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Heavy Metals in U.K. Estuaries: PML Data and Mapping Program

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HEAVY METALS IN U.K. ESTUARIES: PML DATA AND MAPPING PROGRAM

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EXECUTIVE SUMMARY

A floppy disk containing information on concentrations of heavy metals in sediments and benthic indicator organisms from most estuaries in England and Wales has been created for NRA use. The data are the results of measurements carried out at the Citadel Hill site of the Plymouth Marine Laboratory over the past 20 years. Metals determined included Ag, As, Cd, Co, Cr, Cu, Fe Hg, Mn, Ni, Pb, Sn, Zn. Indicator organisms employed (13 in number) include the seaweed *Fucus vesiculosus*, ragworms *Nereis diversicolor* and clams *Scrobicularia plana* or *Macoma balthica*. Also included on the disk is a Windows program for displaying concentrations as vertical bars on maps showing the geographical distribution of metal contamination in estuarine sediments or organisms: specific areas of the UK, sample types and metals are all selectable and a hard copy can be produced

The present R&D Note is intended to accompany the data disk: it includes instructions for using the disk and map program and information on the data. Separate descriptions are given of the data for sediments and indicator organisms but both include information on sampling, sample treatment and metal determinations. Also included are tables giving examples of the the extent to which concentrations of metals in sediments and biota vary among U.K. estuaries. To aid in the interpretation of the biological data the metal-indicator abilities of the different species are described and compared. Finally, two bibliographies are provided: the first comprises literature references to projects involving the data on the disk and the second includes recent references to heavy metals in sediments and organisms in U.K. estuaries.

KEY WORDS

Metals, estuaries, sediments. biota, England, Wales, United Kingdom, distribution, maps.

The NRA acknowledges the kind permission of the Natural Environment Research Council, Plymouth Marine Laboratory to use the data contained in the database associated with this document. The intellectual property rights for the data reside with the NERC and any comments regarding the origin or other facets of the data should be directed towards PML. Any use of the raw data for purposes other than internal use should be referred to the Project Leader in the first instance.

1. PROJECT DESCRIPTION

1.1 Objectives

1. To supply the NRA with information on heavy-metal levels in UK estuaries based on measurements carried out on sediments and indicator organisms over the past 20 years.

2. To provide the data on a floppy disk together with a program enabling the information to be mapped.

1.2 Source of data

Studies of estuarine metal contamination have been carried out at the Citadel Hill site of the Plymouth Marine Laboratory for more than 20 years. Objectives included:

(1) to assess the usefulness of benthic invertebrates and seaweeds as analytical indicators of metal contamination.

(2) to study factors governing the availability of dissolved and sediment-bound metals to benthic organisms.

(3) to identify heavily contaminated sites where deleterious biological effects might be observed.

Monitoring was not the primary objective, although ultimately most estuaries in England and Wales were visited. A few estuaries were sampled only once whilst some of the more polluted received far more attention. Thus, rather than being a continuous record the results are a series of snapshots of a large number of estuaries.

This report has two principal aims. The first is to describe the significance of the data on heavy metals in sediments and indicator organisms. The second is to provide instructions for using the data-mapping program.

2. DESCRIPTION OF THE PML DATA

The data stored on the floppy disk include metal concentrations in estuarine sediments and a range of benthic indicator organisms.

Sediments are considered first.

2.1 Sediment metals

2.1.1 Extraction and determination of metals

Oxidized surface sediments (usually sieved through 100 µm mesh) were digested with concentrated nitric acid. Atomic absorption techniques (flame, graphite furnace, and flameless) were used to determine up to 13 metals (Bryan et al 1985).

These are:

Ag (silver)
As (arsenic)
Cd (cadmium)
Co (cobalt)
Cr (chromium)
Cu (copper)
Fe (iron)
Hg (mercury)
Mn (manganese)
Ni (nickel)
Pb (lead)
Sn (tin)
Zn (zinc)

2.1.2 Sediments - some important facts:

1. From 1977 onwards sediments were sieved through 100μm plastic mesh prior to analysis.

2. Previously sediments were not sieved, but the majority (especially the most polluted) would have passed through 100 μm mesh. Earlier results are therefore included in the database.

3. All 13 elements were not determined in all sediments particularly in the early 1970s when interests were more limited. Even so, data on 10 metals (Ag, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn) are available for most of the 1970s.

4. Prior to 1978 all measurements were made by flame atomic absorption for which detection limits for Ag and especially Cd (around 0.1 ug/g) were inadequate for clean or sandy sediments. This was overcome with the introduction of graphite-furnace atomic absorption in 1978.

5. Measurements of As, Hg and Sn by flameless atomic absorption also commenced in 1978. These determinations are far more time-consuming and generally there are fewer data.

6. Digestion with concentrated nitric acid does not extract all metals completely. Tests showed that whilst most were almost totally extracted (by comparison with dissolution in hydrofluoric acid), recovery of Mn, Fe and Cr was usually around 90%, and could be less (appreciably so in Plym Estuary sediments containing china-clay wastes).

7. Much of the Sn in sediments is often present as the mineral cassiterite: this is largely insoluble in nitric acid and is of relatively low environmental significance. However, most other anthropogenic forms of Sn are extracted with nitric acid.

2.1.3 Sediment data: a brief summary

Heavily contaminated estuarine sediments are found in most NRA regions. This is illustrated in Table 2.1 which lists some of the most contaminated localities with respect to each metal.

Maxima and minima

Maximum concentrations are summarised in Table 2.2 and are thought not to be fliers. Also shown in Table 2.2 are means of the 32 lowest sieved-sediment values for each metal. The contrasts between these low values and the maxima are exaggerated by the fact that the lowest numbers generally apply to sandy sediments where the <100 μm fraction did not include much fine material. On the other hand, some of the most contaminated sediments were largely comprised of the smaller particle sizes.

Particle size effects: possibilities for normalization

Overcoming, the particle size effect can sometimes be accomplished by normalizing metal values to concentrations of a sediment component that varies with particle size and (ideally) is not an anthropogenic contaminant. Relating metal values to those for Al has been used successfully in some areas (Windom et al 1989; Din 1992) and Rb was employed in the Humber (Grant and Middleton 1990). Of the elements determined in the present work, Fe is probably the best for normalization purposes although in estuaries like the Humber and Fal it is a significant anthropogenic contaminant.

Typical results

Examples of metal data from around England and Wales (Solway to Tweed) are shown in Table 2.3: as far as possible sandy sediments were excluded. Whereas there are many examples of gross contamination it is virtually impossible to find pristine sediments in England and Wales.

Since Zn is a very widespread contaminant, relatively uncontaminated sediments are often characterised by having a Zn concentration of around 100 μg/g (Fig 2.1). Estuaries that appear relatively uncontaminated with Zn (and most other metals) include the Solway (sediment no.1 in Table 2.3) and the Teifi Estuary in west Wales (no. 7). Samples from the Erme (Devon) and Tweed (nos 13 and 30) appear uncontaminated apart from having fairly high levels of Hg (Fig. 2.2). In East Anglia, the Blackwater, Deben, Alde and Blakeney sediments (nos 19, 20, 21, 23) are relatively low in metals although the former displays evidence of Ag contamination and the latter is rather high in Zn. An interesting feature of Table 2.3 is that Co shows little evidence of contamination and its concentrations simply covary with those of Fe ($r = 0.86$).

Biological evidence

Support from biological data can be important in determining what should or should not be regarded as a contaminated sediment. For example, evidence of Ag contamination of Blackwater sediment, mentioned above, is confirmed by the presence of a significant amount in the clam *Scrobicularia plana* (no. 22 in Table 2.10).

Table 2.1 Estuaries displaying high levels of sediment contamination

Ag	Gannel	Restronguet Cr.	Looe	Whitehaven	Hayle
As	Restronguet Cr.	Hayle	Gannel	Tamar	Tees
Cd	Whitehaven	Plym	Wear	Poole	Tyne
Cr	Tees	Loughor	Clyde	Whitehaven	Mersey
Cu	Restronguet Cr.	Hayle	Dulas Bay	Waveney	Tamar
Hg	Mersey	Tees	Poole Harbour	Wyre	Neath
Pb	Gannel	Wear	Looe	Restronguet Cr.	Tamar
Sn	Loughor	Fal	Hayle	Gannel	Mersey
Zn	Restronguet Cr.	Gannel	Waveney	Hayle	Dulas Bay

Table 2.2 Comparison of lowest sediment metal concentrations with maximum values

Metal	Mean of 32 lowest values 1978+ µg/g	Maximum µg/g	Estuary
Ag	0.055	28.4	Looe (West)
As	4.4	2738	Restronguet Cr.
Cd	0.08	27.6	Plym (upper)
Co	4.2	51.7	Gannel (upper)
Cr	17	826	Loughor
Cu	8.9	4779	Restronguet Cr.
Fe	11670	76700	Restronguet Cr.
Hg	0.06	8.94	Tees
Mn	119	2183	Mersey
Ni	9.3	76.6	Gannel (upper)
Pb	20	9305	Looe (West)
Sn	0.50	473	Loughor
Zn	50	6095	Restronguet Cr

Table 2.3 **Metals (ug/g) in some United Kingdom estuarine sediments (nitric acid extracts of <100 um fraction)**

No.	Estuary	Site	Ref.	Ag	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sn	Zn
1	**Solway**	**Creetown**	nx473573	0.08	11	0.39	8.1	34	11	19770	0.08	765	23	36	0.3	92
2	Whitehaven	Harbour	nx972183	2.87	29	**8.69**	14.4	145	78	34740	0.58	549	38	101	4.1	233
3	Wyre	Singleton	sd378398	0.30	9	0.66	9.8	46	34	24210	3.71	696	24	58	4.5	177
4	Mersey	Stanlow	sj430776	1.34	63	2.53	15.8	97	131	31330	4.50	1519	44	203	8.7	327
5	Dulas Bay	upper	sh478882	0.05	9	0.36	10.6	25	755	30640	0.11	641	18	24	1.5	934
6	Dyfi	mid	sn663971	0.22	5	0.71	17.8	27	27	45550	0.06	1082	33	208	1.4	239
7	**Teifi**	**St Dogmaels**	sn164468	0.07	9	0.18	10.2	26	13	29440	0.04	647	22	22	1.0	90
8	Loughor	Llangennech	sn564009	0.24	21	0.65	12.3	302	40	22100	0.18	791	32	65	**123.0**	219
9	Severn	New Passage	st544866	0.49	7	0.84	15.6	46	36	32340	0.40	595	37	103	10.5	293
10	Fal	Restronguet	sw803387	**4.61**	**2467**	1.75	27.5	25	**3192**	**66480**	0.53	652	32	315	68.5	**4929**
11	Looe	east upper	sx247557	1.92	16	0.18	11.8	25	36	22260	0.13	464	36	88	4.1	151
12	Tamar	North Hooe	sx423659	0.96	119	1	25.8	52	336	39100	0.88	991	**54**	168	9.3	431
13	Erme	Clyng Mill	sx627490	0.15	6	0.19	8.8	21	18	21160	0.38	342	24	38	2.2	83
14	Poole	inner	sz003929	3.55	10	7.96	11.6	72	76	25890	2.96	156	43	103	9.6	255
15	Itchen	upper	su436146	1.59	8	1.99	6.2	55	160	16870	1.26	130	15	203	12.4	236
16	Hamble	Swanwick	su495092	0.21	14	0.21	7.4	29	38	23940	1.11	218	19	70	4.7	115
17	Medway	Rochester	tq738681	1.73	19	1.44	11.1	50	74	31800	1.32	461	30	111	3.8	294
18	Thames	Tilbury	tq647753	2.04	21	0.79	10.4	58	43	27490	1.15	709	28	98	4.9	163
19	**Blackwater**	**Bradwell**	tl995082	0.72	15	0.15	11.1	49	21	30390	0.36	351	26	39	2.1	92
20	**Deben**	**Waldringfield**	tm287452	0.30	12	0.17	11.3	48	22	30050	0.35	453	24	43	1.9	94
21	**Alde**	**Iken**	tm403562	0.22	10	0.1	17.5	46	21	39260	0.24	741	32	44		103
22	Waveney	Oulton Broad	tm522926	0.26	10	0.44	12	42	108	36263	1.22	389	28	127		220
23	**Blakeney**		tg027449	0.12	22	0.21	7.9	37	16	23750	0.19	378	20	46	2.1	120
24	Great Ouse	lower	tf599236	0.17	17	0.35	10.3	51	19	26060	0.21	792	24	62	2.5	136
25	Welland	lower	tf344338	0.27	32	0.62	14.5	66	32	37820	0.33	**1644**	35	79	3.7	176
26	Humber	Kilnsea	ta402156	0.56	75	0.63	19.3	111	58	44490	0.80	1506	**54**	142	9.8	304
27	Tees	transporter br.	nz502214	1.27	100	5.01	11.8	**665**	298	38990	**8.94**	502	35	**571**	3.7	852
28	Tyne	Felling	nz278633	2.14	30	3.43	11.1	56	115	29980	0.97	349	38	259	6.6	652
29	Blyth	Blyth	nz291823	0.29	27	0.84	13.7	47	57	30760	0.24	445	41	81	3.9	222
30	**Tweed**	**Berwick**	nt996526	0.10	8	0.12	9.3	42	21	23460	0.55	387	31	47	2.5	89

Bold names are least contaminated sediments: Bold numbers are highest values

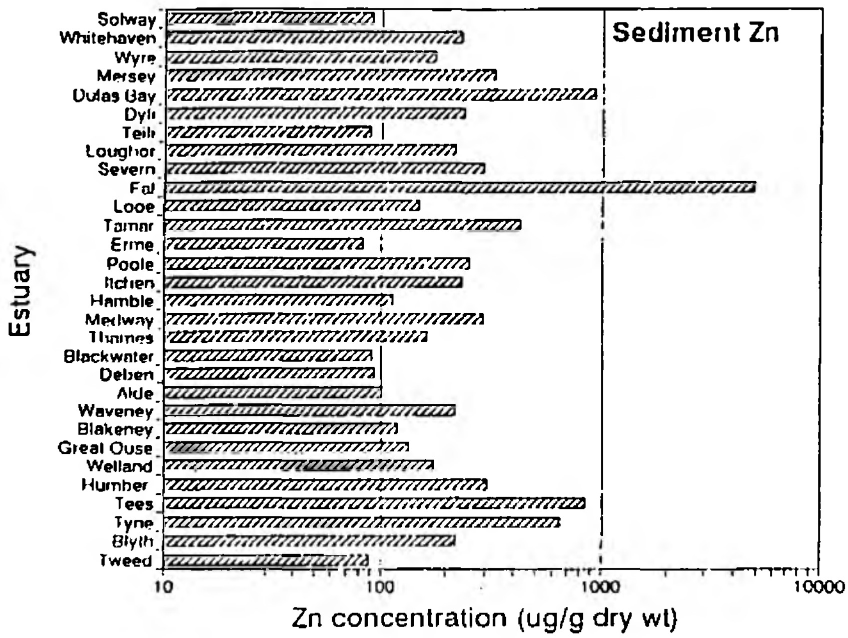

Fig. 2.1 Sediment Zn: bar chart showing variations between sites in England and Wales.

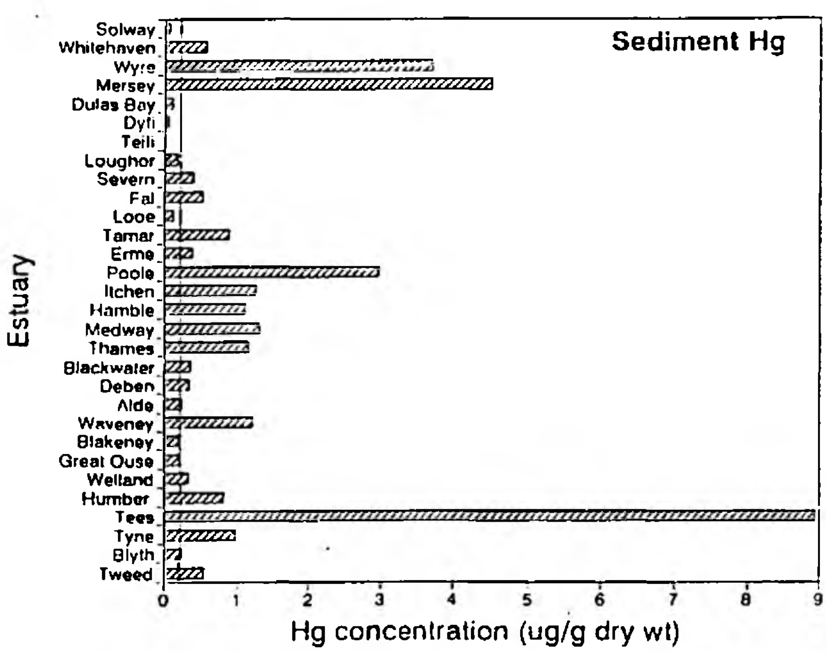

Fig. 2.2 Sediment Hg: bar chart showing variations between sites in England and Wales.

2.2 Metals in estuarine organisms

2.2.1 Introduction

Since most of the metals in estuaries lie in the sediments, analysis of these deposits is very useful for assessing the retention of heavy-metal inputs. Sediment data are also of use in determining whether or not biological effects might be expected. However, such measurements on sediments or water rarely take account of the existence of metals in different chemical forms having different biological availabilities. Biological availability is a pre-requisite for metal pollution and analysis of biological material is therefore most appropriate for assessing contaminant levels and their possible effects.

2.2.2 Organisms included in the database

The most ubiquitous species are:

Fucus vesiculosus (brown seaweed; bladderwrack)
Littorina littorea (a herbivore; common winkle)
Nereis diversicolor (sediment-dwelling worm; ragworm)
Scrobicularia plana (deposit-feeding clam)
Macoma balthica (deposit-feeding clam)

Less frequently sampled were:

Fucus serratus (brown seaweed; used if *F. vesiculosus* absent)
Littorina littoralis (herbivore; winkle)
Littorina saxatilis (herbivore; winkle)
Patella vulgata (herbivore; limpet)
Nucella lapillus (carnivore; dog-whelk)
Mytilus edulis (suspension-feeder; common mussel)
Cerastoderma edule (suspension-feeder; common cockle)
Mya arenaria (deposit-feeding clam)

2.2.3 Cleaning prior to tissue analysis

Various techniques were employed to remove particulate or sedimentary material from surfaces and digestive systems before analysis (Bryan et al 1985). Particularly in burrowing organisms, sediment particles in the gut can produce appreciable errors. This is especially the case for metals such as Fe, Cr and Pb that usually occur at higher concentrations in sediments than in the biota.

2.2.4 Determination of metals

To reduce biological variation (and analytical effort) all samples consisted of tissues pooled from several specimens (e.g. about 6 *Scrobicularia*, 10 *Littorina*, 20 *Nereis*).

Tissues were either wet-digested, mainly with nitric acid, or homogenates were mixed with ashing agents and, after drying, dry-ashed in a muffle furnace (As, Sn). Metals were determined by atomic absorption methods almost identical to those employed for sediments (Bryan et al 1980, 1985, Langston, 1980, 1982).

2.3 Estuarine organisms as indicators of metal availability

2.3.1 Introduction

Environmentally significant forms of metals in waters or sediments are those that are biologically available and capable of having deleterious effects. The best way of assessing the presence of bioavailable metals is by measuring their concentrations in indicator organisms. These are species in which the accumulation of metals in tissues reflects their availabilities in waters or sediments. Few organisms are ideal indicators for all metals. For example, some species are able to control their body concentrations of certain metals by excretion or exclusion: others are poor accumulators of some metals and thus more difficult to analyse. Indicator properties of organisms included in the database are described below. Species are divided into three categories reflecting bioavailabilities of metals in:

1. Water mainly
2. Water and suspended particles
3. Sediment mainly

2.3.2 Indicators of dissolved metals

Fucus vesiculosus **(brown seaweed: bladderwrack)**

Laboratory experiments have shown that metal concentrations in *F. vesiculosus* reflect levels of dissolved metals in sea water (Bryan, 1983). Furthermore, Bryan et al (1985) concluded that under field conditions concentrations in *F. vesiculosus* provided a useful indication of the bioavailabilites of Ag, As, Cd, Co, Cu, Hg, Ni, Pb and Zn as modified by factors including organic and inorganic complexation and inter-element competition.

Data for samples collected in different estuaries are summarised in Table 2.4. Maximum concentrations are compared with the lowest values in Table 2.5. The seaweed is a very good indicator for Cu and Zn, values for which are displayed graphically in Figs 2.3 and 2.4. They show that at relatively uncontaminated sites (e.g. Solway and Tweed) levels of Cu and Zn lie below 10 µg/g and 100 µg/g respectively. On the other hand, values for Cu exceeding 100 µg/g are common in the former mining areas of south-west England (Hayle, Fal, Tamar) and Zn values approaching or exceeding 1000 µg/g are not uncommon (Hayle, Fal, Teign, Thames).

Table 2.4 ***Fucus vesiculosus:*** **metals (ug/g dry tissue) in seaweed from United Kingdom estuaries**

No.	Estuary	Site	Ref.	Ag	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sn	Zn
1	Solway	Creetown	nx473573	0.09	32	1.04	2.5	1.9	6	581	0.03	314	7.8	3	0.1	70
2	Whitehaven	Harbour	nx972183	1.06	20	14.60	10.8	3.3	28	515	0.02	336	14.5	6	0.1	176
3	Ravenglass	mid	sd084966	1.18	29	4.37	4.9	2.4	16	1155	0.13	604	11.9	6	0.1	319
4	Mersey	Eastham	sj365818	0.24	30	0.64	1.4	5.2	21	1250	0.13	113	7.7	11	0.8	329
5	Conwy	upper	sh787718	0.03	27	2.00	4.3	6.9	10	1960	0.03	585	4.7	17	0.3	549
6	Mawddach	mid	sh655175	0.12	28	1.29	7.3	6.6	24	2123	0.09	409	17.2	13	0.3	300
7	Dyfi	mid	sn663971	0.25	26	1.96	6.6	4.6	12	1866	0.12	500	10.9	31	0.2	429
8	Cleddau	Landshipping	sn011118	0.25	20	0.68	5.7	2.4	11	1844		419	12.2	4	0.1	95
9	Loughor	Llanelli Br.	ss564983	0.23	37	1.98	5.6	**30.0**	19	1795	0.02	301	14.5	6		122
10	Severn	Shepperdine	st612963	**2.62**	20	**15.10**	3.6	4.5	41	1343	0.13	396	25.0	6	0.3	545
11	Camel	Wadebridge	sw987731	0.14	39	1.50	9.9	4.1	16	2192	0.04	460	14.5	11	1.2	477
12	Hayle	culvert	sw547364	0.81	50	2.27	3.5	4.6	435	**4808**	0.14	149	21.7	32	**2.7**	1864
13	Fal	Restronguet	sw803387	1.94	**161**	0.65	10.5	1.1	**903**	2190		359	6.2	20	1.6	**2826**
14	Tamar	North Hooe	sx423659	0.44	41	0.37	8.1	4.6	141	3916		490	9.4	**53**	0.5	107
15	Erme	Clyng Mill	sx627490	0.10	33	0.56	5.5	2.8	6	972	0.07	254	5.6	8	0.2	110
16	Teign	upper	sx877722	0.22	23	6.65	3.8	4.2	17	1829	0.27	773	4.6	32	2.5	934
17	Poole	Sterte	sz011911	0.29	12	1.88	10.6	5.0	32	1635	0.15	135	12.1	15	1.9	215
18	Itchen	upper	su436146	0.34	8	3.01	9.0	4.6	40	1341	0.08	552	15.3	24	1.4	572
19	Ouse	Newhaven	tq446015	0.83	29	2.36	6.4	2.7	26	1424	0.09	520	20.0	19	0.3	294
20	Thames	Grays	tq614774	1.63	14	4.85	1.9	5.3	24	2081	0.12	177	**52.6**	11	0.4	1252
21	Blackwater	Bradwell	tl995082	0.74	21	1.11	7.4	7.8	15	4457	0.11	274	12.7	16	0.8	98
22	Stour	Wrabness	tm162320	0.32	14	0.71	4.5	3.2	8	1256	0.09	119	10.3	3	0.4	65
23	Deben	Waldringfield	tm287452	0.40	23	0.84	8.3	4.5	10	1984	0.22	301	12.5	6	0.7	74
24	Nene	lower	tf493267	0.13	37	0.59	2.8	1.9	8	899	0.05	336	5.2	7	0.1	45
25	Humber	Kilnsea	ta402156	0.44	25	1.89	3.4	2.4	26	842	0.28	269	16.5	4	0.1	231
26	Tees	lower	nz542283	0.59	47	1.01	5.0	6.8	23	410	**0.37**	430	8.1	8		454
27	Wear	bridge	nz385579	0.30	16	2.11	7.1	4.3	13	975	0.22	527	6.5	29	0.5	234
28	Tyne	Jarrow	nz340658	0.42	28	0.36	1.1	3.2	19	1612	0.29	105	1.5	43	1.0	126
29	Blyth	Blyth	nz291823	0.28	19	1.70	**22.8**	5.6	20	4309	0.10	**874**	22.6	18	1.4	479
30	Tweed	Berwick	nu002524	0.11	17	0.71	1.9	2.0	6	1020	0.04	196	7.6	3	0.2	72

Bold type shows highest values;

Table 2.5 Comparison of lowest *Fucus vesiculosus* metal concentrations with maximum values

Metal	Mean of 32 lowest values µg/g	Maximum µg/g	Estuary
Ag	0.07	7.4	Bristol Channel
As	9.40	181	Restronguet Cr.
Cd	0.34	58.2	Severn
Co	0.70	67	Port Talbot
Cr	0.25	53.5	Loughor
Cu	4.9	3476	Restronguet Cr.
Hg	0.02	50.5	Poole Harbour
Ni	2.0	58	Severn
Pb	0.95	610	Tamar (mine)
Sn	0.07	11.8	Poole Harbour
Zn	48	4035	Restronguet Cr.

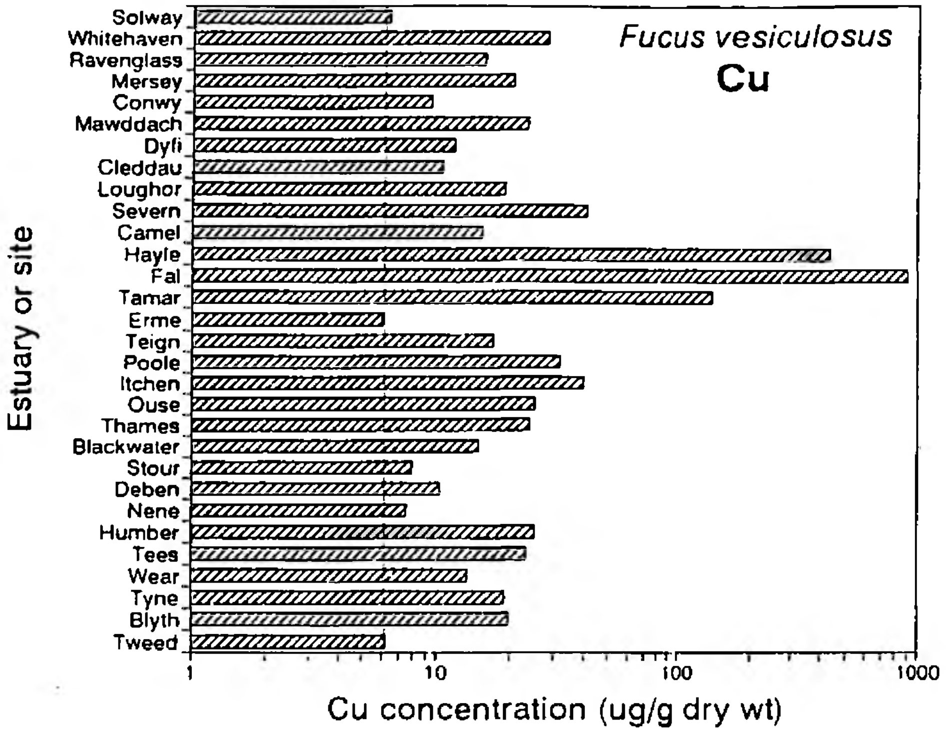

Fig. 2.3 ***Fucus vesiculosus*** **Cu: bar chart showing variations between sites in England and Wales.**

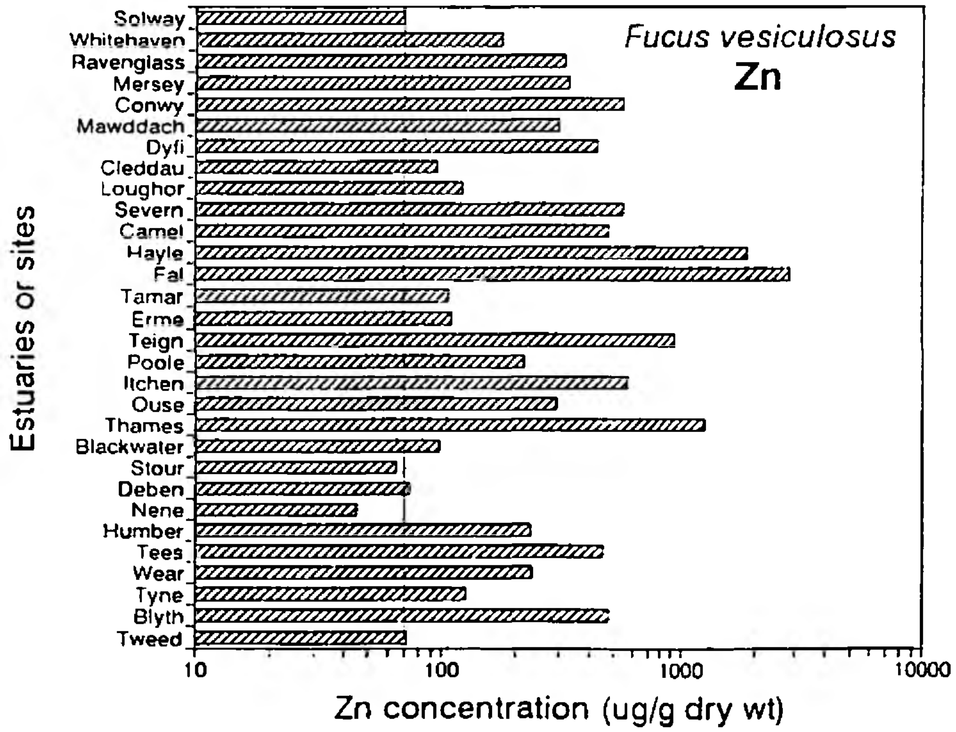

Fig. 2.4 ***Fucus vesiculosus*** **Zn: bar chart showing variations between sites in England and Wales.**

Littorina littorea **(common winkle)**

Winkles usually occur on hard substrates and penetrate into the middle reaches of many estuaries where they feed on algae and algal films. Examples of data for UK estuaries are shown in Table 2.6. Bryan et al (1983) observed very significant relationships between concentrations of Ag, As, Cd and Pb in winkles and those of the seaweed *Fucus vesiculosus*. This suggested that, directly or indirectly, concentrations in the animal reflect those of the overlying water. Significant relationships between the two species were also observed for Cu, Fe, Hg and Zn, but the slopes were relatively shallow: in particular, elevated concentrations of Zn were only found in the most contaminated estuaries such as the Fal (Fig. 2.5). The ease with which Ag can be measured in the winkle makes it a good indicator for this metal (Fig. 2.6). In relatively uncontaminated areas concentrations of Ag lay below 2 µg/g whereas levels exceeding 10 µg/g were observed in Cumbria, and the Severn, Looe, Medway and Thames estuaries.

Littorina littoralis **(flat periwinkle)**

This species sometimes has a similar estuarine distribution to *Littorina littorea* and is usually collected by shaking the fronds of *Fucus vesiculosus* on which it feeds. Comparisons between these two species of winkles from the same sites showed that *L. littoralis* usually contains higher metal concentrations (Bryan et al 1985). It seems to be a particularly good indicator of Cd and tissue concentrations exceeding 100 ug/g were observed in the Severn Estuary (Table 2.7). In addition, *L.littoralis* responds far better than *L. littorea* to changing enviromental concentrations of Zn (Bryan 1983).

Littorina saxatilis **(rough periwinkle)**

Metal concentrations in this small winkle were observed by Bryan et al (1985) to be of the same order as those of *Littorina littorea*.

Patella vulgata **(common limpet)**

Limpets are common herbivores on rocky shores and penetrate into the lower reaches of some estuaries. Based on good relations observed between their body concentrations and those of the seaweed *Fucus vesiculosus* they appear to be useful indicators for dissolved Cd. Cu and Pb (Bryan et al 1985).

Nucella lapillus **(dog-whelk)**

Dogwhelks are found on rocky coasts and. before being largely eliminated by tributyltin pollution, were found in the lower reaches of some estuaries. Although they are carnivores and feed on mussels and barnacles. good relations between dogwhelk tissue concentrations and those of the seaweed *Fucus vesiculosus* indicate that they reflect dissolved concentrations of Cd and Cu.

Table 2.6 *Littorina littorea:* **metals (ug/g dry tissue) in common winkles from United Kingdom estuaries**

No.	Estuary	Site	Ref.	Ag	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sn	Zn
1	Solway	Kippford	nx836548	8.9	37	2.2	0.3	0.44	145	262	0.22	58	2.6	2.5	0.1	85
2	Whitehaven	Harbour	nx972183	27.2	14	19.3	3.1	0.51	158	539	0.28	52	7.1	8.4	1.0	120
3	Ravenglass		sd084966	17.0	23	3.8	0.8	0.68	162	511	0.58	95	2.8	4.4	0.2	103
4	Mersey	Egremont	sj318924	2.7	16	2.6	1.7	0.59	125	397	1.15	80	4.0	8.6	0.3	196
5	Dee	Rhyl	sj019824	2.5	21	2.8	1.3	0.32	210	481	0.92	82	8.5	7.8	0.1	122
6	Bangor	harbour	sh588729	5.2	48	3.5	0.8	1.26	112	811	0.39	91	2.1	8.7	0.0	99
7	Porthmadog		sh567375	0.7	28	1.2	1.6		87	265	0.16	43	2.2	2.4	0.1	87
8	Teifi	St Dogmaels	sn164468	1.2	25	1.5	1.1	0.36	133	379	0.31	70	3.4	3.1	0.0	93
9	Cleddau	Little Milford	sm971116	13.4		3.7	0.7	1.23	111	962		145	3.7	2.5		100
10	Loughor	Llanelli	ss508977	2.4	26	6.8	1.6	1.44	147	394	0.34	84	7.7	4.2	0.6	117
11	Severn	Brean	st284593	44.4		**38.7**	4.9	3.32	157	1151		99	12.4	7.7		124
12	Duckpool	shore	ss200115	3.5		2.0	0.9	0.53	44	526		37	1.6	5.0		76
13	Godrevy	shore	sw581428	0.6		2.9	1.6		372	332		20		1.7		92
14	Hayle	harbour	sw557377	0.9		1.6	13.9	1.61	718	**1582**		225	8.6	9.2		224
15	Fal	Restronguet	sw813375	2.5	**84**	2.5	**14.3**	0.83	**748**	520	0.14	166	5.8	7.7	1.1	**400**
16	Looe	east	sx252548	30.0	25	1.6	1.2	0.53	154	361	0.37	26	2.8	17.4	1.2	232
17	Wembury	reef	sx519483	1.6	15	1.1	1.5	0.53	119	324	0.47	27	5.6	9.8	5.0	108
18	Poole		sz016902	7.6	18	9.4	3.7		167	530	**4.81**	46		7.9	4.2	108
19	Itchen	Northam	su439130	3.7	18	1.5	2.3	0.98	200	781	0.42	48	3.8	11.6	**11.0**	123
20	Hamble	Swanwick	su495092	0.7	21	2.1	1.8	0.12	91	422	1.13	42	2.4	4.1	6.4	96
21	Medway	Queenborough	tq905724	23.9	24	2.9	1.8	0.21	117	346	0.48	59	7.1	1.3	0.5	97
22	Thames	Grays	tq614774	**101.0**	11	13.2	1.9	0.69	417	322	0.88	55	5.5	4.0	0.5	141
23	Humber	Kilnsea	ta402156	4.4	50	4.3	2.1	0.68	326	477	1.05	232	**12.7**	3.6	0.9	124
24	Tees	lower	nz542283	3.4	24	0.7	2.1	2.34	275	418	0.93	77	4.6	4.2	3.2	116
25	Wear	bridge	nz385579	1.7	20	4.7	3.4	**6.38**	194	899	0.23	**506**	11.6	**24.5**	1.0	156
26	Tyne	Jarrow	nz340658	2.7	25	1.6	2.2		157	416	0.54	110		12.1	1.2	109
27	Blyth	Blyth	nz291823	2.5	19	1.6	2.7	0.52	193	533	0.16	107	9.2	3.7	0.4	122
28	Coquet	Amble	nu259052	1.9	38	1.6	1.9	0.34	142	597	0.27	119	4.8	2.8	0.6	98
29	Alne	Alnmouth	nu243108	4.0	28	1.6	0.9	0.53	92	648	0.30	116	4.0	3.1	0.1	94
30	Tweed	Berwick	nu002524	3.2	31	2.1	2.2	0.57	75	549	0.26	99	4.4	2.6	0.1	119

Bold type shows highest values:

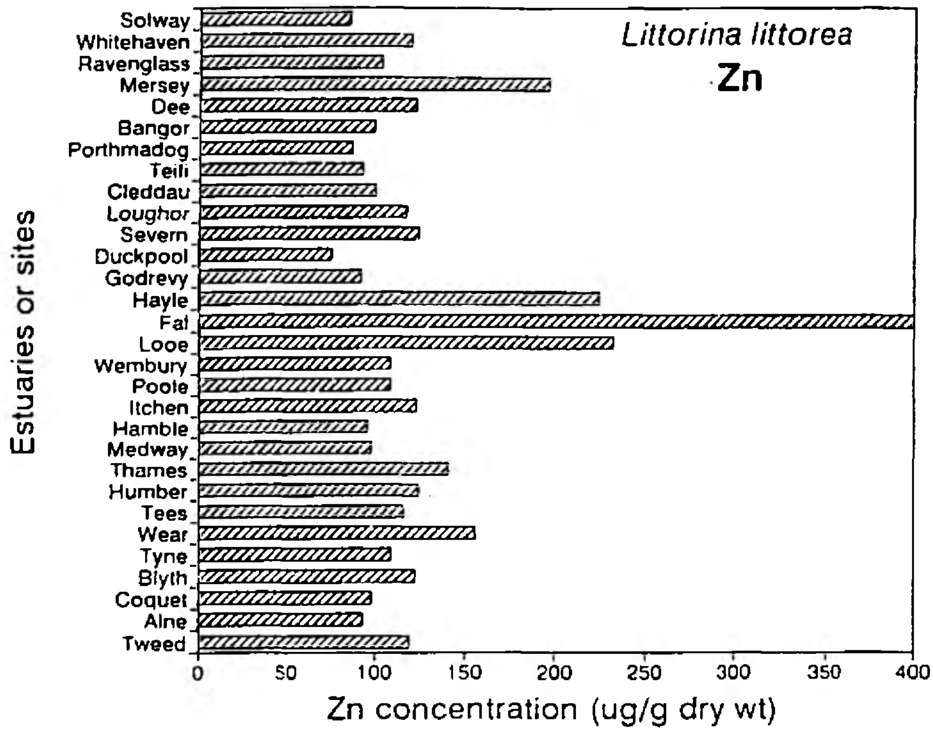

Fig. 2.5 ***Littorina littorea*** **Zn: bar chart showing variations between sites in England and Wales.**

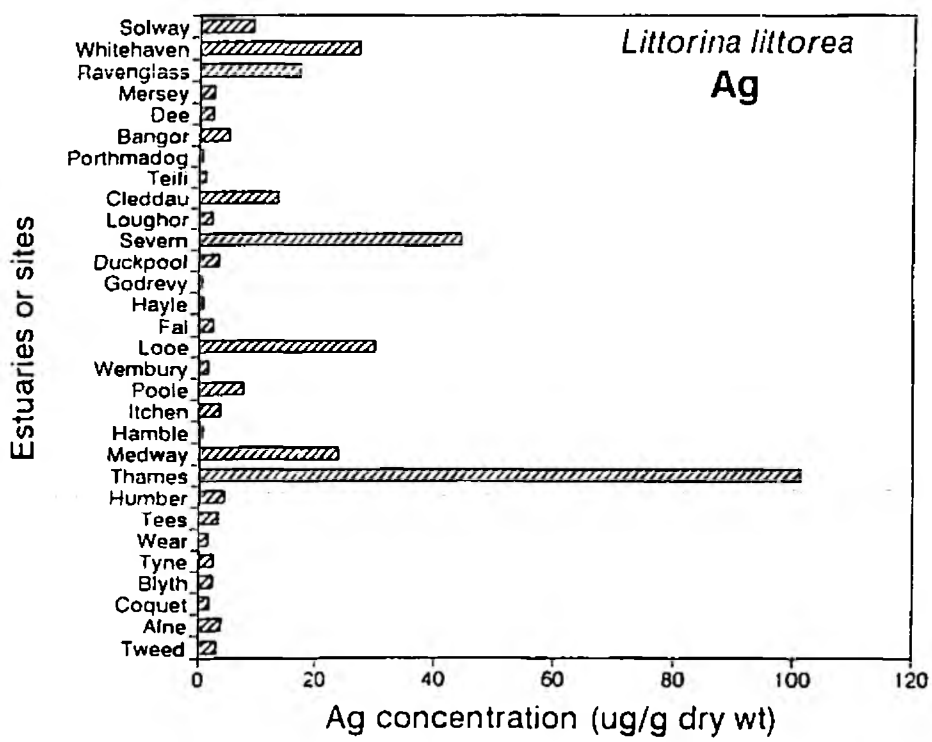

Fig. 2.6 ***Littorina littorea*** **Ag: bar chart showing variations between sites in England and Wales.**

Table 2.7 *Littorina littoralis:* **metals (ug/g dry tissue) in flat periwinkles from United Kingdom estuaries**

No.	Estuary	Site	Ref.	Ag	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sn	Zn
1	Maryport	beach	ny034370	**16.3**	25	34.6	0.6		339	**625**	0.29	105		18.9	0.99	150
2	Lune	Crook Cottage	sd429544	1.9		2.3	0.2	0.55	89	572		97	**4.5**	4.2		110
3	Anglesey	west	sh276805	6.3	27	6.4	1.3	0.72	263	479	0.39	49	3.5	3.6		130
4	Loughor	Pwll	sn485004	1.0		2.1	0.5	**0.85**	139	316		50	3.3	3.7		98
5	Severn	New Passage	st544866	11.6	18	**132.0**	0.2	0.03	145	258	0.17	25	3.2	2.5		272
6	Fal	Mylor	sw810356	1.4	**99**	6.0	**6.6**	0.10	**1183**	378	0.52	98	3.5	4.7		**847**
7	Looe	confluence	sx253540	10.9		7.6	1.4	0.40	352	470		43	2.8	**23.3**		133
8	Wembury	reef	sx519483	4.2	26	5.8	0.3	0.49	120	217	0.46	19	1.5	1.9	**7.05**	114
9	Tees	lower	nz542283	5.7	31	4.2	1.7		576	241	**0.54**	81		6.7		169
10	Beale Sands		nu082427	2.6	26	4.7	1.3	0.44	91	317	0.28	**159**	2.8	2.4	0.19	111

Bold type shows highest values:

2.3.3 Indicators of metals in water and suspended particles

***Mytilus edulis* (mussel)**

Mussels are suspension feeders and well known indicators of metal contamination. However, they are relatively uncommon in many UK estuaries. Results for only about 200 samples are included in the database and a few examples are included in Table 2.8. Mussels are very useful indicators for Cd, Cr, Hg and Pb but at moderate levels of contamination appear to considerably underestimate Cu and Zn contamination (Bryan et al 1985). In addition they are not regarded as reliable indicators for As (Langston, 1984).

***Cerastoderma edule* (cockle)**

Cockles were not widely used as indicators and the data are confined to about 100 samples of which 10 examples are given in Table 2.9. They tend to live in the lower reaches of estuaries often in rather sandy areas. Although not regarded as being particularly good indicators they reflect contamination with Ag, As and Cd. They also accumulate unusually high levels of Ni (Wilson 1983). Cockles also respond to high levels of Cu and Zn but tend to underestimate moderate levels of contamination (Bryan et al 1985).

Table 2.8 *Mytilus edulis:* **metals (ug/g dry tissue) in mussels from United Kingdom estuaries**

No.	Estuary	Site	Ref.	Ag	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sn	Zn
1	Whitehaven	mine	nx972183	44.50	10	28.0	1.2	5.6	13	307	0.61	6.9	3.2	14.4	0.07	181
2	Mersey	Egremont	sj318924	0.15	15	6.9	0.8	2.8	11	478	2.01	11.0	4.0	29.6	0.07	439
3	Dee	Rhyl	sj019824	0.05	17	2.7	0.9	4.0	11	370	0.61	24.0	2.3	10.0		254
4	Fishguard	harbour	sm962373	0.53	7	1.8	0.3	0.7	9	117	0.18	6.2	0.9	5.0	0.28	82
5	Swansea	bay	ss618893	0.07	13	19.5	2.2	5.6	8	341	0.60	11.9	9.4	13.9		136
6	Bristol Channel	Brean	st284593	2.99		57.0	1.2	11.9	14	533		27.9	5.7	15.2		194
7	Godrevy	point	sw580434	0.03	14	2.0	2.3	1.6	49	218	0.32	3.9	1.3	2.5	0.04	299
8	Red River		sw582423	0.22	16	2.3	4.4	0.9	149	435	0.48	6.9	2.4	3.3	0.28	453
9	Poole	Sterte	sz011911	0.32	8	15.1	1.2		9	554	4.07	12.7		10.6	5.10	145
10	Thames	Thorpe Bay	tq916844	5.06	13	7.7	0.5	2.0	9	293	0.58	5.4	3.7	12.5	1.01	289

Bold type shows highest values:

Table 2.9 *Cerastoderma edule:* **metals (ug/g dry tissue) in cockles from United Kingdom estuaries**

No.	Estuary	Site	Ref.	Ag	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sn	Zn
1	Whitehaven	harbour	nx972183	13.90	8	2.6	2.0		10.2	1091	0.39	32.3		10.6	0.23	78
2	Mersey	Egremont	sj318924	0.03	12	0.6	1.7	1.3	4.8	480	1.17	28.6	62	1.5	0.50	128
3	Fishguard	harbour	sm962373	0.04	11	0.5	3.2	0.8	6.5	728	0.54	21.3	52	2.3	0.40	61
4	Loughor	Pwll	sn485004	0.04	9	0.8	2.8	5.5	5.2	838	0.05	31.7	48	2.4		72
5	Fal	Mylor	sw806359	0.40	28	1.8	4.1	3.9	97.8	2437	0.28	38.2	27	14.1	1.1	271
6	Tamar	Antony	sx391554	0.12	18	0.9	3.9	4.3	13.7	1154	0.26	33.2	54	9.7	0.29	99
7	Poole	harbour	sz044889	0.09	6	1.0	4.3	2.6	3.0	221	0.31	2.6	36	0.3	0.69	57
8	Test	Cracknore	su404110	0.05	12	0.7	1.4	4.1	8.9	1350	0.25	13.6	48	8.9	1.59	129
9	Ouse	Newhaven	tq446015	0.23	12	0.5	4.4	1.4	5.1	738	0.69	11.6	122	0.9	0.66	69
10	Thames	Thorpe Bay	tq916844	10.94	18	1.7	3.5	3.2	9.5	819	0.48	10.8	165	3.5	0.64	83

Bold type shows highest values:

2.3.2 Indicators of sediment metals

Scrobicularia plana (clam)

Relationships have been observed between metal levels in these clams (Ag, As, Cd, Co, Cr, Hg, Pb, Zn) and concentrations in sediments (Luoma and Bryan 1979, 1982, Langston, 1980, 1982, Bryan and Langston, 1992). The relationships may not necessarily be direct. For example, the availability of sediment Hg is influenced by the sediment-organic content. Thus, the best fit was observed between tissue-Hg levels and the sediment ratios:- Hg/organic content (Langston, 1982). An example of a direct relationship between clam and sediment Cr concentrations is illustrated in Fig. 2.7.

Scrobicularia appears unsuitable as an indicator for Cu (Luoma and Bryan 1982): high concentrations were observed in clams at several ostensibly uncontaminated sites and appeared to be related in some way to the very anoxic condition of the sediment (e.g. Looe estuary in Table 2.10). However, it is possible that these high levels of Cu contribute to the deleterious effects of anoxic conditions on clams.

Examples of data collected around England and Wales are given in Table 2.10: they are based on clams of about 40 mm shell length. Contrasts between maximum values observed and the lowest can be very considerable (Table 2.11). Inter-estuary variation is particularly evident for Ag (Fig. 2.8). Values range from less than 0.5 µg/g at uncontaminated sites to more than 10 µg/g in 6 estuaries. *Scrobicularia* is also a useful indicator for Cd (Fig. 2.9). Since Cd has a tendency to remain in solution, the high clam concentrations observed in estuaries such as the Severn probably also reflect accumulation of the dissolved metal.

Macoma balthica

In a few estuaries the small (10-20 mm) clam *Macoma balthica* was more common than *Scrobicularia plana* and was used in conjunction with or instead of the latter. Both clams appear to accumulate metals in the same way and at some but not all sites possessed similar concentrations of Ag, As, Cr, Cu, Fe, Hg, Mn and Zn (Bryan et al. 1980). Concentrations of Cd, Co and Pb were always higher in *Scrobicularia* and it is regarded as the superior indicator. As with *Scrobicularia*, *Macoma* appears unsuitable as an indicator of Cu. A summary of results for samples from 20 estuaries is given in Table 2.12.

Mya arenaria

Only about 70 samples of this species were analysed. The majority were collected in Poole Harbour although others were collected in the Solway, Northumbria and East Anglia.

Table 2.10 *Scrobicularia plana:* metals (ug/g dry tissue) in clams from United Kingdom estuaries

No.	Estuary	Site	Ref.	Ag	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sn	Zn
1	Solway	Creetown	nx473573	0.55	16	0.65	3.3	1.4	16	778	0.18	249	5.7	14	0.04	978
2	Whitehaven	Harbour	nx972183	9.81	22	3.34	3.1	2.1	22	1036	0.41	18	2.2	25	0.80	420
3	Mersey	Egremont	sj318924	0.62	29	0.99	5.9	3.0	56	429	1.19	79	2.7	28	0.82	1225
4	Conwy	mid	sh801761	0.28	20	1.49	8.1	2.2	23	925	0.41	61	5.3	34	0.31	1429
5	Dyfi	mid	sn663971	0.33	19	0.56	4.4	0.9	25	746	0.36	50	1.8	51	0.25	903
6	Teifi	St Dogmaels	sn164468	0.43	42	1.22	13.7	2.0	29	1329	0.85	148	7.4	26	0.51	1569
7	Loughor	Llangennech	sn564009	0.15	16	0.77	4.6	7.2	12	1298	0.07	40	3.1	11	3.51	377
8	Severn	Shepperdine	st612963	22.80		**26.10**	6.8	3.7	51	3827	**2.20**	131	6.5	32		1012
9	Camel	Wadebridge	sw987731	0.23	27	0.37	4.5	0.9	20	989	0.24	18	2.7	8	0.65	309
11	Fal	Restronguet	sw803387	0.35	**191**	4.55	12.0	1.4	**156**	2700	0.17	17	4.2	50	2.70	3158
12	Looe	east upper	sx247557	**100.00**	31	2.52	16.4		141	2964	0.79	84		106	0.98	1044
13	Tamar	North Hooe	sx423659	0.27	60	9.75	35.3	**8.3**	49	**7276**	0.23	97	9.1	93	1.39	2816
14	Erme	Clyng Mill	sx627490	0.70	42	0.92	12.8	3.1	60	1097	0.83	33	11.1	49	0.32	1049
15	Teign	upper	sx877722	0.66	37	4.88	22.7	2.7	37	3425	0.34	156	5.7	83	**8.36**	1918
16	Exe	Topsham	sx967875	3.31	12	1.08	14.1	3.9	37	3306	0.46	65	5.7	29	1.32	1604
17	Poole	inner	sz003929	22.50	13	12.00	7.2	5.8	46	1490	1.08	6	10.7	18	1.44	878
18	Itchen	upper	su436146	0.65	13	0.58	5.8	2.0	33	827	0.11	7	2.9	30	0.96	1156
19	Rother	Rye	tq925206	3.95	22	1.00	11.9	2.5	52	1228	1.57	59	9.9	25	1.72	403
20	Thames	Grays	tq614774	25.80	21	4.94	12.0	4.7	63	4019	0.82	55	7.0	41	2.66	2748
21	Gannel	mid	sw804607	0.74	98	9.09	**70.0**	3.8	61	2733	0.90	**333**	**14.9**	**459**	0.90	**4915**
21	Crouch	Burnham	tq994956	18.80	23	1.15	10.9	1.1	67	526	0.74	24	6.0	28	1.40	929
22	Blackwater	Bradwell	tl995082	6.16	29	0.60	9.4	0.8	18	523	0.53	21	5.9	21	0.98	732
23	Yare	L. Breydon	tg510088	10.30	17	0.60	12.5	2.4	47	1747	0.29	40	10.0	30	0.95	1148
24	Nene	lower	tf493267	0.41	20	0.29	4.2	1.4	14	831	0.29	51	3.1	17	0.11	348
25	Boston	lower	tf396393	0.27	26	0.33	6.4	1.0	15	618	0.22	40	3.0	12		511
26	Humber	Kilnsea	ta402156	0.64	28	3.46	11.6	2.8	21	1240	0.24	56	7.2	22	1.98	1549
27	Tees	Bran Sands	nz558264	0.26	17	0.61	4.2	6.9	27	348	0.61	24	1.0	15	0.58	652
28	Tyne	Jarrow	nz340658	4.61	30	3.24	5.3	3.6	33	805	0.99	20	3.6	109	5.55	1177
29	Coquet	Amble	nu259052	0.37	22	0.40	5.2	2.2	15	1118	0.79	86	12.6	16	0.93	1057
30	Tweed	Berwick	nt996526	0.35	21	0.40	4.2	2.9	49	510	0.38	71	4.9	27	0.63	1002

Bold type shows highest values:

Table 2.11 Comparison of lowest Scrobicularia plana metal concentrations with maximum values

Metal	Mean of 32 lowest values µg/g	Maximum µg/g	Estuary
Ag	0.10	259	Looe (East)
As	7.70	295	Restronguet Cr.
Cd	0.28	39.7	Rhymney
Co	2.10	97	Gannel
Cr	0.62	23.8	Loughor
Cu	11.8	752	Erme
Hg	0.08	2.58	Poole Harbour
Ni	1.5	17.8	Chichester H.
Pb	7.6	1077	Gannel
Sn	0.17	15.4	Poole
Zn	302	5169	Restronguet Cr.

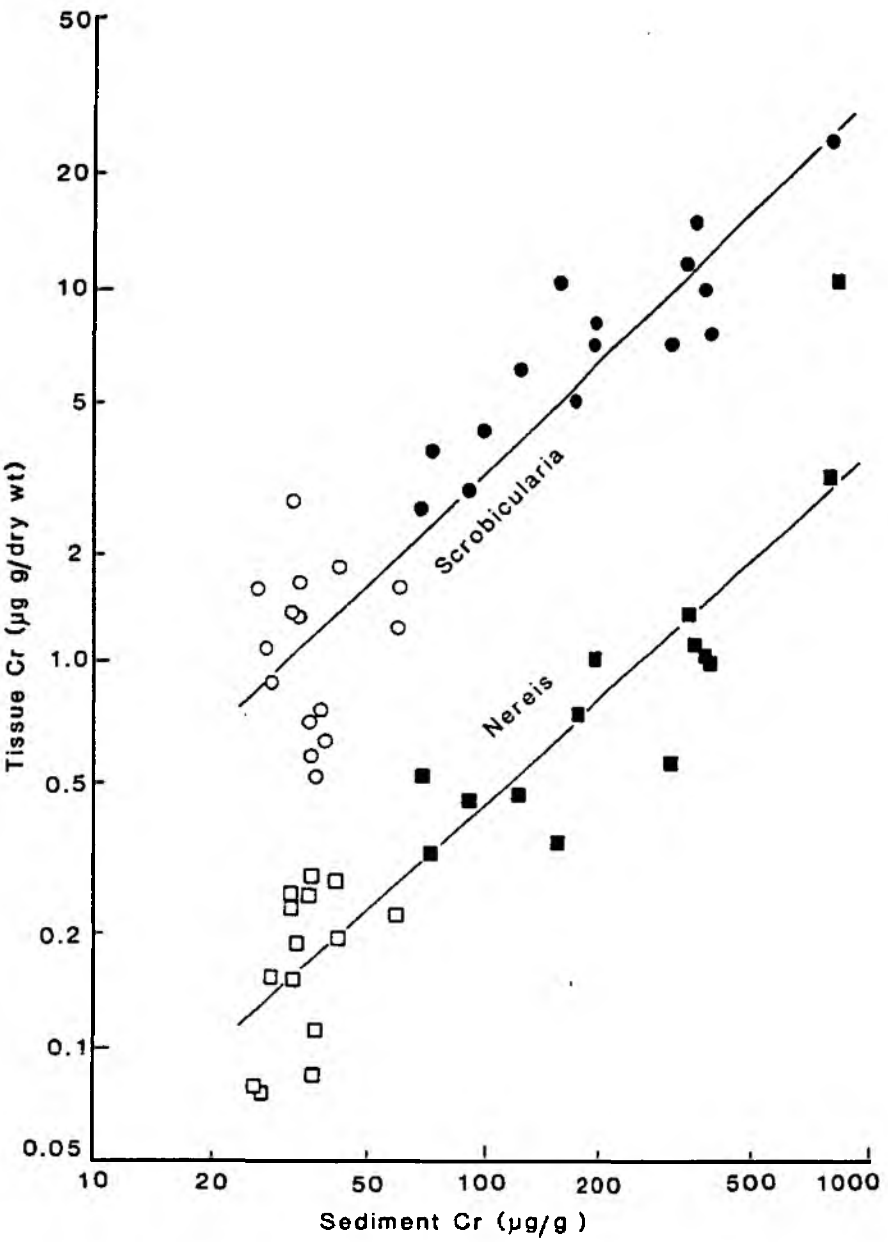

Fig. 2.7 *Scrobicularia plana* and *Nereis diversicolor* Cr: relations between body concentrations and those in nitric acid digests of sediments (<100 µm fraction). Closed symbols are Loughor Estuary and open symbols are other south Wales estuaries.

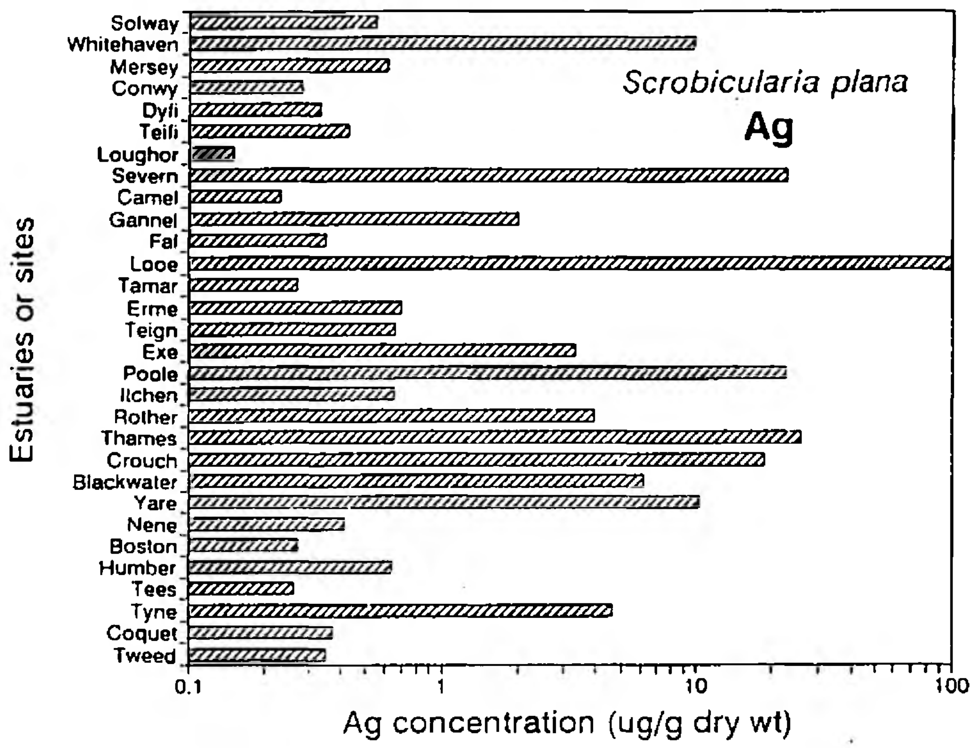

Fig. 2.8 *Scrobicularia plana* Ag: bar chart showing variations between sites

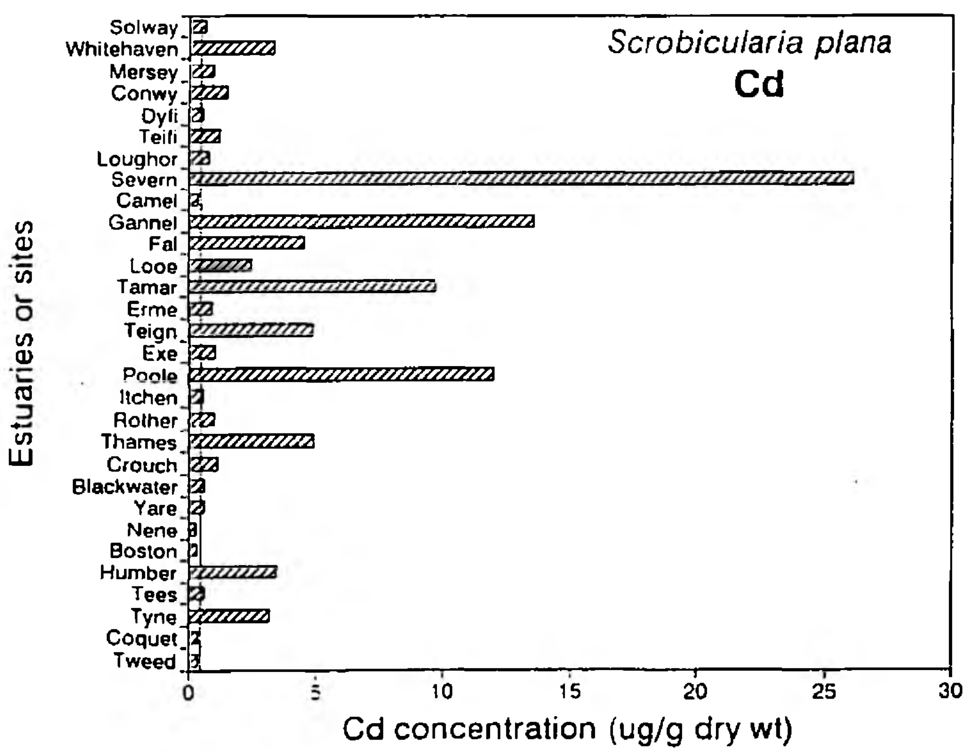

Fig. 2.9 *Scrobicularia plana* Cd: bar chart showing variations between sites

Table 2.12 *Macoma balthica:* **metals (ug/g dry tissue) in clams from United Kingdom estuaries**

No.	Estuary	Site	Ref.	Ag	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sn	Zn
1	Solway	Annan	ny209647	0.60	9	0.30	0.9	0.93	29	574	0.16	23	2.1	4.6	0.4	520
2	Whitehaven	Harbour	nx972183	18.70	10	1.00	1.4	1.60	38	494	0.33	8	0.9	10.7	0.2	533
3	Mersey	Egremont	sj318924	1.38	28	0.37	0.3		97	470	1.04	23		**35.1**	0.7	664
4	Dee	Hoylake	sj217897	0.73	20	0.14	1.4	0.85	53	292	1.10	35	1.4	2.1	0.4	493
5	Dyfi	upper	sn668973	0.30	20	0.87	2.9	0.64	33	769	0.96	102	2.6	16.6	0.8	771
6	Cleddau	Landshipping	sn011118	2.22		0.13		0.79	46	569		21	1.0	2.8		491
7	Loughor	Llanelli	ss508977	0.28	11	0.16	1.1	2.45	32	210	0.12	8	1.6	2.4		396
8	Severn	New Passage	st544866	44.90	22	**5.47**	4.2	4.20	110	**1766**	1.28	**107**	4.4	9.9	0.5	**1788**
9	Bristol Channel	Blue Anchor	st029436	6.01	22	1.21	1.0	6.30	30	218	0.56	11	2.8	2.3	0.5	621
10	Torridge	lower	ss453308	1.30		0.19	3.9	1.02	69	1087		39	7.2	11.6		522
11	Looe	east	sx249555	**301.00**			2.1	**8.70**	**208**	724		21	5.2	28.5		586
12	Tavy	Bere Ferrers	sx462636	0.66		1.60	5.2	1.00	113	858		30	2.0	22.8		769
13	Poole	Sterte	sz011911	3.33	7	1.25	4.3		38	794	0.74	8		5.7	3.6	513
14	Thames	Thorpe Bay	tq916844	86.60	18	0.10	6.7		86	819	**1.47**	10		5.2	**5.9**	568
15	Orwell	upper	tm196391	13.20	26	0.16	3.0	0.96	123	874	0.77	12	1.7	2.9	2.7	686
16	Great Ouse		tf599236	1.59	**29**	0.15	2.5	1.24	56	843		32	3.7	6.2	2.9	818
17	Humber	Kilnsea	ta402156	2.65	26	0.67	3.1	0.88	65	1721	0.51	90	1.9	5.9		742
18	Tees	Bran Sands	nz558264	1.46	18	0.22	1.2	3.02	152	241	1.03	18	0.3	5.1	0.5	414
19	Blyth	Blyth	nz291823	0.32		0.16	1.7	0.16	21	710		21	1.2	5.9		261
20	Coquet	Amble	nu259052	1.68	13	0.58	5.3	2.13	48	1072	0.21	50	5.4	7.1	0.5	1340

Bold type shows highest values:

Nereis diversicolor (ragworm)

Of the estuarine species being considered, the ragworm usually penetrates farthest upstream. Table 2.13 shows a comparison between the lowest and maximum levels observed in the worm and Table 2.14 gives examples of data collected at sites in 30 different estuaries. The results show, that concentrations of Cu and Pb in *Nereis* extend over ranges of about 2 and 3 orders of magnitude respectively. In south-west England estuaries, very significant relationships were observed between ragworm-tissue concentrations (Cu, Pb, Ag) and levels in sediments (Fig. 2.10). Data for Cr in Fig. 2.7 also show a clear relationship between tissue and sediment concentrations, although levels in the ragworm are rather low. However, tissue concentrations of Zn do not respond markedly to environmental changes and thus the worm is an unsuitable indicator for this metal (Fig. 2.10). If sediment-metal levels are low but the overlying water is contaminated, relationships can occur between concentrations in the worm and those of the seaweed *Fucus vesiculosus* (which reflects dissolved concentrations). Data for Cd in the Severn Estuary and south Wales provide a good example (Fig. 2.11).

Table 2.13 Comparison of lowest Nereis diversicolor metal concentrations with maximum values

Metal	Mean of 32 lowest values μg/g	Maximum μg/g	Estuary
Ag	0.10	36.4	Gannel
As	4.16	119	Restronguet Cr.
Cd	0.05	10.2	Severn
Cr	0.05	10.3	Loughor
Cu	10.0	2322	Restronguet Cr.
Hg	0.05	2.8	Mersey
Pb	0.54	1193	Gannel
Sn	0.03	16.4	Itchen
Zn	112	553	Fal

Table 2.14 *Nereis diversicolor:* **metals (ug/g dry tissue) in ragworms from United Kingdom estuaries**

No.	Estuary	Site	Ref.	Ag	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sn	Zn
1	Solway	Annan	ny209647	0.35	9	0.33	2.3	0.08	19	397	0.09	21.0	1.5	0.7	0.1	155
2	Whitehaven	Harbour	nx972183	4.49	12	1.26	4.2	0.24	46	500	0.14	12.7	3.7	3.2	0.7	166
3	Ravenglass		sd088943	1.49	13	0.30	3.0	0.49	31	569	0.27	29.0	2.4	1.2	0.4	173
4	Mersey	Stanlow	sj430776	2.45	26	2.59	4.9	1.30	64	895	1.79		9.0	18.1	1.1	294
5	Clwyd		sj000799	0.48	11	0.16	3.4	0.18	17	256	0.67	37.0	4.0	1.3		133
6	Dulas Bay	lower	sh480885	0.51		1.40	3.1	0.30	1789	333		12.1	2.0	1.8		196
7	Dyfi	mid	sn663971	0.14	11	0.10	4.2	0.11	15	562	0.12	20.0	1.9	3.5	0.3	158
8	Teifi	St Dogmaels	sn164468	0.25	11	0.15	5.8	0.18	24	372	0.18	16.0	2.6	1.5		175
9	Cleddau	Landshipping	sn011118	0.24	10	0.07	3.0	0.28	23	634	0.06	11.3	2.5	1.4	0.2	119
10	Loughor	Llangennech	sn564009	0.21	11	0.22	3.8	1.09	15	424	0.01	20.1	7.2	0.9	0.1	147
11	Severn	New Passage	st544866	9.38	12	6.12	4.0	0.24	48	316	1.05	7.0	5.2	3.0	0.3	336
12	Camel	Wadebridge	sw987731	0.14	7	0.23	4.7		15	488	0.09	17.0		1.6	0.2	125
13	Gannel	upper	sw808606	12.16	21	1.75	22.5	0.54	150	392	0.08	8.9	9.1	1193.0	1.3	510
14	Hayle	culvert	sw547364	5.34		0.47	10.3	0.16	1210	734		5.7	9.1	4.2		260
15	Fal	Restronguet	sw803387	2.40	119	0.76	6.6		496	278	0.11	13.0	6.9	0.9	0.3	324
16	Looe	east upper	sx247557	2.79	15	0.35	3.3	0.29	22	395	0.08	13.6	10.1	2.6	0.1	163
17	Erme	Clyng Mill	sx627490	0.14	13	0.19	3.4		25	526	0.17	12.8		4.4	0.1	157
18	Poole	inner	sz003929	0.49	7	0.64	5.0	0.60	12	337	0.24	11.5	8.9	3.6	1.1	165
19	Itchen	upper	su436146	0.28	12	0.33	3.3	0.38	27	439	0.11	8.3	6.7	2.7	0.6	185
20	Ouse	Newhaven	tq446015	0.34	24	0.18	3.2	0.03	16	449	0.17	9.3	1.6	0.0	1.2	183
21	Medway	Rochester	tq738681	1.22	11	0.25	4.9	0.89	56	507	0.40	12.6	4.2	0.7	2.5	250
22	Thames	Tilbury	tq647753	3.71	12	0.25	6.7	0.35	102	472	0.29	23.0	7.3	3.7	1.6	201
23	Deben	Waldringfield	tm287452	0.56	11	0.18	8.5	0.05	20	298	0.24	8.8	3.4	0.0	0.9	149
24	Blakeney		tg027449	0.11	23	0.11	4.7	0.06	10	338	0.10	15.0	4.0	1.5	0.3	151
25	Boston	lower	tf396393	0.14	20	0.04	3.8	0.34	14	453	0.04	17.2	3.3	0.7	0.2	161
26	Humber	bridge	ta027235	5.97	22	2.39	5.5	0.56	143	482	0.67	16.0	10.0	3.4		299
27	Wear	bridge	nz385579	0.16	11	0.17	2.2	0.84	12	506	0.14	9.5	3.7	6.0	4.2	186
28	Tyne	Felling	nz278633	0.17	15	0.32	1.4	0.34	13	482	0.31	10.0	3.1	3.1		127
29	Blyth	Blyth	nz291823	0.13	7	0.10	3.8	0.14	14	471	0.06	10.2	4.9	1.5	0.8	153
30	Coquet	Amble	nu259052	0.51		0.25	4.9	0.32	22	415		17.8	5.5	3.2		182

Bold type shows highest values:

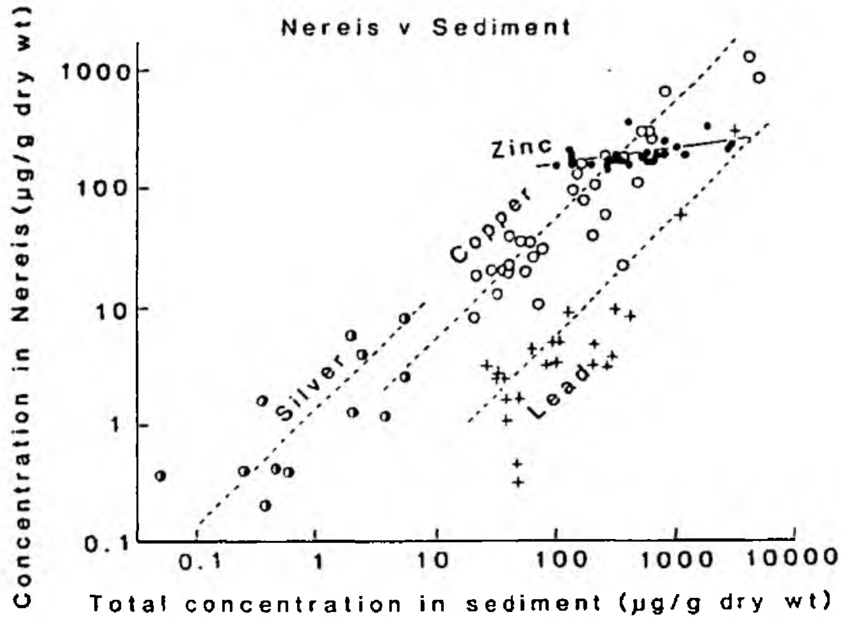

Fig. 2.10 *Nereis diversicolor*: relations between tissue concentrations of Ag, Cu, Pb and Zn and total concentrations in sediments in south-west England.

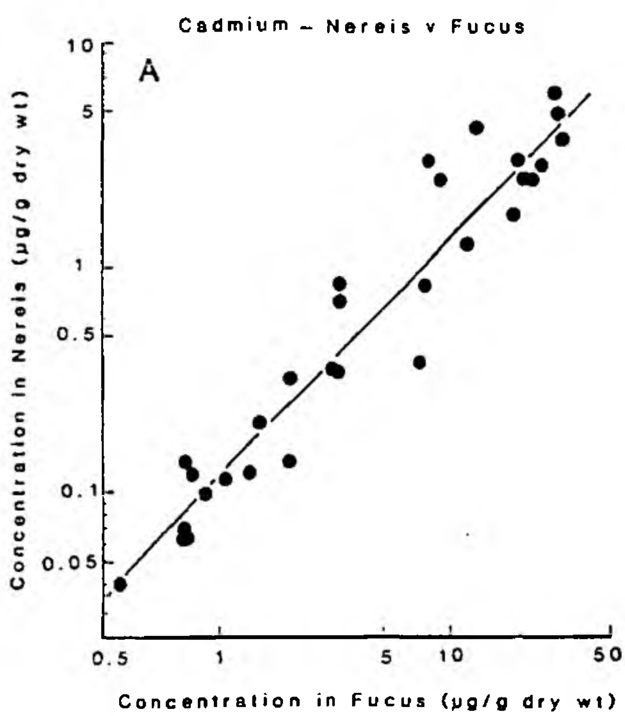

Fig. 2.11 *Nereis diversicolor*: relations between tissue concentrations of Cd and those in the seaweed *Fucus vesiculosus* (reflecting dissolved concentrations) in the Severn

2.3.5 Comparison of indicator species

The properties of estuarine indicator species are summarised in Table 2.15. Some are considered better indicators of bioavailable metals than others. Usually, species in the 'better' category not only reflect environmental concentrations but are good accumulators and more easily analysed.

Further information on indicator organisms and their use in United Kingdom estuaries is contained in publications by Bryan et al (1985) and Bryan and Langston (1992).

Table 2.15 **Summary of indicator organisms for different metals and metalloids**

Better indicators are in Bold Type

Metal or metalloid	Indicators of dissolved metals direct or via diet	Indicators of dissolved and particulate metals	Indicators of sediment metals direct or via diet
Arsenic	*Fucus vesiculosus* ***Littorina littoralis***	*Cerastoderma edule*	***Scrobicularia plana*** ***Macoma balthica***
Cadmium	***Fucus vesiculosus*** ***Patella vulgata*** ***Littorina littoralis*** ***Littorina littorea*** ***Nucella lapillus***	***Mytilus edulis*** *Cerastoderma edule*	***Scrobicularia plana*** *Macoma balthica* *Nereis diversicolor*
Cobalt	*Fucus vesiculosus*	*Mytilus edulis*	***Nereis diversicolor***
Chromium	*Fucus vesiculosus**	***Mytilus edulis***	*Scrobicularia plana*
Copper	***Fucus vesiculosus*** ***Patella vulgata*** ***Nucella lapillus***	*Mytilus edulis*** *Cerastoderma edule***	***Nereis diversicolor***
Lead	*Fucus vesiculosus** *Patella vulgata*	***Mytilus edulis***	***Scrobicularia plana*** *Nereis diversicolor*
Mercury	*Fucus vesiculosus*	*Mytilus edulis*	***Scrobicularia plana*** ***Macoma balthica***
Nickel	***Fucus vesiculosus***	*Cerastoderma edule*	*Scrobicularia plana*
Silver	***Littorina littorea*** *Fucus vesiculosus*	*Cerastoderma edule* *Mytilus edulis*	***Scrobicularia plana*** ***Macoma balthica*** *Nereis diversicolor*
Tin	*Fucus vesiculosus**	*Mytilus edulis*	*Scrobicularia plana*
Zinc	***Fucus vesiculosus***	*Mytilus edulis***	*Scrobicularia plana*

* Particulate contamination can be very significant; ** Mainly useful at high concentrations.

3. MAPPING THE DATA

3.1 Overview

A computer program was developed to enable the geographical distribution of metals at different sites to be visualised. The program requires an IBM compatible computer with Microsoft Windows installed. Files (dBase 3) of metal data for sediments and organisms in each appropriate NRA region are provided with the program. After selecting suitable co-ordinates, an outline map of any estuary can be produced on screen. Values corresponding to the map can then be extracted from the dBase file after defining the map co-ordinates, the type of sample (sediment or species of organism), the metal and the sampling date or dates. Data for each site are then displayed on the map as vertical bars the heights of which correspond to concentrations shown on a vertical scale. If the date is not defined, the bar height represents a mean value for all similar sample types at that site. A mean is also given when a time period is defined by inserting two dates. Information including the area co-ordinates, sample type and metal is included with the map and a facility is provided for additional comments to be typed in. The chart can be printed or can be stored as a file for later use. The dBase files of raw data can be viewed in any dBase 3-compatible database program (e.g. Paradox).

A map created from the sediment data is shown in Figure 3.1.

3.2 Program instructions

Detailed instructions for using the program are given in Appendix A

4. CONCLUSIONS

The heavy-metal data provided on disk for the NRA comprise analyses of up to 13 metals in about 5000 samples collected mainly from estuaries in England and Wales over a period of about 20 years. Samples include surface sediments and 13 indicator species in which tissue concentrations of some metals reflect their bioavailabilities in waters, suspended particles or sediments. The data identify many of the contaminant hot-spots in U.K. estuaries and also provide information against which future trends may be assessed. The Windows program provided for viewing the geographical distribution of the metal data enables maps to be printed or stored as files for future reference. Provided the information is presented as correctly formatted dBase 3 files, the program could also be employed to map other sets of NRA data.

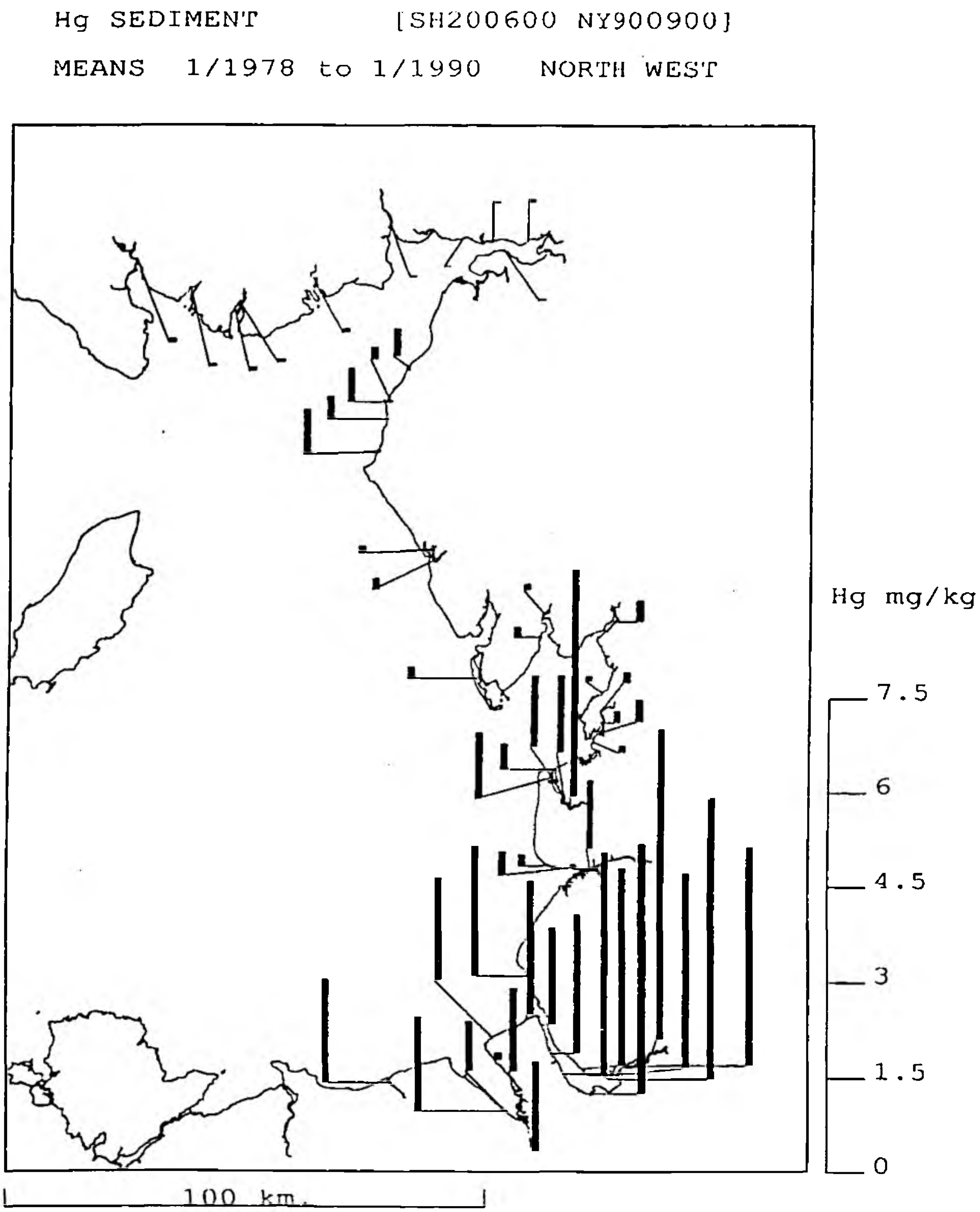

Fig. 3.1 Sediment Hg: mean concentrations (<100 μm fraction) in north-west England.

5. BIBLIOGRAPHY

References used in the text together with others supplied for information have been divided into 2 sections. The first comprises publications directly related to the results in the database. The second list contains references to United Kingdom estuaries many of which include concentrations of metals in sediments and biota.

5.1 References to the data on disk (Annotated)

The following list includes publications based on information contained in the database. Notes on their contents are included in **bold type**.

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Cooper, B.S. and Harris R.C. 1974. Heavy metals in organic phases of river and estuarine sediment. Marine Pollution Bulletin, 5, 24-26. **(Blyth, Northumbria)**

Craig, P.J. and Moreton, P.A. 1983. Total mercury, methyl mercury and sulphide in River Carron sediments. Marine Pollution Bulletin, 14, 408-411. **(Carron-Scotland)**

Craig, P.J. and Moreton, P.A. 1986. Total mercury, methyl mercury and sulphide levels in British estuarine sediments. Water Research, 9, 1111-1118. **(south-west England; Mersey; Clyde)**

Davies, C.A.L., Tomlinson, K. and Stephenson, T. 1991. Heavy metals in River Tees Estuary sediments. Environmental Technology, 12, 961-972. **(Tees)**

Davies, I.M. 1987. Trace metals and organochlorine compounds in the Forth, Scotland. Proceedings of the Royal Society of Edinburgh, 93B, 315-326. **(Forth)**

Din, Z.B. 1992. Use of aluminium to normalize heavy-metal data from estuarine and coastal sediments of Straits of Melaka. Marine Pollution Bulletin, 24, 484-491. **(Sediments)**

Edwards, A., Freestone, R. and Urquhart, C. 1987. The water quality of the Humber Estuary 1986. Humber Estuary Committee, Anglian Water, Huntingdon, 27pp. **(Humber)**

Foster, P., Hunt, D.T.E. and Morris, A.W. 1978. Metals in an acid mine stream and estuary. The Science of the Total Environment, 9, 75-86. **(Afon Goch, Anglesey)**

Franklin, A. 1992. Monitoring and surveillance of non-radioactivecontaminants in the aquatic environment and activities regulating thedisposal of wastes at sea, 1990. Aquatic Environment Monitoring Report, 30, 66p. **(General)**

Fuge, R. and James, K.H. 1974. Trace metal concentrations in *Fucus* from the Bristol Channel. Marine Pollution Bulletin, 5, 9-12. **(Severn-Bristol Channel)**

Gould, D.J., Dyer, M.F. and Tester, D.J. 1987. Environmental quality and ecology of the Great Ouse Estuary. Water Pollution Control, 86, 84-103. **(Great Ouse)**

Grant, A., Hately, J.G. and Jones, N.V. 1989. Mapping the ecological impact of heavy metals on the estuarine polychaete *Nereis diversicolor* using inherited metal tolerance. Marine Pollution Bulletin, 20, 235-238. **(Fal, Humber)**

Grant, A. and Middleton, R. 1990. An assessment of metal contamination of sediments in the Humber Estuary, U.K. Estuarine, Coastal and Shelf Science, 31, 71-85. **(Humber)**

Hamilton, E.I., Watson, P.G., Cleary, J.J. and Clifton, R.J. 1979. The geochemistry of recent sediments of the Bristol Channel-Severn Estuary System. Marine Geology, 31, 139-182. **(Severn-Bristol Channel)**

Head, P.C., D'Arcy, B.J. & Osbaldeston, P.J. 1980. The Mersey Estuary bird mortality, Autumn-Winter 1979 - Summary Report, North West Water Directorate of Services, Scientific Report DSS-EST-80-2, Dawson House, Warrington,U.K. **(Mersey)**

Hitchcock, D.R. and Thomas, B.R. 1992. Some trace metals in sediments from Cardiff Bay, UK. Marine Pollution Bulletin, 24, 464-466. **(Cardiff Bay)**

Howard, A.G. and Apte, S.C. 1989. Seasonal control of arsenic speciation in an estuarine ecosystem. Applied Organometallic Chemistry, 3, 499-507. **(Itchen)**

Humphrey, N.C., Pattinson, C. and Stoner, J.H. 1980. Water quality studies in Swansea Bay. In Industrial Embayments and their Environmental Problems: a case study of Swansea Bay (eds M.B. Collins et al), Pergamon Press, pp. 409-437. **(Swansea Bay)**

Ireland, M.P. and Wootton, R.J. 1977. Distribution of Lead, zinc, copper and manganese in the marine gastropods *Thais lapillus* and *Littorina littorea* around the coast of Wales. Environmental Pollution, 12, 27-41. **(Coasts of Wales)**

Jaffe, D. and Walters, J.K. (1977). Intertidal trace metal concentrations in some sediments from the Humber Estuary. The Science of the Total Environment, 7, 1-15. **(Humber)**

Jones, A.S.G. 1973. The concentration of copper, lead, zinc and cadmium in shallow marine sediments, Cardigan Bay (Wales). Marine Geology, 14, M1-M9. **(Cardigan Bay)**

Jones, L.H. (1979). Heavy metals in the Humber Estuary and its organisms. In: The Humber Estuary, Natural Environment Research Council Publications Series C, no. 20, pp. 13-16. **(Humber)**

Jones, P.G.W. 1980. A review of nutrient salt and trace metal data in U.K. tidal waters. Aquatic Environment Monitoring Report, MAFF Directorate of Fisheries Research, Lowestoft, No. 7, 22 pp. **(General)**

Klumpp, D.W. and Peterson, P.J. 1979. Arsenic and other trace metals in the waters and organisms of an estuary in S.W. England. Environmental Pollution, 19, 11-20. **(Fal)**

Leatherland, T.M. and Burton, J.D. 1974. The occurrence of some trace metals in coastal organisms with particular reference to the Solent region. Journal of the Marine Biological Association of the United Kingdom, 54, 457-468. **(Solent)**

Luoma, S.N. 1986. A comparison of two methods for determining copper partitioning in oxidized sediments. Marine Chemistry, 20, 45-59. **(south-west England)**

Martin, M.H., Beckett, C.L. 1992. Heavy metal pollution in the Severn estuary. Proceedings of the Bristol Naturalists' Society, 50, 105-112. **(Severn)**

Mason, A.Z. and Simkiss, K. 1983. Interactions between metals and their distribution in tissues of *Littorina littorea* (L.) collected from clean and polluted sites. Journal of the Marine Biological Association of the United Kingdom, 63, 661-672 **(Fal, Menai Straits)**

Middleton, R. and Grant, A. 1990. Heavy metals in the Humber Estuary: *Scrobicularia* clay as a pre-industrial datum. Proceedings of the Yorkshire Geological Society, 48, 75-80. **(Humber)**

Miller, B.S. 1986. Trace metals in the common mussel *Mytilus edulis* (L.) in the Clyde estuary. Proceedings of the Royal Society of Edinburgh, 90B, 377-391. **(Clyde)**

Millward, G.E., Marsh, J.G. 1986. Dissolved arsenic behaviour in estuaries receiving acid mine wastes. In: Lester, J.N., Perry, R., Sterritt, R.M., editors. Proceedings of the international conference on chemicals in the environment. p.470-477. Selper. London. **(Tamar, Fal)**

Morris, A.W., 1984. The chemistry of the Severn Estuary and Bristol Channel. Marine Pollution Bulletin, **15**, 57-61. **(Severn - Bristol Channel)**

Morris, A.W. and Bale, A.J. 1975. The accumulation of cadmium, copper, manganese and zinc by *Fucus vesiculosus* in the Bristol Channel. Estuarine and Coastal Marine Science, 3, 153-163. **(Severn-Bristol Channel)**

Morris, A.W., Bale, A.J., Howland, R.J.M., Millward, G.E., Ackroyd,D.R., Loring, D.H., Rantala, R.T.T. (1986). Sediment mobility and its contribution to trace metal cycling and retention in a macrotidal estuary. Water Science and Technology,18, 111-119. **(Tamar)**

Murray, A.J. 1982. Trace metals and organochlorine pesticide and PCB residues in mussels from England and Wales, 1978. Chemistry in Ecology, 1, 33-45. **(Mussels)**

Murray, L.A., Norton, M.G., Nunny, R.S. and Rolfe, M.S. (1980). A field assessment of the effects of dumping wastes at sea: 6. The disposal of sewage sludge and industrial waste off the River Humber. MAFF Fisheries Research Technical Report, no. 55, 35 pp. **(Humber)**

Nelson, L.A. (1979). Minor elements in the sediments of the Thames Estuary. Estuarine and Coastal Marine Science, 9, 623-629. **(Thames)**

Nickless, G., Stenner, R. and Terrille, N. 1972. Distribution of cadmium, lead and zinc in the Bristol Channel. Marine Pollution Bulletin, 3, 188-190. **(Severn-Bristol Channel)**

Owens, M. 1984. Severn Estuary - an appraisal of water quality. Marine Pollution Bulletin, 15, 41-47. **(Severn)**

Ozoh, P.T.E. (1992). The importance of adult *Hediste (Nereis) diversicolor* in managing heavy metal pollution in shores and estuaries. Environmental Monitoring and Assessment, 21, 165-171. **(Humber)**

Peden, J.D., Crothers, J.H., Waterfall, C.E. and Beasley, J. 1973. Heavy metals in Somerset marine organisms. Marine Pollution Bulletin, 4, 7-9. **(Bristol Channel)**

Perkins, E.J., Gilchrist, A.R.S., Abbott, O.J. and Halcrow, W. (1973). Trace metals in Solway Firth sediments. Marine Pollution Bulletin, 4, 59-61. **(Solway)**

Preston, A., Jefferies, D.F., Dutton, J.W.R., Harvey, B.R. and Steele, A.K. 1972. British Isles coastal waters: the concentrations of selected heavy metals in sea water, suspended matter and biological indicators - a pilot survey. Environmental Pollution, 3, 69-82. **(Seaweed)**

Radford, P.J.,Uncles, R.J. & Morris, A.W. 1981. Simulating the impact of technological change on dissolved cadmium distribution in the Severn Estuary. Water Research, **15**, 1045-1052. **(Severn)**

Riley, J.D. and Towner, J.V. 1984. The distribution of alkyl lead species in the Mersey Estuary. Marine Pollution Bulletin, 15, 153-158. **(Mersey)**

Rostron, D.M., Little, D.I., Howells, S.E. 1986. A study of the sediments and communities in Milford Haven, Wales. Oil and Chemical Pollution, 3, 131-136. **(Milford Haven)**

Say, P.J., Burrows, I.G., Whitton, B.A. 1986. Use of estuarine and marine algae to monitor heavy metals. Final report to Department of the Environment. Volumes 1 and 2. 26p.; 104p. Northern Environmental Consultants. Consett. **(Range of UK estuaries)**

Shackley, S.E. 1986. Trace metal inputs to an industrialized embayment related to concentrations in benthic fauna and sediments. Rapports et Proces-verbaux des Reunions. Conseil International pour l'Exploration de la Mer, 186, 449-467. **(Swansea Bay)**

Shillabeer, N. and Tapp, J.F. 1989. Improvements in the benthic fauna of the Tees Estuary after a period of reduced pollution loadings. Marine Pollution Bulletin, 20, 119-123. **(Tees)**

Simpson, R.D. 1979. Uptake and loss of zinc and lead by mussels (*Mytilus edulis*) and relationships with body weight and reproductive cycle. Marine Pollution Bulletin, 10, 74-78. **(Tyne, Coquet)**

Soulsby, P.G., Lowthian, D. and Houston, M. 1978. Observations on the effects of sewage discharged into a tidal harbour. Marine Pollution Bulletin, 9, 242-245. **(Portsmouth Harbour)**

Southgate, T., Slinn, D.J. and Eastham, J.F. 1983. Mine-derived metal pollution in the Isle of Man. Marine Pollution Bulletin, 14, 137-140. **(Isle of Man)**

Taylor, D. 1979. The effect of discharges from three industrialized estuaries on the distribution of heavy metals in the coastal sediments of the North Sea. Estuarine and Coastal Marine Science, 8, 387-393. **(Tees, Tyne, Humber)**

Taylor, D. 1986. Changes in the distribution patterns of trace metals in sediments of the Mersey Estuary in the last decade (1974-83). The Science of the Total Environment, 49, 257-295. **(Mersey)**

Tomlinson, D.L., Wilson, J.G., Harris, C.R. and Jeffrey, D.W. 1980. Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. Helgolander Meeresunters, 33, 566-575. **(General)**

Topping, G. 1983. Guidelines for the use of biological material in first order pollution assessment and trend monitoring. Department of Agriculture and Fisheries for Scotland. Marine Laboratory. Scottish Fisheries Research Report, 28 ISSN 0308 8022, 28 pp. **(General)**

Wharfe, J.R. and Van Den Broek, W.L.F. 1977. Heavy metals in macroinvertebrates and fish from the lower Medway Estuary, Kent. Marine Pollution Bulletin, 8, 31-34. **(Medway)**

Wilson, J.G. 1983. The uptake and accumulation of Ni by *Cerastoderma edule* and its effect on mortality, body condition and respiration rate. Marine Environmental Research, 8, 129-148. **(Cockles)**

Wilson, K.W., Head, P.C. and Jones, P.D. 1986. Mersey Estuary (UK) bird mortalities - cause, consequences and correctives. Water Science Technology, 18, 171-180. **(Mersey)**

Windom, H.L., Schropp, S.J., Calder, F.D., Ryan, J.D., Smith, R.G.Jr., Burney, L.C., Lewis, F.G. and Rawlinson, C.H. 1989. Natural trace metal concentrations in estuarine and coastal sediments of the southeastern United States. Environmental Science and Technology, 23, 314-320. **(Sediments)**

Yim, W.S. 1972. A further investigation on the distribution of certain elements in the sediments of the Fal Estuary, Cornwall. Camborne School of Mines Magazine, 72, 29-35. **(Fal)**

Yim, W.W.-S. 1976. Heavy metal accumulation in estuarine sediments in a historical mining, of Cornwall. Marine Pollution Bulletin, 7, 147-151. **(Hayle)**

APPENDIX A

PML METAL-MAPPING PROGRAM INSTRUCTIONS

CONTENTS

A.1 Installation

1. Computer must be IBM compatible and have WINDOWS installed.

2. In WINDOWS click on **File** and then **Exit** to give the DOS prompt.

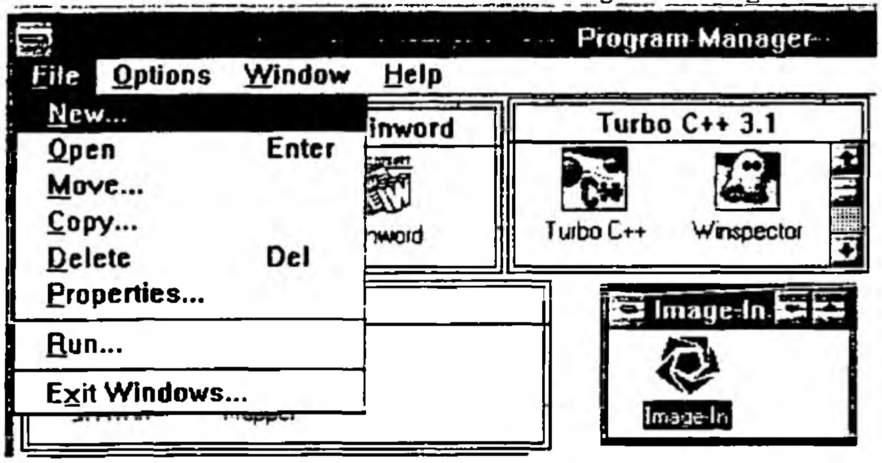
3. INSERT DISK

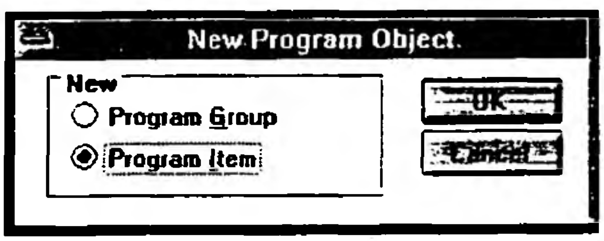
4. Type **A:** and **Enter**

5. Type:- **INSTALL C:\MAPS C:\WINDOWS** to copy the files from the disk. The first parameter given to **INSTALL** is the directory to which the files will be copied, the second is the Windows directory.

6. Type:- **C:** and **Enter** followed by **WIN** and **Enter** at the prompt to start WINDOWS.

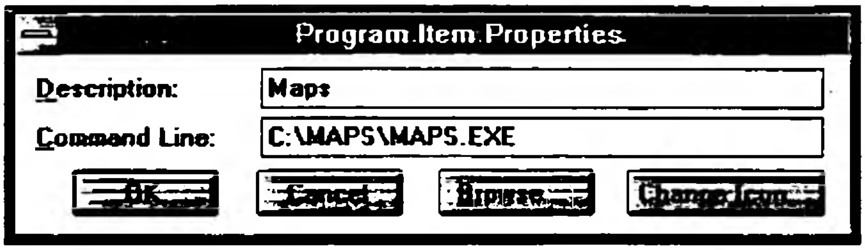
7. Select **New** from the **File** menu in the Program Manager (below)





8. Select **Program Group**, **OK** and type **Maps** in **Description**.

9. Select **New** from the **File** menu in the Program Manager and then select **Program Item**, **OK**.
   a. Type **Maps** in Description Box
   b. Type **C:\MAPS\MAPS.EXE** (if program installed in the directory MAPS) in Command Line box and **OK** (see below).



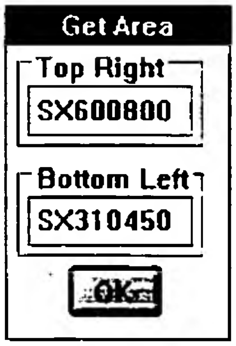
10. The DOS utility **SHARE** has to run to enable the program to support file sharing. To install **SHARE** insert a line with the word SHARE in your **AUTOEXEC.BAT**. The program will run without **SHARE** as long as no other task attempts to access the database file in use.

A.2 Getting Started : A quick guide to using the program.

Ideally the user should have maps from which the co-ordinates can be read. (see Page 54)

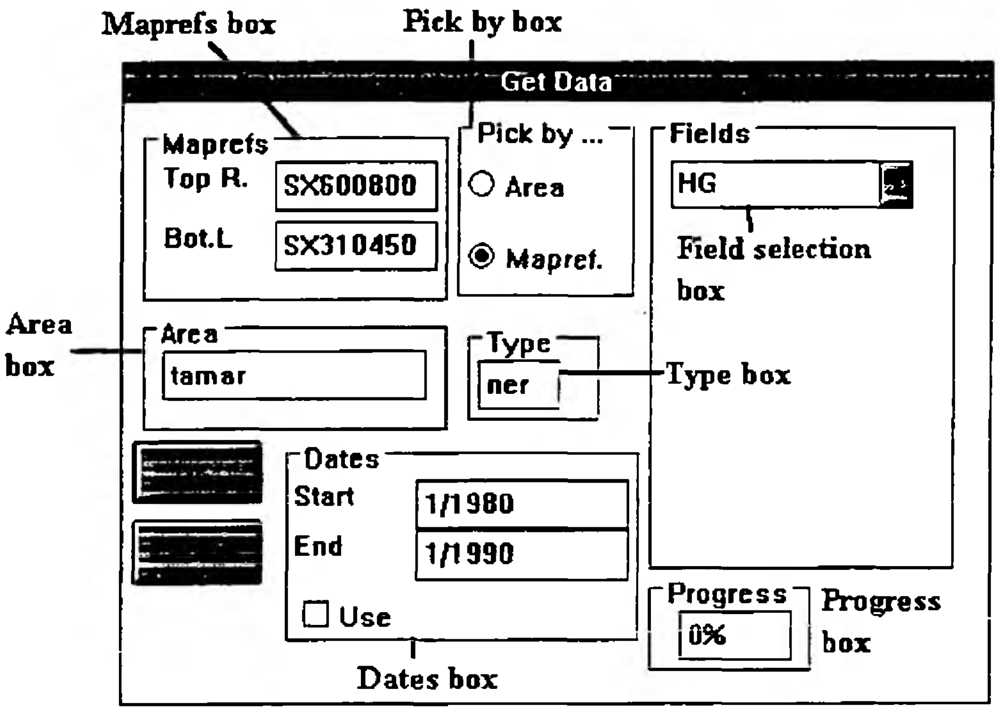
1. Double click on the icon for the **Maps** program.

2. When the program has loaded and the **Mapper** window is displayed select **Get Area** from the **File** menu. This will display a dialogue enabling the user to enter the map references.



3. On entry to this dialogue box the cursor will be in the bottom of two text fields. Delete the existing text and enter **SX310450** in the bottom field, labelled Bottom Left. Pressing **TAB** will cycle through the fields. So by pressing **TAB** twice the top text field, labelled Top Right, will be highlighted. If the user then presses the **Delete** key the existing entry will be deleted, and **SX600800** can then be entered in this top field. Click on **OK** and a map of the Plymouth area will be displayed on the screen.

4. Select **Read data** from the **Marks** menu. A **File Selection Dialogue** will then be displayed. This box will display all the dBase (*.DBF) files in the current directory. Select the file **SOUWEST.DBF** by clicking on this file name and then selecting the **OK** button, or by double clicking on the file name **SOUWEST.DBF**.
   The dialogue box below will then be displayed. In the box labelled **Maprefs** the coordinates of the currently displayed map will be presented. If the user then clicks on the button labelled **Mapref** in the box to the right of the map references the program will only extract values for sites contained in the area of the displayed map.

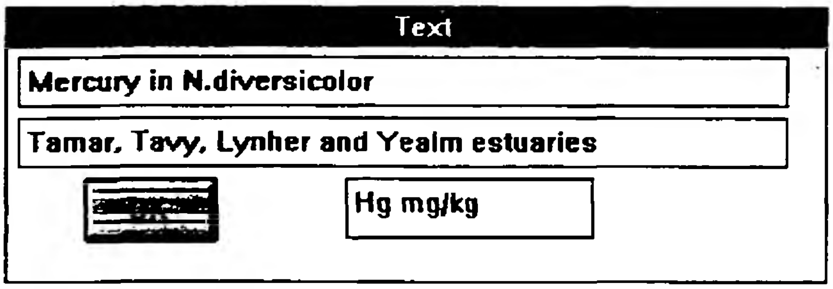


5. In box headed **Type** type in **ner** (*Nereis diversicolor*). See Page 58 for whole list

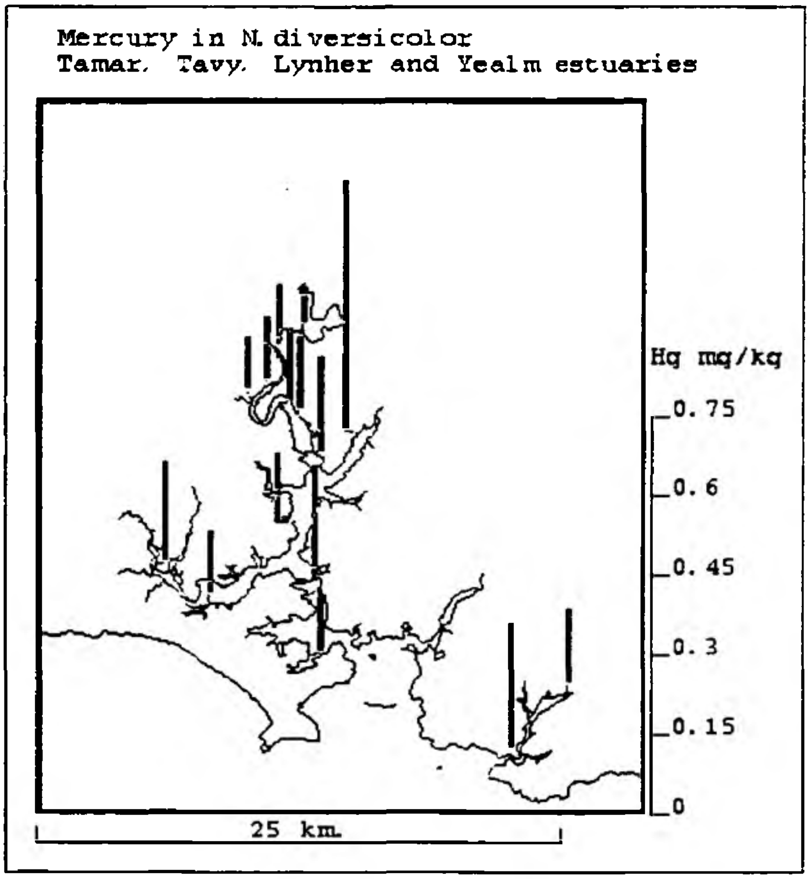
6. In **Fields** box click on the down-wards pointing arrow on the right and select the metal **HG** (Mercury) from the displayed metals.

7. Click on **OK** and wait. The **Progress** box shows the percentage of the database read so far. A map of the Plymouth area appears with concentration bars.

8. Select **Move Marks** from the **Marks** menu. A bar will start flashing and can be positioned with cursor keys on keyboard. Press **Enter** when each bar is correctly positioned. To abort the process press **Esc**. If a flashing bar does not respond to **Enter**, press **Control - Break**, followed by No and then **Enter.**



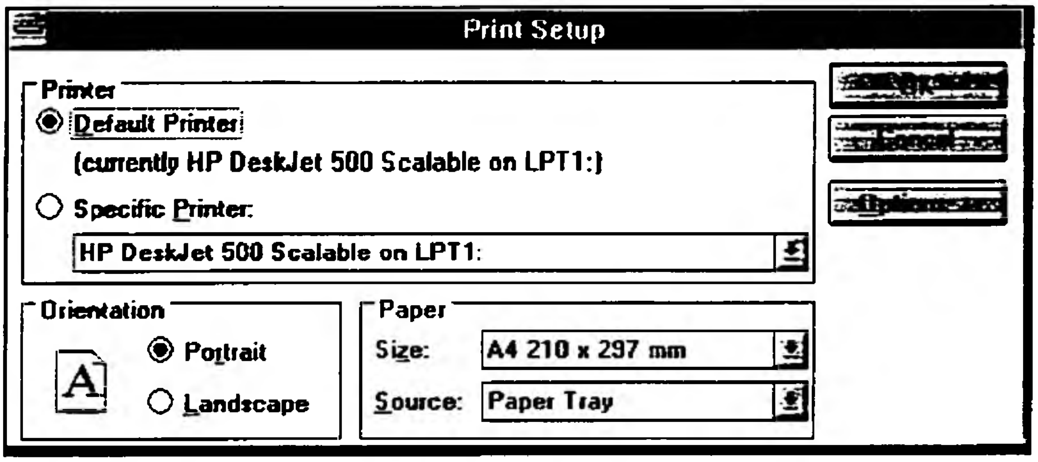
9. Select **Text** from the **Text** menu and type in the text displayed above. The top two boxes are the text displayed above the map, the bottom box is the text displayed over the metal concentrations scale bar. When finished click on **OK**. A map similar to the one displayed below should now be visible.



10. To save the map to disk select **Save** from the **File** menu. Go to **File Name** in the dialogue box and type **NER_HG.DAT** and select **OK**.

A.2.1 Printing

To configure the printer select **Setup printer** from the **File** menu. This will display the dialogue below. This dialogue enables the paper orientation to be changed. With some printer drivers the Portrait and Landscape options will be greyed out. In this case the program will be incapable of altering the printer driver and any alterations will have to be made using the Windows Control Panel.



Select **Print** from the **File** menu, then select **Thin** from the dialogue that is displayed to print the map.

To exit the program select **Quit** from the **File** menu and then click on the **Yes** box of the "Are you sure" box.

A.2.2 Viewing Data

These data are contained in a dBase 3 format (.DBF) database file. These data can be read by most IBM database programs. With databases other than **dBase**, Paradox, for example, dBase 3 files can be read, usually by importing the data.

A.3 Program Overview.

The program is designed to display graphically, spatial information on metal concentrations in U.K. estuaries An IBM compatible computer with Microsoft Windows (Version 3.0, or later) is required. The computer should be capable of running Windows in **Standard** or **386 Enhanced** Modes. A 386SX computer with two or more megabytes of system memory, a hard disk and mouse should be regarded as the minimum practical configuration. Hard disk installation uses approximately 2 megabytes of storage.

The program will display user-definable maps of heavy-metal distributions on the screen of the computer or on an attached graphics printer. Concentrations of heavy metals are presented as vertical bars that are moveable. Areas and sites are defined by Ordnance Survey map references. Files supplied with the program contain the entire coast-line of England and Wales in a high-resolution format, and the entire mainland U.K. in a lower resolution. Supplied with the program are dBase 3 format database files containing metal concentration data in organisms and sediments in various NRA regions.

Region	**Filename**	**O.S. Grid Squares**
North West	N_WEST.DBF	NY, NX, SD, SJ
Welsh	WELSH.DBF	SH. SJ.SM, SN, SO, SR, SS. ST
South West	SOUWEST.DBF	SV. SW, SX, SS, SY
Wessex	WESSEX.DBF	SS. ST. SU, SY, SZ
Southern	SOUTHERN.DBF	SU, SZ. TQ, TR, TV
Anglian	ANGLIAN.DBF	SE. TA, TF, TG, TL, TM. TQ, TR
Yorkshire	YORKS.DBF	SE. TA, NZ
Northumbria	NORTHUMB.DBF	NT. NU, NZ

The database files need to possess the following fields :

FIELD NAME	**DESCRIPTION**
SITE	Name of site.
AREA	Name given to a grouping of sites, usually an estuary name. (See **Area box** P.57)
MAPREF	The Ordnance Survey map reference of the site.
YEAR	The year the sample was collected, format YYYY (i.e. 1992).
MONTH	The month the sample was collected (1 - 12)
TYPE	A three character abbreviation representing the sample type, (See **Type box** P.58).

These are followed by fields containing concentrations of heavy-metals, Ag, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn, Hg, As, Sn (µg/g dry wt.), and sediment organics (%). As most DOS database programs are capable of reading dBase 3 format database files, these files can be viewed and/or edited with virtually any other database program. However to remain compatible with this program the files **must** retain the above-mentioned fields, and be saved as dBase 3 format files. **Commas must not be included in any text fields.**

The program can search these files using various methods. However, it always requires the user to enter a three character abbreviation into the **Get Data** dialogue box (**Type** field) specifying the sample type for retrieval (See **Type box** P.58) and a metal must be selected in the **Fields** box. The program will use the mean value of all valid (>0) metal concentrations found for each retrieved map reference.

The methods of data retrieval are:.

1: By map references, usually those of the displayed map. Data for any sites contained in a box defined by the two map references will be retrieved by the program. These numbers are displayed on entry to the data retrieval section of the program. They can be changed by the user, but the program will always, by default, use the co-ordinates of the displayed map. On re-entry to the **Get Data** dialogue box any references changed by the user will be replaced by the co-ordinates of the displayed map.

2: By named area. The program will search the database and retrieve only those sites from the specified area name (See **Area box** P.57).

3: In addition to these two methods of data retrieval, the user can define a starting and ending date for the data. Only those data collected between these two dates will be retrieved (including the starting and ending months). The dates supplied must match the date format used in the database, **MM/YYYY** (e.g. 12/1992).

Maps created by the program can also be saved as ASCII files containing all the data used by the program to create the map. These files, with a **.DAT** file extension can be loaded into the program at a later date to re-create the map in one step, or imported into a Word Processor. The format of these files is as follows;

The first line **must** contain the string "Map Data File". This is used by the program as a check for the correct file format.
This is followed by three lines containing the various titles displayed with the map, the first two being those displayed above the map and the third the title of the metal scale bar.
Two lines contain the map references of the displayed area, **Bottom Left** followed by **Top Right**.
Next there is a line containing the maximum metal concentration displayed.
This is followed by lines containing;
Site Name, Map reference, Metal value, Horizontal bar offset, Vertical bar offset

e.g.

```
Map Data File
Mercury in S.plana
Area SX210510 to SX280600
Hg mg/kg
SX210510
SX280600
0.7696
limit.w.looe,sx236545,0.3941,1,5
opp.ruin,sx238544,0.4073,0,4
boatyard,sx245542,0.7696,-8,1
limit.e.looe,sx247557,0.574,-5,0
op.hut,sx250555,0.5098,0,6
railway.hut,sx251554,0.5294,4,3
1/2.way,sx252548,0.508,6,4
confluence,sx253540,0.4103,22,0
```

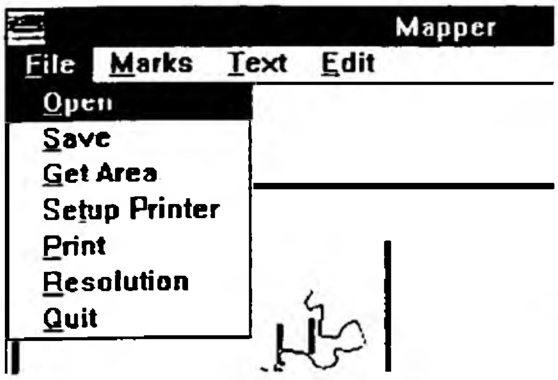
The program expects to be used with screens and graphics printers having a square aspect ratio. That is, the vertical pixels per inch match the horizontal pixels per inch. With devices having a non-square aspect ratio the output will be distorted.

Because the dynamic link libraries used by the program for operation are not re-entrant, only one instance of the program can be run at any time. The program will detect an attempt to run a second instance of itself and display a warning message and abort the second instance.

A.4 Description of Menus

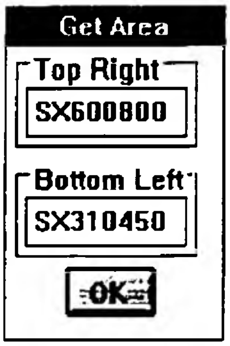
There are four Menu titles with which the program is controlled, these are;

A.4.1 File Menu



Open This presents the user with a File Selection dialogue box which enables the user to select a **.DAT** file. These are files created by the program and contain all the information required to display a map on the screen. This includes the area of the map, the site names, site positions, sizes of any data markers and the text to be displayed. After the file is loaded the map will be drawn on the screen. The program checks to see if the file is of the correct format, and if it is not satisfied an error box will be displayed and the process aborted. The program expects the first line of the file to contain the line "Map Data File".

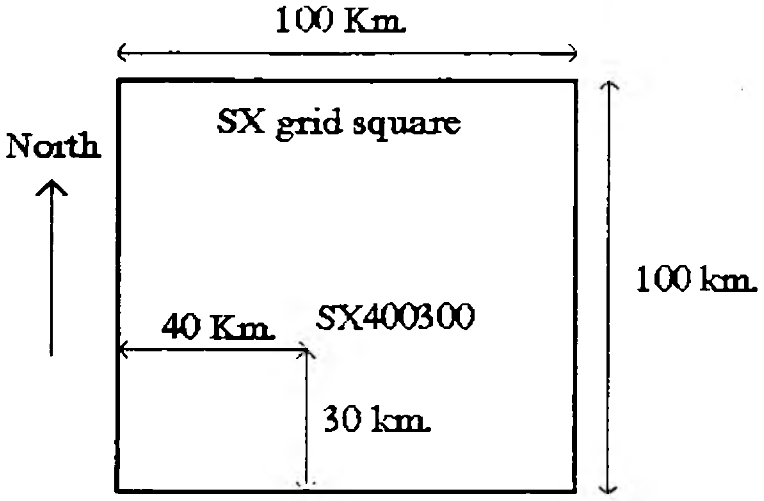
Save This presents a File Selection dialogue box which enables the user to select the name of a **.DAT** file. All the information for the currently displayed map will then be saved to this file. If the file already exists the user will be asked to confirm overwriting it.



Get Area
The above dialogue is displayed and by entering valid map references into the text fields and selecting OK the desired area can be displayed on the screen. If incorrect references are entered a warning will be issued. If the program thinks that the map references have been reversed, **Top Right** in **Bottom Left**, the user will be asked if they wish to swap the references. The minimum size of a map is at least one kilometre square, anything smaller will be ignored.

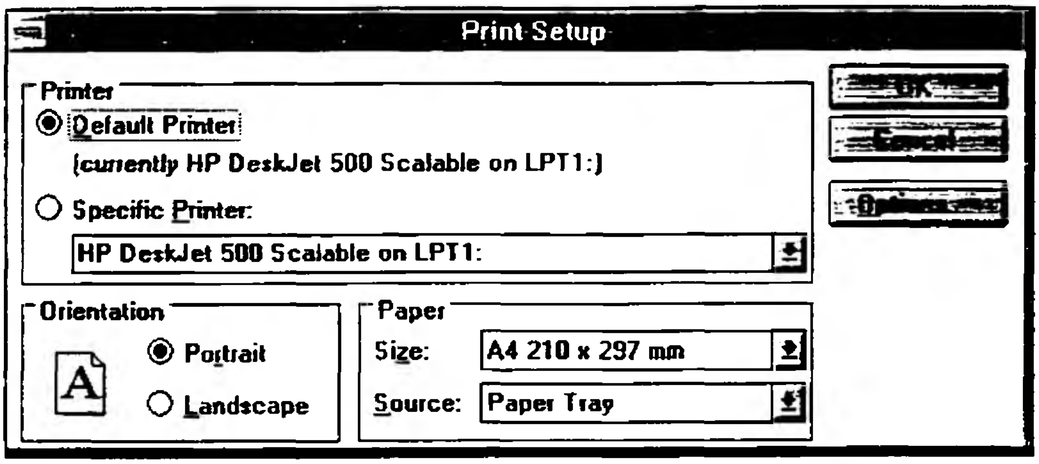
A.4.2 Map References

Map References consist of two parts, the first is a two letter name for the 100 km. square containing the map reference, e.g. **SX**. This is followed by a six digit number. The number is comprised of two three digit numbers, the first three digits are tenths of a kilometre east of the grid-square origin, and the last three digits are tenths of a kilometre north of the grid-square origin.



In the example above, the map reference **SX400300**, is located 40 km. east and 30 km. north of the **SX** square origin.

Setup Printer



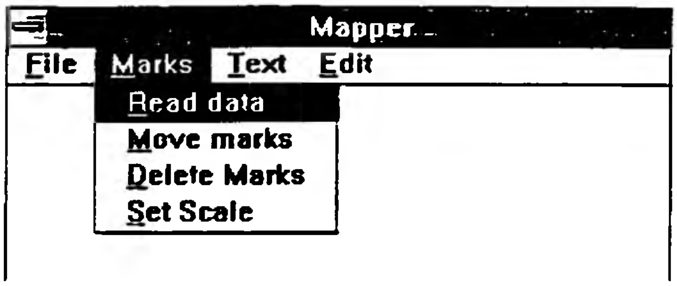
The above dialogue will be displayed enabling the user to alter the paper orientation of the printer. With some printer drivers the **Portrait** and **Landscape** options will be greyed out (un-selectable). In this case the program will be incapable of altering the printer driver, and any alterations will have to made using the Windows Control Panel. After altering the paper orientation the screen window will alter in size to reflect the new paper size.

Print The displayed map will be copied to the printer. The user will be asked whether to use thick or thin lines on the print-out. On high-resolution printers, such as lasers, the thinner lines used to display the map can be too thin to reproduce well on a photo-copier.

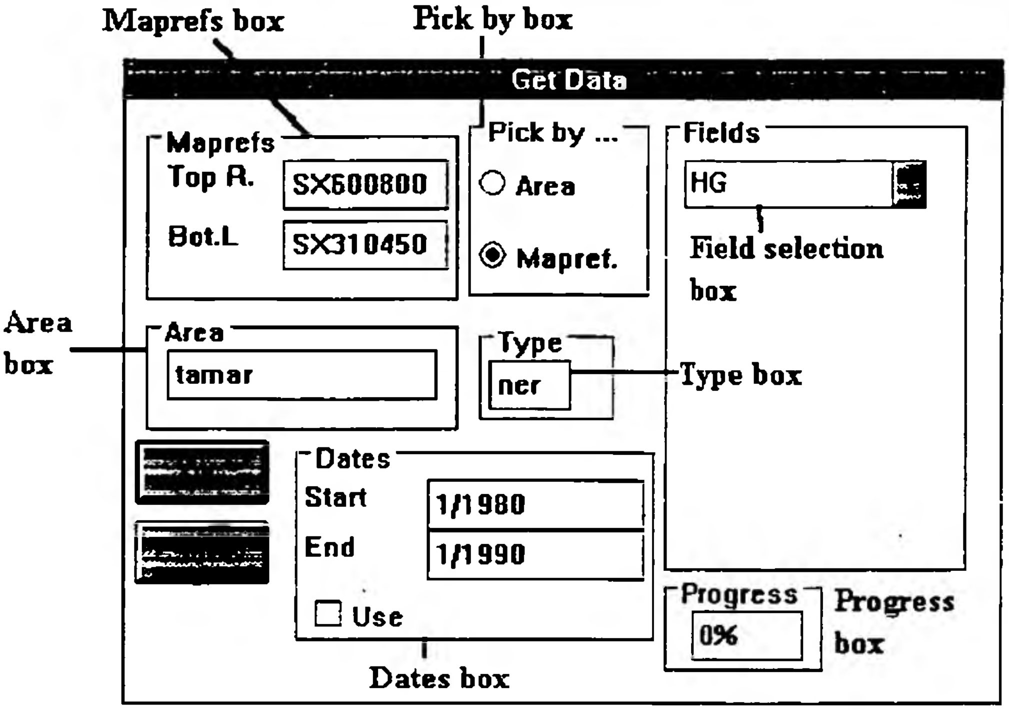
Resolution The user will be presented with a dialogue with two buttons, **High** and **Low**. By selecting either button the program will in future use either high or low resolution map data files. The low resolution files cover the entire country, but in poor detail. Whereas the high resolution files have a more limited coverage but with much better detail. With maps containing many data bars, it is usually easier to position the bars when using low resolution maps.

Quit Terminates the program. The user will be asked to confirm this action.

A.4.3 Marks Menu



Read Data A File Selection dialogue will be displayed enabling the user to select a dBase 3 (.DBF) file. When the file has been selected the following dialogue will be displayed;



The dialogue is split into seven main groups.

Field selection box This enables the user to select the field from the database that contains the required values. On opening the database, the program reads in all the field names. The metals are shown by their symbols in upper-case. On opening the dialogue, only the top of the Combo Box will be displayed. By clicking on the downwards pointing arrow on its right side a scroll box displays all the field names. The selection is made by clicking on the desired metal. The box at the top contains the currently selected field.

Pick by box There are two radio buttons (when one button is selected the other is de-selected) displayed in this box, enabling the user to select sites by either the area name (usually the estuary name) or by map references (see **Maprefs**).

Maprefs box If the user has decided to select sites by map references (Mapref button selected) only those sites falling into a box defined by the two displayed map references will be read. Both entries are editable, but on entry are set to the area of the displayed map.

Area box If the user has decided to select sites by area (Area button selected) only those sites with the same area name in the database will be read..

Name	Area	Name	Area
Avon (Devon)	**avon**	Bridlington	**bridlington**
Camel	**camel**	Clyde	**clyde**
S.Cornwall	**cornwall**	Cumbria	**cumbria**
Dart	**dart**	Dee	**dee**
E.Anglia	**e.anglia**	E.Coast	**e.coast**
Erme	**erme**	Whitby	**esk**
Exe & Axe	**exe**	Fal	**fal**
Restronguet Creek	**fal**	Forth	**forth**
Fowey	**fowey**	Gannel	**gannel**
Helford	**helford**	Humber	**humber**
Isle of Wight	**iow**	E. & W. Looe	**looe**
Mersey	**mersey**	St.Ives Bay	**n.cornwall**
North West	**n.west**	Plym	**plym**
Poole Harbour	**poole**	S.Coast	**s.coast**
S.Wales	**s.wales**	Kingsbridge	**salcombe**
Scarborough	**scarborough**	Isles of Scilly	**scilly**
Severn Estuary	**severn**	Solway Firth	**solway**
Southampton area	**soton**	Tamar Lynher & Tavy	**tamar**
Tees	**tees**	Teign	**teign**
Thames & Medway	**thames**	Torbay	**torbay**
Taw & Torridge	**torridge**	Tyne & Northumbria	**tyne**
N. & Mid Wales	**wales**	Wash	**wash**
Yealm	**yealm**		

Type box The three letter abbreviation corresponds to a type of sample (See Appendix 1). Values for only that sample type will be read from the database.

List of samples

Type	Species
cer	*Cerastoderma edule*
fuc	*Fucus vesiculosus*
lit	*Littorina littorea*
mac	*Macoma balthica*
mya	*Mya arenaria*
myt	*Mytilus edulis*
ner	*Nereis diversicolor*
nuc	*Nucella lapillus*
obt	*Littorina littoralis*
pat	*Patella vulgata*
sax	*Littorina saxatalis*
scr	*Scrobicularia plana*
sed	Sediment Nitric acid extract
ser	*Fucus serratus*

Dates box Gives the user the option of limiting the selection of data to a period of time. The dates in the two text boxes can be changed, but the format must be "mm/yyyy" (Numeric month / full numeric year, i.e. 1/1971). To select data using dates the **Use** button must be checked (click on with mouse to toggle).

Progress box When all selections have been made and the **OK** button clicked this will display the percentage of the database that has been read.

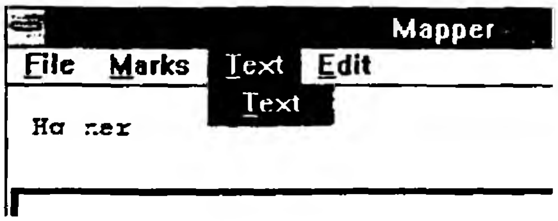
If the user selects cancel on either the **File Open dialogue** or the **Get Data dialogue** any existing marks will remain valid. After new data have been read from the database the program will offset the data bars slightly to the right to enhance the visibility of any small bars.

Move Marks Enables the user to move the data marks on the screen. Each data marker will be seen to flash on the screen in turn. The mark can be moved using the **Cursor Keys**. Pressing **Enter** will select the next data marker. Pressing **Esc** will abort the process. Occasionally, it may be difficult to see very small marks flashing: this is usually overcome by using the **Cursor Keys** to reveal the mark. In addition, if the data have been selected by area rather than map references it is possible that some of the data will be displayed outside the visible area. In this case, the user will have to press **Enter** until a bar is seen flashing. If the flashing bar does not respond to **Enter**, press **Control - Break** followed by **No** and then **Enter**.

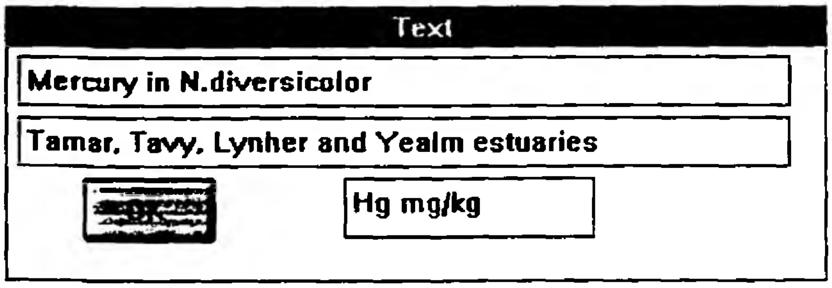
Delete Marks Enables the user to remove all the marks from the map. The user will be asked to confirm this action.

Set Scale The height of the scale bar on the map is normally determined by the maximum value of the selected data. To produce maps having the same concentrations scales the number displayed in the dialogue should be changed to the same value for each of the maps.

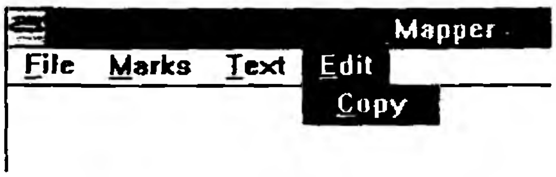
A.4.4 Text Menu



This menu has only one option **Text**. Selecting this will display the following dialogue box enabling the user to alter the titles displayed on the map. The top two items are the titles displayed above the map, and the bottom item is the legend for the metal scale bar.

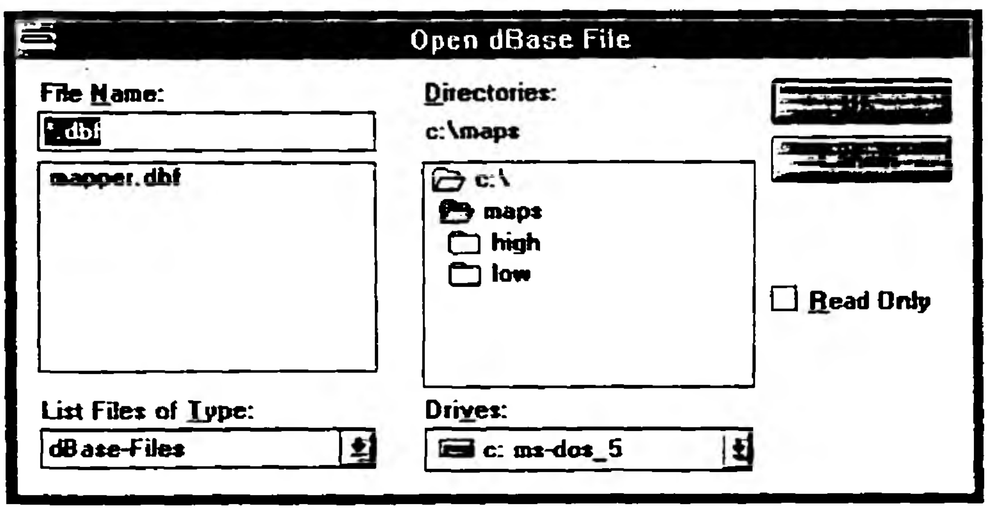


A.4.5 Edit Menu



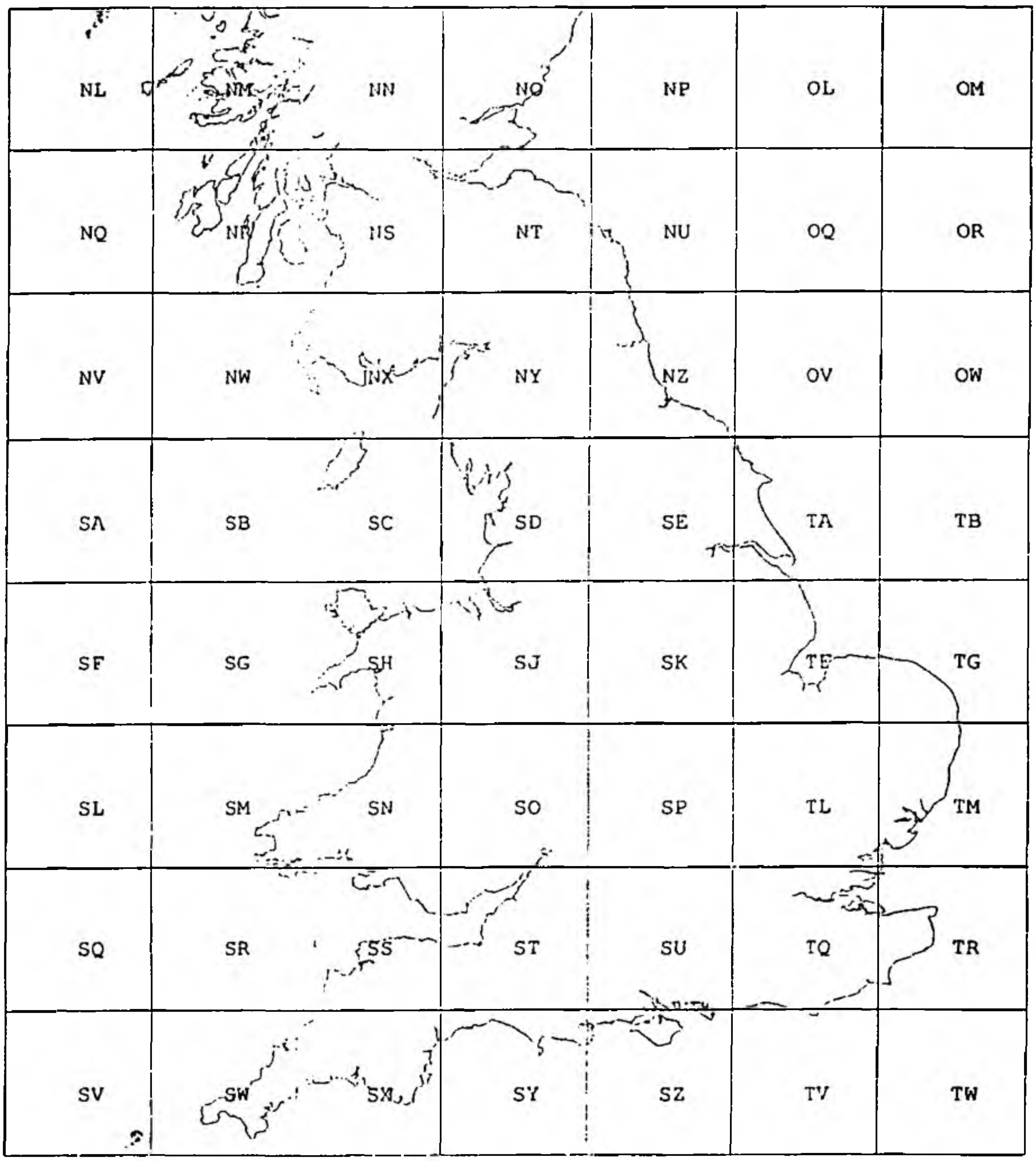
This menu has one option **Copy**. Selecting this will copy a bit-image of the displayed screen to the Windows Clip-board. This can then be pasted into other applications.

A.4.6 File Selection Dialogues



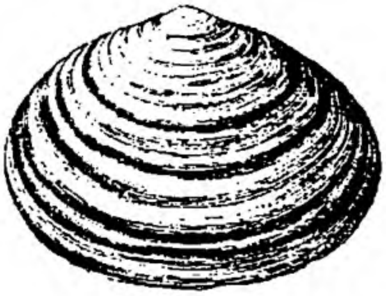
This dialogue will display only those files with a file extension matching the specified type. To change directory double click on entry in the **Directories** box. In the example above double

clicking on the c:\ will change to the root directory of drive C:. To change to new drive click on the arrow to the right of the **Drives** box, a list of all available drives will then be displayed.
To select a file that already exists click on its name in the file list box. To create a new file its name must be typed into the top left box (contains *.dbf in the example above). Selecting **OK** will close the dialogue and open the selected file. **Cancel** aborts the process.



Ordnance Survey grid squares

Macoma balthica



Scrobicularia plana

(Both natural size.)