	13	2.0	51	978	-	-	-
		Canal	SW563:378	Sept. 79	-	-	-	-	-	-	-	-	-	-	106	0.17	2.90
6	Helford	Upper	SW707:266	Jan. 80	0.1	1.1	3.4	1.5	18	1050	10	2.0	15	1170	15	0.16	2.43
		Mid	SW735:275	Dec. 74	0.2	0.6	2.9	0.9	36	452	10	2.9	18	936	-	-	-
7	Restronguet	Upper	SW803:387	Aug. 78	0.3	4.5	12.0	1.3	156	2700	17	4.2	50	3160	191	0.17	2.70
		Mid	SW813:386	Mar. 79	0.2	2.3	4.9	1.2	89	2860	19	2.4	51	2580	190	0.04	2.30
8	Truro	Upper	SW833:438	Dec. 74	1.1	8.3	22.5	1.9	55	2410	20	5.2	101	4190	-	-	-
		Mid	SW835:430	Sept. 79	0.7	1.2	6.3	1.1	54	931	16	1.7	35	1970	46	0.20	8.50
		Lower	SW827:385	June 76	0.2	0.4	2.7	1.3	39	902	18	1.8	22	939	-	-	-
9	Tresillian	Upper	SW862:458	Jan. 80	0.3	6.1	15.0	1.5	27	1460	12	3.2	40	3200	33	0.20	2.39
9x	Fal	Mid	SW878:404	Sept. 79	0.1	1.3	9.2	0.9	31	707	32	1.8	14	2060	32	0.17	0.79
10	Fowey	Upper	SX109:578	May 77	0.4	2.2	12.2	2.3	80	1100	23	3.0	27	2620	-	-	-
		Mid	SX115:570	Jan. 80	0.4	1.7	13.0	2.3	84	1020	20	5.8	52	1530	31	0.26	2.04
		Lower	SX127:555	May 77	0.2	0.6	2.7	1.2	11	792	31	1.6	14	491	-	-	-

Appendix 2. (S. plana) continued

No.	Estuary	Site	Map ref.	Date	Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	As	Hg	Sn
11	West Looe	Upper	SX238:543	Mar. 77*	10.2	2.1	19.8	5.9	315	1310	70	12.3	489	2426	28	0.47	1.20
		Mid	SW245:541	Mar. 77*	6.8	1.3	8.1	4.1	356	580	49	7.7	225	1280	53	1.30	1.58
12	E. Looe	Upper	SX248:556	Mar. 77*	259	3.6	20.3	6.6	277	1750	107	15.9	149	2060	31	0.79	0.98
		Lower	SX252:540	Mar. 77*	10.8	0.4	14.6	7.1	95	1617	21	21.0	246	569	50	0.46	0.71
13	Lynher	Upper	SX364:572	Dec. 74*	<0.1	4.0	17.6	2.6	35	2240	38	5.4	101	2130	47	0.19	1.39
		Lower	SX407:570	Dec. 74*	0.3	1.4	10.3	1.7	26	598	29	5.0	62	1280	28	0.21	0.89
14	Tamar	Lower	SX433:564	Nov. 74*	0.4	1.8	11.1	2.4	46	759	41	5.7	99	1450	29	0.20	0.79
15		Upper	SX422:649	Nov. 74*	0.2	6.0	33.0	2.0	41	2290	38	8.0	101	2790	47	0.19	1.00
16	Tavy	Upper	SX462:636	Nov. 74*	0.4	7.5	28.0	2.8	103	1100	32	9.3	81	2800	40	0.24	0.75
17	Plym	Upper	SX515:560	Feb. 77	0.3	31.5	9.3	5.9	24	1050	23	3.6	25	2170	-	-	-
		Mid	SX508:553	Sept. 78	0.3	7.6	4.0	2.8	22	1040	17	2.1	25	1200	27	0.23	2.0
		Lower	SX503:544	Feb. 77	0.9	6.0	3.4	5.1	104	597	16	3.3	39	1260	-	-	-
18	Yealm	Upper	SX563:509	Jan. 80	0.2	0.7	10.6	1.7	22	975	20	4.3	25	1030	24	0.45	0.52
		Mid	SX546:502	Nov. 74	0.3	0.6	5.9	2.1	32	640	28	5.9	53	776	-	-	-
19	Erme	Upper	SX625:497	Dec. 77	0.2	1.2	12.9	3.0	66	1026	38	10.0	52	1290	-	-	-
		Mid	SX622:493	Dec. 74	2.5	1.4	14.0	2.5	619	508	39	12.0	66	1560	-	-	-
		Mid	SX622:493	Jan. 80	0.7	0.9	12.8	3.1	60	1100	33	11.0	49	1050	42	0.83	0.32
20	Avon	Mid	SX683:467	Dec. 77	1.0	0.5	7.8	4.1	84	541	36	9.6	23	683	23	0.90	0.26
21	Kingsbridge	Upper	SX747:433	Jan. 80	0.5	0.4	3.9	1.5	18	552	11	2.7	32	733	36	0.32	0.67
22	Dart	Upper	SX847:567	Jan. 80	0.5	0.5	2.8	1.5	19	714	26	2.9	17	504	14	0.29	0.65
23	Teign	Upper	SX877:722	June 78	0.7	4.9	22.7	2.7	36	3420	156	5.7	82	1918	37	0.34	-
		Mid	SX903:724	June 78	0.4	1.2	16.7	1.7	19	859	26	5.0	73	1620	21	0.14	-
		Lower	SX926:724	June 78	0.5	0.6	5.2	1.3	14	664	33	2.7	38	719	30	0.46	-
24	Exe	Upper	SX967:875	Jan. 80	3.3	1.1	14.1	3.8	36	3300	65	5.7	29	1600	12	0.46	1.32
		Mid	SX974:844	Jan. 80	1.2	0.6	8.4	5.1	31	1920	61	5.6	34	737	35	0.75	0.74
25	Otter	Mid	SY075:823	Jan. 80	0.5	1.2	27.1	2.9	62	873	48	10.9	24	1500	22	0.63	0.25
26	Axe	Upper	SY256:916	May 77	1.2	0.6	10.3	1.6	35	708	49	3.1	10	780	-	-	-
		Lower	SY253:902	Jan. 80	5.4	1.7	18.0	3.1	35	1530	73	14.3	25	1070	21	1.20	1.19

Appendix 2. (*S. plana*) continued

No.	Estuary	Site	Map ref.	Date	Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	As	Hg	Sn
									South Wales and Severn								
1a	Usk/Severn	-	ST314:831	Nov. 78	1.9	23.0	8.8	2.6	33	1290	48	5.0	42	1330	**26**	0.58	**<0.1**
2a	Rhymney/ Severn	-	ST227:775	Oct. 76[1]	2.9	**39.7**	13.3	5.6	38	1010	22	5.0	**103**	**2440**	16	0.28	<0.1
3a	Cardiff	Harbour	ST187:739	Nov. 78	1.4	6.2	4.7	2.3	24	1170	34	5.9	25	580	20	0.41	<0.1
4a	Barry	Harbour	ST110:667	Oct. 76[1]	4.9	4.6	9.2	3.6	57	731	40	10.8	55	782	26	0.57	<0.1
5a	Neath	Upper	SS733:942	Oct. 78	0.8	2.9	4.3	-	32	973	42	-	20	349	13	0.70	<0.1
		Mid	SS732:935	May 79	0.5	3.3	**14.1**	1.9	19	1100	36	5.6	49	1010	25	0.55	0.57
6a	Swansea Bay	West Cross	SS618:892	May 79	1.7	1.8	10.2	1.6	68	617	73	8.8	24	872	26	0.60	0.85
		University	SS631:912	May 79	0.7	2.2	7.4	1.3	21	597	43	5.4	35	668	17	**0.75**	0.16
7a	Loughor	Upper	SN563:009	May 79	**0.1**	0.8	4.6	7.2	12	1300	40	3.1	10	377	15	0.07	3.5
		(1) Mid	SS523:980	May 79	0.3	1.1	4.8	**23.8**	16	**1550**	37	3.7	24	367	11	0.08	**14.0**
		(2) Mid	SS537:960	May 79	0.3	1.3	5.0	5.1	12	620	30	3.0	11	556	20	0.15	3.2
		Lower	SS437:999	May 79	0.5	1.4	3.9	2.7	**9**	**367**	**112**	2.7	11	446	17	**0.02**	1.0
8a	Gwendraeth	Upper	SN396:064	Oct. 78	0.6	0.9	7.6	1.4	18	884	29	3.1	20	689	14	0.16	0.15
9a	Tywi	Upper	SN386:138	Oct. 78	0.6	0.6	4.9	1.1	21	656	47	2.5	14	429	12	0.29	0.28
		Mid	SN367:129	Oct. 78	1.2	6.9	13.2	2.8	21	922	99	**14.2**	37	622	24	0.44	0.32
		Lower	SN358:108	Oct. 78	0.4	1.0	5.7	0.9	15	380	24	3.2	15	594	13	0.15	0.15
10a	Taf	Upper	SN300:129	Oct. 78	0.5	0.9	10.3	1.3	22	772	49	3.9	25	349	12	0.21	0.27
		Mid	SN315:123	Oct. 76	0.7	1.7	8.7	1.2	24	441	41	3.5	18	766	-	-	-
		Lower	SN304:109	Oct. 78	0.3	0.3	2.7	0.8	12	494	28	1.9	8	**268**	12	0.14	0.14
11a	W. Cleddau	Upper	SM976:136	Oct. 78	1.1	0.2	3.5	**0.5**	18	577	**18**	**1.2**	7	360	**5**	0.12	0.17
	E. Cleddau	Mid	SN032:139	Oct. 78	0.2	**0.2**	**2.0**	0.6	18	856	36	2.2	**6**	361	-	-	-
									Severn and southern Bristol Channel								
2b	Severn	Shepperdine	SO612:963	Nov. 78	**11.7**	9.9	5.8	-	**75**	-	-	9.1	21	555	-	-	0.44
8b	Watchet	Harbour	ST072:435	Nov. 76[1]	2.8	6.3	8.7	3.6	41	1220	52	4.4	77	1080	13	0.39	0.50
9b	Dunster	-	ST007:447	Sept. 77	9.0	11.5	4.4	3.0	32	393	53	5.4	20	740	-	-	-
10b	Minehead	Harbour	SS972:471	Dec. 78	10.8	1.3	4.9	1.9	27	785	21	4.9	27	554	14	0.33	0.29

Appendix 3. METALS IN DIGESTIVE GLAND OF *SCROBICULARIA PLANA* - TYPICAL ANALYSES

Extreme values from two main areas (1-26 and remainder) are in boxes

			Concentration (ppm dry weight)								
No.	Estuary	Site	Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
1	Taw	Mid	1.1	6.2	29	5.7	21	1200	130	17	95	2460
2	Torridge	Upper	1.9	6.7	38	4.9	27	723	102	22	102	836
		Lower	1.9	5.8	47	5.6	33	616	182	22	108	3320
3	Camel	Upper	0.5	2.6	15	3.5	56	1580	68	15	63	690
		Lower	<0.2	1.9	25	4.6	78	1090	124	18	129	3040
4	Gannel	Upper	0.5	23.3	230	3.5	46	1530	208	35	2590	10000
		Mid	2.2	26.0	147	5.0	129	2030	209	34	1080	8280
5	Hayle	Upper	0.3	8.3	28	3.1	365	3750	124	11	70	4690
6	Helford	Upper	0.4	6.6	22	6.0	42	613	30	8.4	72	7750
		Mid	<0.2	2.9	12	4.9	58	533	35	7.9	99	4430
7	Restronguet	Upper	0.7	14.2	56	1.9	436	2430	51	9.2	194	10890
8	Truro	Upper	0.5	31.9	79	2.9	56	799	47	12	399	14600
9	Tresillian	Upper	0.3	19.0	63	5.4	58	1210	36	13	159	12400
10	Fowey	Mid	0.6	9.2	38	6.4	103	1090	45	12	153	6760
11	W. Looe	Mid	28.7	4.7	25	5.6	73	683	74	27	936	3060
12	E. Looe	Upper	269	4.6	29	8.6	433	2170	92	20	396	4260
13	Lynher	Upper	0.1	10.7	64	6.2	50	1440	82	14	280	7180
		Lower	0.7	8.1	45	6.7	73	708	103	15	328	4880
14	Tamar	Lower	0.9	7.3	42	6.9	100	1510	162	16	366	4800
15	Tamar	Upper	0.4	16.4	82	6.7	67	1160	72	24	295	7140
16	Tavy	Upper	0.6	24.7	76	6.4	122	418	75	22	245	7422
17	Plym	Upper	0.5	139	17	24.4	42	1050	32	5.1	118	8030
		Lower	0.2	38.2	12	15.3	34	695	103	8.2	152	4760
18	Yealm	Upper	1.2	2.4	47	5.0	62	1220	60	19	91	3530

Appendix 3 continued

No.	Estuary	Site	Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
		Mid	0.3	2.3	17	6.4	37	1030	104	16	170	2090
19	Erme	Mid	1.5	3.7	29	4.3	273	554	123	22	173	3580
20	Avon	Mid	0.7	1.0	36	4.1	127	519	183	28	52	1620
21	Kingsbridge	Upper	0.3	1.8	18	7.4	22	561	46	13	194	2980
22	Dart	Upper	0.4	2.4	13	6.1	25	535	196	7.5	82	2810
23	Teign	Mid	0.8	6.8	49	3.4	21	1040	80	5.0	268	5780
		Lower	2.0	4.4	34	5.3	29	1090	104	13	262	3790
24	Exe	Upper	10.6	5.6	32	9.3	27	751	76	12	92	4870
		Mid	8.3	4.6	31	11.8	29	1140	93	18	122	3760
25	Otter	Mid	0.6	1.7	41	5.4	51	659	146	11	57	3750
26	Axe	Upper	1.6	1.6	31	3.1	45	947	128	7.7	27	2130
		Lower	4.1	2.9	49	5.5	25	1690	117	35	44	2100
					South Wales and Severn							
1a	Usk/Severn	-	9.4	97.5	23	10.6	91	610	151	20	126	4007
2a	Rhymney/Severn	-	7.6	147	49	18.1	59	842	45	15	362	8190
3a	Cardiff	Harbour	4.1	37.6	40	8.7	43	533	93	19	199	4320
4a	Barry	Harbour	12.9	13.6	28	8.6	85	1050	101	31	157	1930
7a	Loughor	Mid	0.5	4.3	19	34.9	30	923	126	9.0	25	1830
		Lower	0.2	7.2	20	20.2	20	734	133	11	34	2020
8a	Gwendraeth	Upper	0.6	3.7	25	2.8	25	646	93	8.3	73	2080
9a	Tywi	Mid	1.4	19.3	32	5.1	33	745	228	36	91	1120
10a	Taf	Mid	0.7	6.1	31	2.9	29	618	130	10	68	2550
11a	W. Cleddau	Mid	7.8	3.4	20	3.2	160	786	112	13	28	2480
					Southern Bristol Channel							
8b	Watchet	Harbour	8.4	25.3	33	8.0	64	1590	158	11	301	3970
10b	Minehead	Harbour	41.8	18.0	21	6.6	245	723	125	17	263	2830

Appendix 4. METALS IN SOFT PARTS OF *MACOMA BALTHICA* - TYPICAL ANALYSES

Extreme values are in boxes

*Analyses of As, Hg and Sn in 1978

No.	Estuary	Site	Map ref.	Date	Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	As	Hg	Sn
										Cornwall							
12	E. Looe	Upper	SX249:555	Mar. 76*	122	0.7	6.8	16.3	208	1540	21	7.7	36.5	1164	46	0.97	-
17	Plym	Mid	SX508:553	Jan. 80	1.0	1.0	2.3	1.8	74	626	9	1.6	9.1	559	33	0.50	1.5
										South Wales and Severn							
1a	Usk/Severn	-	ST314:831	Oct. 76	12.3	4.1	3.9	2.9	64	1640	158	5.3	10.8	1150	-	-	-
2a	Rhymney/ Severn	-	ST227:775	Oct. 76*	5.0	6.4	4.3	3.2	88	1950	29	2.9	28.6	1690	19	0.18	< 0.1
4a	Barry	Harbour	ST110:667	Oct. 76*	7.4	1.6	5.4	2.1	124	1520	34	4.6	9.8	1023	27	0.26	< 0.1
6a	Swansea Bay	-	SS631:912	May 79	0.7	0.6	3.2	1.8	44	535	75	4.4	16.9	668	22	0.59	0.48
7a	Loughor	Mid	SS508:977	Oct. 78	0.3	0.2	1.1	2.4	32	210	8	1.6	2.3	396	11	0.12	1.22
11a	W. Cleddau	Mid	SM988:121	Oct. 76	2.7	0.5	2.7	1.1	67	623	20	2.5	9.0	825	-	-	-
	E. Cleddau	Mid	SN011:118	Oct. 78	2.2	0.1	-	0.8	46	569	20	1.0	2.8	491	-	-	-
										Severn and Southern Bristol Channel							
1b	Severn	Sharpness	SO666:019	Nov. 76	100	9.4	3.6	4.0	224	1300	356	12.7	19.4	1510	-	-	-
3b		New Passage	ST544:865	Nov. 78	44.9	5.5	4.2	4.2	110	1770	107	4.4	9.9	1790	22	1.3	0.48
6b		Weston	ST308:589	Nov. 78	6.8	2.2	3.1	3.6	54	1810	73	3.8	8.7	899	22	0.44	1.69
9b	Blue Anchor	-	ST029:436	Dec. 78	6.0	1.2	1.0	6.3	30	218	11	2.8	2.3	621	22	0.56	0.49

Appendix 5. METALS IN WHOLE NEREIS DIVERSICOLOR - TYPICAL ANALYSES

Extreme values from two main areas (1 - 26 and remainder) are in boxes

Most sites and dates given in Appendices 2 and 4. *Map ref. SW813:607; ‡SW787:389

No.	Estuary	Site	Dry weight	Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	As	Hg	Sn
				Concentration (ppm dry weight)												
				Cornwall and Devon												
1	Taw	Mid	0.079	0.18	0.16	3.1	0.3	12	326	17.4	3.9	2.6	129	8.9	0.22	0.06
2	Torridge	Upper	0.034	0.28	0.22	8.2	<0.3	20	532	15.5	5.4	0.2	183	13.0	0.26	0.13
		Lower	0.037	0.26	0.44	7.6	< 0.3	21	604	13.9	4.4	2.0	163	14.0	0.28	0.09
3	Camel	Upper	0.052	0.60	0.17	6.3	0.5	32	561	15.5	6.9	2.5	249	7.0	0.09	0.21
		Lower	0.039	1.6	0.28	8.3	< 0.3	10	485	7.1	4.5	9.9	179	-	-	-
4	Gannel	Upper*	0.02	5.3	1.23	14.2	0.5	91	349	14.1	13.3	685	466	21	0.08	1.3
		Mid	0.034	1.9	0.37	7.0	0.7	86	372	15.5	3.7	13	222	-	-	-
		Lower	0.02	3.7	0.40	11.2	0.5	257	431	10.9	3.9	49	267	-	-	-
5	Hayle	Upper	0.025	5.3	0.47	10.3	<0.3	1210	734	5.7	9.1	4.2	260	84	0.22	0.08
6	Helford	Upper	0.056	0.6	0.34	3.8	< 0.3	60	384	6.4	3.3	6.1	176	12	0.20	1.39
		Mid	0.111	0.6	0.09	2.3	< 0.3	56	356	5.9	2.0	2.0	121	-	-	-
7	Restronguet	Upper‡	0.036	6.0	0.53	11.0	0.6	1430	554	12.0	2.3	5.2	262	23	0.05	0.16
		Upper	0.042	3.0	0.81	4.5	0.4	832	378	12.3	3.6	4.0	318	87	0.23	-
		Mid	0.034	6.2	0.97	7.5	0.7	932	268	14.1	3.9	9.8	302	57	0.18	0.46
8	Truro	Upper	0.022	9.5	1.44	7.3	<0.3	196	424	6.9	5.3	3.1	389	-	-	-
		Lower	0.090	0.8	0.20	1.8	0.8	73	355	6.5	2.1	2.2	142	-	-	-
9	Tresillian	Upper	0.021	2.2	0.69	5.9	<0.3	70	494	7.0	3.8	1.0	272	15	0.21	1.6
9X	Fal	Mid	0.026	0.9	0.60	6.6	6.5	47	481	8.5	4.1	2.3	190	-	-	-
10	Fowey	Upper	0.025	0.71	0.21	5.2	0.6	96	551	13.3	3.7	3.1	234	-	-	-
		Mid	0.028	0.62	0.24	4.2	0.7	39	453	10.7	2.6	3.8	219	12	0.15	2.6
		Lower	0.081	0.38	0.20	3.3	0.7	44	456	13.5	3.0	8.7	181	-	-	-
11	W. Looe	Upper	0.020	1.02	0.41	6.6	4.0	29	399	11.8	3.3	25.9	257	20	0.17	0.46

				Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	As	Hg	Sn
12	E. Looe	Upper	0.024	7.6	0.70	6.2	2.2	30	385	9.7	3.3	4.4	219	15	0.08	0.09
		Lower	0.047	1.2	0.25	2.2	0.9	44	596	9.6	2.1	13.7	177	15	0.19	0.50
13	Lynher	Upper	0.025	2.2	0.96	8.9	<0.3	306	701	11.5	3.7	10.2	229	19	0.19	0.74
		Lower	0.051	0.5	0.19	4.5	<0.3	55	589	8.2	4.0	8.3	164	15	0.12	0.16
14	Tamar	Lower	0.031	0.78	0.27	4.4	<0.3	46	377	6.9	3.1	5.2	163	13	0.22	0.09
		Upper	0.027	0.63	0.53	8.0	<0.3	130	591	12.8	4.3	7.0	179	13	0.14	0.34
16	Tavy	Upper	0.016	1.71	2.7	9.4	<0.3	218	484	12.0	4.5	31	207	17	0.47	0.17
17	Plym	Upper	0.041	1.02	2.9	4.1	3.9	28	351	8.1	6.2	5.4	201	-	-	-
		Mid												16	0.35	1.06
		Lower	0.046	0.33	0.3	1.3	5.0	34	524	10.6	5.2	9.4	147	-	-	-
18	Yealm	Upper	0.047	0.07	0.28	8.2	0.6	17	427	8.0	3.7	3.4	220	10	0.14	0.45
		Mid	0.122	0.24	0.03	2.7	0.5	36	423	7.8	2.7	4.4	136	-	-	-
19	Erme	Mid	0.039	0.26	0.17	3.4	0.3	25	446	6.3	2.3	5.8	150	13	0.17	0.13
20	Avon	Mid	0.034	0.13	0.14	5.1	0.5	19	564	11.8	3.3	5.4	197	7.8	0.07	0.09
219	Kingsbridge	Upper	0.027	0.11	0.45	3.3	0.3	15	380	10.0	2.2	17.3	197	16	0.14	1.1
22	Dart	Upper	0.035	0.14	0.73	0.7	<0.3	15	227	5.6	1.5	1.3	91	16	0.13	0.27
23	Teign	Upper	0.064	0.29	1.06	5.7	0.5	14	290	32.1	7.5	12.7	191	9	0.13	-
		Mid	0.041	0.23	0.20	6.7	<0.3	13	503	11.0	2.6	6.9	180	11	0.13	-
		Lower	0.087	0.13	0.09	3.5	<0.3	11	319	9.3	2.1	2.7	122	8	0.10	-
24	Exe	Upper	0.029	0.37	0.40	4.4	<0.3	20	517	12.5	4.4	6.3	189	7	0.32	1.44
		Mid	0.038	0.16	0.61	3.5	0.4	17	387	6.8	4.4	1.7	196	9.7	0.21	0.34
25	Otter	Mid	0.079	0.15	0.10	4.2	0.4	13	348	26.2	2.3	0.6	169	5.6	0.22	0.50
26	Axe	Upper	0.055	0.28	0.15	8.2	1.6	12	446	25.1	3.2	3.3	189	-	-	-
		Lower	0.053	0.34	0.17	5.4	0.4	13	338	18.5	2.8	1.5	195	9.9	0.22	0.16

Appendix 5 continued

				Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	As	Hg	Sn
									South Wales and Severn							
1c	Wye	ST546:920	0.024	9.6	3.8	4.1	0.2	37	316	10.2	4.8	3.3	246	14	2.3	< 0.1
2c	Severn	Beachley	0.025	11.8	3.0	4.3	0.2	53	402	11.5	3.9	2.1	247	16	2.1	< 0.1
3c		Black Rock	0.023	11.0	2.5	5.8	0.2	16	448	11.9	3.6	2.8	224	14	1.8	< 0.1
4c		Redwick	0.025	8.5	4.3	6.1	0.2	44	370	10.5	5.3	3.0	249	18	2.0	< 0.1
1a	Usk/Severn	-	0.021	6.9	3.9	6.1	0.2	37	379	10.8	5.8	3.8	278	24	2.4	< 0.1
2a	Rhymney/Severn	-	0.024	2.1	3.1	4.1	0.2	28	288	7.7	5.1	2.9	253	16	0.5	< 0.1
3a	Cardiff	Harbour	0.027	3.2	5.8	6.9	0.2	42	364	8.5	6.3	3.7	262	19	0.79	< 0.1
4a	Barry	Harbour	0.025	2.3	0.84	5.8	0.1	50	387	9.9	3.9	2.7	227	20	0.62	< 0.1
5a	Neath	Upper	0.047	1.51	0.85	8.9	< 0.3	36	359	11.9	6.4	2.5	175	13	1.7	< 0.1
6a	Swansea Bay	West Cross	0.050	0.92	0.35	6.9	< 0.3	48	400	12.1	2.8	3.5	200	6.7	0.58	< 0.1
7a	Loughor	Upper	0.093	0.37	0.54	4.3	0.6	28	564	24.8	4.8	0.9	173	9	0.09	0.61
		(1) Mid	0.062	0.60	0.35	2.9	3.1	41	589	20.5	2.9	1.3	178	17	0.11	0.81
		(2) Mid	0.051	0.29	0.32	4.8	0.5	18	402	10.2	4.8	1.3	192	14	0.03	0.22
		Lower	0.032	0.49	0.49	2.6	0.5	14	402	13.3	1.9	2.3	204	13	0.29	0.10
8a	Gwendraeth	Upper	0.060	0.16	0.11	3.1	0.3	12	449	10.9	2.9	1.9	151	11	0.05	< 0.1
9a	Twyi	Upper	0.067	0.19	0.13	2.9	0.1	10	333	14.0	2.8	1.3	119	9	0.02	< 0.1
		Lower	0.047	0.41	0.20	4.1	0.1	13	428	14.6	4.1	1.9	150	10	0.13	< 0.1
10a	Taf	Upper	0.039	0.26	0.12	4.0	0.2	14	426	12.8	3.1	1.8	156	10	0.07	0.23
		Lower	0.063	0.13	0.12	3.1	0.1	13	469	12.4	1.8	2.0	131	14	0.02	0.12
11a	W. Cleddau	Upper	0.099	0.25	0.04	3.3	0.1	13	549	10.0	2.6	1.6	114	9.7	0.05	< 0.1
	E. Cleddau	Mid	0.115	0.24	0.07	3.0	< 0.3	22	634	11.3	2.5	1.4	119	10	0.06	0.16

Appendix 5 continued

				Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	As	Hg	Sn
									Severn and Southern Bristol Channel							
1b	Severn	Sharpness	0.011	18.0	5.0	5.3	0.2	81	615	9.6	5.4	3.3	292	16	2.5	1.0
2b		Shepperdine	0.019	6.3	4.4	4.1	0.3	41	384	12.8	5.4	5.0	203	11	1.4	< 0.1
5c	Avon (Upper)	ST563:740	0.048	2.8	1.7	3.7	0.1	49	324	10.6	5.0	2.5	207	6	0.16	< 0.1
	(Lower)	ST524:763	0.028	4.8	2.9	4.4	0.2	33	313	12.5	5.2	1.4	237	8.4	2.0	< 0.1
6b	Severn	Weston	0.021	4.6	2.4	7.3	0.2	49	468	12.1	7.1	2.6	256	13	0.88	< 0.1
6c	Parrett	ST262:425	0.025	4.2	3.2	4.3	0.4	28	272	14.3	3.8	3.4	275	-	-	-
		ST298:474	0.019	8.9	3.9	5.8	-	39	301	34.3	4.9	1.0	285	-	-	-
8b	Watchet	Harbour	0.028	1.3	0.38	8.9	0.1	67	509	11.9	3.4	3.3	237	13	0.33	< 0.1
10b	Minehead	Harbour	0.031	2.4	0.32	7.3	0.1	67	499	11.1	3.0	3.1	218	11	0.30	0.19

Appendix 6. METALS IN SEDIMENTS - TYPICAL ANALYSES

Concentrations in nitric acid digest of 100 µm fraction (fusion used for Sn)

Sites are those shown in Appendices 2,3,5 and 6: **Nereis* only site

Extreme values from two main areas (1 - 26 and remainder) are in boxes

No.	Estuary	Sites	Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	As	Hg	Sn
			Concentration (ppm dry weight) except Fe (%)												
								Cornwall and Devon							
1	Taw	Mid	0.3	0.5	15	40	30	3.20	790	32	58	169	13	0.63	41
2	Torridge	Upper	0.3	0.8	14	31	27	2.88	725	29	47	145	11	0.50	37
		Lower	0.2	0.5	12	33	24	2.79	642	27	48	140	11	0.39	62
3	Camel	Upper	0.4	0.5	12	33	80	2.76	552	28	64	215	55	0.16	741
		Lower	0.6	0.3	11	15	45	1.14	275	14	30	60	-	-	-
4	Gannel	Upper*	2.9	3.0	40	29	217	3.32	1160	49	2175	1215	233	0.09	305
		Mid	0.4	0.5	22	28	91	2.75	1120	25	381	419	115	0.06	550
		Lower	0.7	0.3	22	35	103	2.68	922	25	376	357	-	-	-
5	Hayle	Upper	1.3	1.0	28	36	782	5.15	742	32	218	942	550	0.06	1750
		Dock	1.3	2.8	30	84	688	4.50	646	39	322	1345	-	-	-
		Canal	2.5	0.5	19	23	676	4.26	650	22	129	715	950	0.25	1680
6	Helford	Upper	0.6	1.4	8	37	252	2.85	296	32	63	616	23	0.68	1070
		Mid	0.6	<0.1	9	45	328	2.77	236	32	76	281	-	-	-
7	Restronguet	Upper*	2.8	0.9	14	21	1733	4.75	401	25	204	1587	1076	0.24	2672
		Upper	4.1	1.2	22	37	2540	5.76	559	32	290	3515	2520	0.22	1730
		Mid	3.5	1.3	18	23	2170	6.30	466	37	396	3000	1600	0.45	1350
8	Truro	Upper	2.7	1.1	8	43	344	2.76	214	27	220	759	-	-	-
		Mid	2.0	1.0	6	25	335	2.57	172	17	137	628	120	0.43	700
		Lower	0.8	0.2	11	43	527	3.42	252	34	219	613	-	-	-
9	Tresillian	Upper	1.1	1.0	8	23	256	2.21	260	21	100	400	88	0.61	591
9X	Fal	Mid	0.4	0.4	3	15	129	1.21	116	9	48	252	56	0.20	125

Appendix 6 continued

			Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	As	Hg	Sn
10	Fowey	Upper	0.5	0.3	9	43	136	2.14	346	26	73	199	-	-	-
		Mid	0.4	0.7	10	29	122	2.79	393	27	74	189	47	0.5	424
		Lower	0.3	0.2	9	49	115	2.10	355	24	67	173	-	-	-
11	W. Looe	Upper	1.3	0.3	12	25	57	2.12	452	36	256	145	12	0.30	54
		Mid	0.7	<0.1	11	24	43	2.01	477	33	131	115	9.3	0.25	42
12	E. Looe	Upper	1.9	0.4	12	25	36	2.23	464	36	88	151	16	0.13	67
		Lower	0.4	<0.1	9	22	30	1.79	418	31	61	85	8.6	0.23	49
13	Lynher	Upper	1.1	0.9	19	44	349	3.82	660	41	229	408	115	0.81	181
		Lower	0.7	0.6	16	40	249	2.53	575	37	163	301	97	0.83	129
14	Tamar	Lower	0.7	0.5	13	41	173	2.35	465	34	148	254	56	0.65	106
15	Tamar	Upper	0.9	1.5	23	44	305	2.81	758	49	156	392	85	0.90	101
16	Tavy	Upper	0.8	0.6	19	48	290	3.75	660	42	176	339	131	0.84	151
17	Plym	Upper	0.5	1.8	4	40	70	1.10	175	12	65	171	-	-	-
		Mid	0.6	2.6	3	22	80	1.10	77	13	65	179	42	0.41	-
		Lower	0.7	3.6	5	43	92	1.49	185	17	96	216	-	-	-
18	Yealm	Upper	0.2	0.3	11	26	35	2.73	368	25	50	110	34	0.82	126
		Mid	0.3	0.2	12	46	46	2.61	279	34	83	141	-	-	-
19	Erme	Upper	0.2	0.4	12	39	35	3.48	354	30	70	147	-	-	-
		Mid	0.1	0.2	9	21	18	2.12	342	24	38	83	6.0	0.38	40
20	Avon	Mid	0.1	0.3	10	37	19	1.94	417	28	39	98	13	0.12	28
21	Kingsbridge	Upper	0.2	0.3	8	41	30	2.84	305	26	66	122	12	0.85	20
22	Dart	Upper	0.3	0.8	10	42	38	3.19	538	27	73	145	24	1.0	58
		Lower	0.1	0.1	7	35	20	1.78	239	19	51	88	-	-	-
23	Teign	Upper	1.0	1.8	18	35	68	2.16	777	30	382	375	74	0.36	176
		Lower	0.3	0.8	8	32	21	1.76	319	20	66	148	12	0.14	33
24	Exe	Upper	0.4	0.8	10	36	27	2.81	403	27	60	149	9.9	0.42	13
		Mid	0.4	0.9	14	44	38	3.44	735	36	73	192	12	0.18	11

			Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	As	Hg	Sn
25	Otter	Mid	0.1	0.4	15	33	25	2.65	834	24	55	128	11	0.38	8.4
26	Axe	Upper	<0.1	0.2	11	33	16	1.58	214	22	30	94	-	-	-
		Lower	0.1	0.3	6	23	13	1.55	303	11	34	62	4.8	0.20	8.6
								South Wales and Severn							
1c	Wye	Mid	0.4	1.0	15	43	66	3.20	594	35	96	283	9.1	0.48	53
2c	Severn	Beachley	0.5	1.0	16	48	55	3.42	652	38	105	314	10	0.56	45
3c	Severn	Black Rock	0.4	1.0	15	44	50	3.14	600	35	96	284	8.5	0.52	50
4c	Severn	Redwick	0.7	1.1	14	41	54	2.98	604	33	88	255	8.0	0.48	58
1a	Usk/Severn	-	0.5	1.1	15	44	66	3.38	597	36	94	284	9.2	0.36	56
2a	Rhymney/Severn	-	0.7	1.2	16	50	56	3.72	643	38	108	329	11	0.53	46
3a	Cardiff H.	-	0.6	1.0	15	46	61	3.55	582	38	107	320	12	0.56	50
4a	Barry H.	-	0.4	0.5	12	34	50	2.60	451	27	76	206	8.1	0.45	66
5a	Neath	Upper	0.7	2.1	18	39	89	3.11	524	40	98	327	12	1.2	54
		Mid	0.4	1.6	15	42	43	1.87	650	35	75	269	20	0.54	26
6a	Swansea Bay	West	0.3	0.4	17	60	37	2.15	836	36	95	256	18	0.56	45
7a	Loughor	Upper	0.2	1.4	12	302	40	2.21	791	32	65	219	21	0.18	255
		(1) Mid	0.2	1.1	13	799	47	3.81	631	31	77	220	22	0.13	320
		(2) Mid	0.2	0.7	12	170	32	1.99	715	29	58	167	18	0.17	97
		Lower	0.2	0.3	12	69	26	1.89	653	27	55	143	12	0.11	62
8a	Gwendraeth	Upper	0.1	0.6	8	31	16	1.71	363	20	39	107	7.7	0.14	44
9a	Tywi	Upper	0.2	0.7	10	26	17	1.68	376	21	45	121	5.6	0.09	49
		Lower	0.1	0.6	10	27	18	1.82	421	22	42	151	8.3	0.07	55
10a	Taf	Upper	0.2	0.8	10	32	19	1.73	432	21	43	118	14	0.20	50
		Lower	0.2	0.8	11	35	24	1.93	385	25	55	137	3.4	0.06	57
11a	W. Cleddau	Upper	0.4	0.6	13	34	27	2.35	378	28	56	165	12	0.15	40
		Mid	0.3	0.6	13	36	27	2.24	481	29	54	164	8.6	0.21	34
	E. Cleddau	Upper	0.3	0.6	13	33	29	2.77	460	26	55	154	8.5	0.20	-
		Mid	0.3	0.5	12	34	26	2.23	377	29	58	156	9.2	0.23	72

Appendix 6 continued

			Ag	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	As	Hg	Sn
								Severn and Southern Bristol Channel							
1b	Sharpness	-	0.4	0.9	15	41	35	2.95	599	34	94	278	7.3	0.56	59
2b	Shepperdine	-	0.4	0.8	14	40	33	2.90	554	32	87	258	7.8	0.46	53
5c	Avon	Upper	0.4	0.9	16	45	37	3.15	620	37	101	291	9.9	0.57	61
		Lower	0.4	0.9	16	51	40	2.98	624	36	107	284	7.3	0.52	59
4b	Portishead	-	0.4	0.9	13	46	37	2.43	516	31	83	225	7.6	0.43	52
6b	Weston	-	0.5	0.7	14	41	33	2.92	560	33	88	252	7.8	0.42	53
6c	Parrett	Mid	0.3	0.5	16	88	37	2.46	791	35	101	281	-	-	-
		Lower	0.4	0.7	15	92	39	2.56	838	39	105	314	-	-	-
8b	Watchet H.	-	0.3	1.3	11	37	32	2.11	377	26	67	171	7.7	0.37	44
9b	Blue Anchor	-	0.1	0.4	7	25	18	1.79	311	18	32	85	9.5	0.08	-
10b	Minehead H.	-	0.3	0.4	12	37	28	2.76	358	31	72	207	9.7	0.35	57