NATIONAL RIVERS AUTHORITY

AWDURDOD AFONYDD CENEDLAETHOL

WELSH REGION

RHANBARTH CYMRU

[redacted]

AAC

NRA

Guardians of the Water Environment

Diogelwyr Amgylchedd Dŵr

Results of the NRA Welsh Region

Marine Bioaccumulation Programme

1991-1995

SE/EAU/95/9

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REPORT SUMMARY

1. A marine bioaccumulation study at 30 sites around the Welsh coastline with *Fucus vesiculosus, Mytilus edulis* and *Cerastoderma edule* as the target species, for a suite of determinands consisting of trace metals and organic compounds, commenced in 1993. Prior to that some bioaccumulation studies had been carried out, but at a limited number of sites mainly in South Wales (Swansea Bay and the Severn Estuary). Bioaccumulation is an useful addition to water quality monitoring, as substances that only exist in very low levels in the environment (such as trace metals and organic compounds), can be detected in tissue. Results have to be interpreted very cautiously however, to put them into context, as there are no Environmental Quality Standards for bioaccumulation.

2. NRA standard methodology has been used.

3. Higher levels (compared to the rest of the Welsh Coastline) of Copper, Zinc, Mercury, Lead and Nickel were found in each target organism associated with the industrial embayments, such as Swansea Bay and within the two major estuaries of Wales - the Dee and the Severn. In comparison with the earlier Welsh Water Authority Tidal Waters Bioaccumulation Programme 1978/1979 data (Welsh Water Authority, 1982; Appendix V), the spatial variations found in this report are very similar and can be linked mainly to anthropogenic inputs from the heavy industries, such as metal refining and coal-mining. 'Natural' inputs, associated with old metalliferous mining areas and discharged via rivers draining these areas, are also a factor and give rise to localised elevations in otherwise clean areas e.g. the levels of lead in *Mytilus edulis* at Castlerocks, Aberystwyth, which is affected by the Ystwyth and Rheidol catchments that drain old metalliferous mining areas.

4. Some areas within Wales have been identified as having had the maximum UK concentrations for some metals (Burt *et al.*, 1992) and included:
   i) Cadmium concentrations in the Severn
   ii) a maximum lead concentration recorded at Aberystwyth during 1985
   iii) elevated chromium concentrations in the Loughor Estuary.

   For all other metals, the highest levels were from the Cornwall metalliferous mining areas. These levels were orders of magnitude above the Welsh levels.

5. There is some evidence that concentrations of Zinc, Cadmium and Nickel in the shellfish species from Burry Inlet, Swansea Bay and the Severn Estuary have reduced over the years. This is probably linked to the decline in heavy industries, such as metal refining and coal-mining, in those areas and pollution abatement measures.

6. Copper was found in higher concentration in *Mytilus edulis* than in previous years during 1995 only. As the levels of Copper in *Fucus* in 1995 were similar to previous years then this may not reflect a real increase in the environment. However, a sharp rise in Copper, Lead, Arsenic and Nickel in *Cerastoderma edule* from the Burry Inlet site of the Loughor Estuary during '94 and '95 probably does reflect a real increase. A spatial survey needs to be performed in '96 to investigate this, in order to determine any recent point source input of these metals to the estuary.

7. Because the conclusions about temporal trends can only be tentative, due to the variability of bioaccumulation data, the Regional Permissive bioaccumulation programme needs to be continued at its current level annually and within the same time period each year. If for any reason sampling has to be performed outside of the sampling window i.e. later than mid February, then it would be better to cancel the survey for that year, rather than collect data that may be spurious.

8. Concentrations of some organic compounds (Chloroform, pp'-TDE and PCB congener 153) above the routine analytical detection limits were recorded at some sites in *Fucus vesiculosus* and *Mytilus edulis* in '94 and '95. All other data i.e. at all sites around the coastline for each species from '91-'95, was below the limits of detection for the suite of organic compounds.

1.0 INTRODUCTION

Bioaccumulation studies are a useful tool for monitoring the concentration of heavy metals and trace organic compounds in the environment. The process of bioaccumulation is well researched and established and can be used to indicate the levels of contaminants in the environment even when they are intermittent or are present in such low levels in the water column as to be below the detection limits of routine analytical techniques. There are recommended target organisms in the marine environment (Barnett, 1990) that the NRA has standardised on:

i) *Fucus,* a brown seaweed that lives on rocky shores in the intertidal zone. It extracts nutrients etc. direct from the water column and the chemical loadings accumulated, consequently reflect the substances dissolved in the water column.

ii) *Mytilus edulis*, the common mussel, that lives attached to the substrate in the intertidal zone. It is a filter feeder that feeds directly from particulate matter suspended in the water column. It therefore reflects the particulate load of contaminants and is a good measure of substances (such as mercury and PCBs) that adsorb onto particulate matter.

iii) *Cerastoderma edule*, the cockle, has been measured at some sites because of its importance as an edible shellfish. It burrows in the substrate and therefore reflects the sediment load of contaminants.

There are no environmental quality standards for substances that are accumulated. The analytical results can only be interpreted by reference to historical information for the locality, if there is any, or by comparison to any available Regional data or by reference to the published literature. There are many factors that can affect bioaccumulation independent of the amount of that substance occurring in the environment e.g. the age of the organism, reproductive state and seasonality. The recommended NRA methodology (Barnett, 1990) takes into account these factors and standardises the size of individuals to be collected and the time of year (February), in order to reduce those variables that may affect the quality of the results. In the case of seaweed only certain tissues are dissected out and analysed.

The bioaccumulation programme is an useful measure of the state of an estuary or section of coastline but the results must be interpreted carefully by comparison, preferably to historical information for the same sites, or in the context of comparison to other sites around the coastline. The programme is intended to be a long-term monitoring programme of sites around the whole Welsh coastline that sets up a database of information upon which to compare spatial and temporal trends.

1.1 Programme development

Following an initial extensive Welsh Water (Tidal Waters Section) marine bioaccumulation sampling programme (Welsh Water Authority, 1982) carried out between 1978-1979 at 51 sites around the Welsh Coastline, a reduced monitoring programme, involving annual sampling from 8 sites within the Severn Estuary and Bristol Channel was implemented from 1982-1988. *Fucus vesiculosus, Mytilus edulis* and *Cerastoderma edule* (in various combinations dependent upon which species were present at each site) were the target organisms, which were analysed for heavy metals only.

In 1991, this programme was merged with the Severn Estuary Baseline Marine Monitoring Programme (which subsequently became part of the National Marine Monitoring Programme) as the site location requirements overlapped, and sampling for the Dee Estuary Baseline Marine Monitoring Programme (and subsequently the National Marine Monitoring Programme) commenced. The analytical suite was expanded to include not only the same heavy metals but a range of organics also.

From 1993 onwards the number of sites was increased to 30 (Table 1, Fig. 1) in order to obtain a more extensive distribution of sites around the Welsh coastline. These sites will continue to be sampled as part of the Welsh Regional Permissive Bioaccumulation monitoring programme established in 1994, in order to build up baseline data, upon which any spatial and temporal trends can continue to be measured.

2.0 METHODOLOGY

2.1 Historical Information

Detailed methodology is not described here (Welsh Water Authority Tidal Waters Section, 1982), but the key difference is that historically, 50 shellfish and 50 subsamples of *Fucus* from each site were analysed separately to give 50 analytical determinations per site for each metal. These have been summarised for 1982-1988 inclusive and reported in a data summary report (Brown, 1989). The data have been presented as histograms of the maximum annual mean for each metal in the results section.

2.2 Baseline Bioaccumulation Survey and National Marine Monitoring Programme Survey

The bioaccumulation methodology recommended in the 'NRA Baseline Estuary and Coastal Waters Monitoring Programme' (summarised in Davies, 1992 - Appendix I) was followed with a minor amendment i.e. the number of shellfish was increased from 50 to 100 per site to ensure that enough tissue was available for analysis.

Essentially, tissue was gathered (shellfish and *Fucus*) by Pollution Control and EAU staff throughout the Region in February of each year. The shellfish samples were submitted to EAU staff in the North and South West Areas, on the same day of collection, for depuration in clean seawater for the specified time period for each species (3-5 days). After cleansing, all samples were submitted to the Llanelli laboratory for analysis. *Fucus* samples were submitted direct to the Llanelli laboratory for cleansing, processing and subsequent analysis.

Unlike the historic data (1982-1988), the tissue for each species from each site was pooled to give a single result for each determinand. This change in methodology was necessary as the costs of analysing 50 shellfish and 50 *Fucus* sub-samples per site for an extensive suite of metals and organics was prohibitive. However, the Cardiff Flats site was analysed by both methods (for the metals suite only and from '94 onwards for Cadmium only) as required for Dangerous Substances Directive reporting purposes (List 1 monitoring).

In the North, where F. vesiculosus was not available *F. serratus* and *F. spiralis* have been substituted instead, although they may not be directly comparable to *F. vesiculosus.*

3.0 METALS DISTRIBUTION

3.1 Spatial Variations

Data are presented graphically by species for each metal i.e. copper, zinc, cadmium, mercury, lead, arsenic, chromium and nickel in ug/g dry weight (Figs. 2-25) and values tabulated in Appendices II, III and IV.

3.1.1 *Fucus spp.*

i) Copper (Cu)

Copper levels in *F. vesiculosus* ranged overall from a minimum value of 2.8 ug/g at Goodwick in 1993 to a maximum of 39.0 ug/g at Beachley Slip in 1991. Recorded levels in *F. spiralis* and *F. serratus* in the North, lie within this range. In general, the Copper concentrations were highest on the South Wales Coast, increasing from Burry Port eastwards and upstream along the Severn Estuary (Fig. 2). A similar pattern, but to a lesser extent, appeared in the North with concentrations increasing eastwards towards the Dee Estuary.

ii) Zinc (Zn)

Zinc levels in *Fucus* (minimum 41 ug/g at Nolton Haven in 1995; maximum 973.0 ug/g at Beachley Slip in 1991) had a similar spatial distribution to Copper levels i.e. increasing from the industrial embayments in North and South Wales to maximum values in the Dee and Severn Estuaries (Fig. 3). High levels (comparable to the Dee Estuary) have also been recorded in the Cardigan Bay area.

iii) Cadmium (Cd)

Cadmium levels in *F. vesiculosus* are very low at most sites around the Welsh coastline but increase markedly from Burry Port eastwards to the Severn Estuary. The overall range is from 0.38 ug/g measured at Hilbre Island in 1994, which is typical of values around most of the coastline, to a maximum of 26.0 ug/g at Beachley Slip in 1991 (Fig. 4).

iv) Mercury (Hg)

Mercury levels are lowest in West Wales and highest within Swansea Bay and the industrial embayments of North Wales and the Severn and Dee Estuaries. Levels in *F. vesiculosus* ranged from 0.012 ug/g at Ferryside in 1994 to 0.191 ug/g at Swansea Bay in 1993 (Fig. 5).

v) Lead (Pb)

Lead in *F. vesiculosus* has a patchy distribution around the coastline and apart from elevations in industrial areas and estuaries, elevations around Cardigan Bay indicate that there may be some input from old metalliferous mining areas that drain into that embayment. The overall range increased from 0.5 ug/g at Nolton Haven in 1993 to 10.05 ug/g at Penrhyn Bay in 1995 (Fig. 6). Concentrations in Fucus spiralis at Tywyn and Porthmadog exceeded this in 1993, but 1994-1995 values are lower.

vi) Arsenic (As)

Arsenic levels in *F. vesiculosus* ranged from 12.58 ug/g at Cardiff Flats in 1992 to 314.0 ug/g at Greenfield in 1992. In contrast to all the other metals, Arsenic appeared to increase spatially from the Severn Estuary, west towards Pembrokeshire, through to Mid and North Wales (Fig. 7).

vii) Chromium (Cr)

Chromium levels in *F. vesiculosus* ranged from 0.47 ug/g at Goodwick in 1993 to 7.1 ug/g at Caernarfon in 1994. During 1991 levels less than the detection limit (<1.5 ug/g) were recorded at all sites (data available from South Wales only). Chromium levels were more elevated around the North Wales coastline (Fig. 8) but only 1994-1995 data were available for North Wales.

viii) Nickel (Ni)

Nickel levels in *F. vesiculosus* ranged from a minimum of 4.5 ug/g at Greenfield in 1994 to a maximum of 35.8 ug/g at Beachley Point in 1994. Levels in *F. spiralis* and *F. serratus* lie within this range. The highest concentrations of Nickel were recorded in the South (increasing eastwards from Burry Port to Beachley Point) but with similar elevations in *Fucus spiralis* from the Dee Estuary (Fig. 9). In 1994 only there was a peak of 29.8 ug/g at Caernarfon.

3.1.2 *Mytilus edulis*

The spatial trends described in the previous section with reference to *Fucus spp*, are similar in *Mytilus edulis* for Zinc (Fig. 11), Cadmium (Fig. 12), Arsenic (Fig. 15) and Nickel (Fig. 17). Lead in *Mytilus* is also spatially similar to *Fucus* (Fig. 14), and there is a peak of concentration around the Cardigan Bay area (but not at the same site) similar to that found in *Fucus*. The spatial trends are much clearer in *Mytilus* for Chromium distribution and increase eastwards from Burry Port to the Severn Estuary (Fig. 16). Prior to '94 and '95 there was no chromium data available from the North. The spatial pattern there is patchy with levels just above those of West Wales. For *Mytilus* only (Fig. 13), concentrations of Mercury increase from Burry Port westwards to Pembrokeshire and Cardigan Bay. Similar elevations appear in the North outside the Dee estuary, with the maximum value of 1.16 ug/g occurring at Conwy in 1994.

Copper values were elevated in *Mytilus* at many locations around the Welsh Coastline (Fig 10) during 1995 only. Levels were >2x the previously recorded values at the following sites: Cardiff Flats, Southerndown, Burry Port Jetty, Ferryside, Nolton Haven, Castlerocks and Mostyn.

Ranges for Zinc (41-348 ug/g), Cadmium (0.5-22.6 ug/g), Arsenic (4-22.92 ug/g) and Nickel (1.11-17.23 ug/g) were all within the range of values recorded for *Fucus*. The metal concentration ranges were similar to levels found in *Fucus*, apart from Zinc, which is much higher in *Fucus* (maximum 1,000 ug/g) indicating that Zinc must be accumulated predominantly from the water column and not from the particulate phase. Copper (5.0-63.8 ug/g), Mercury (0.09-1.16 ug/g), Lead (1.5-36.8 ug/g) and Chromium (0.66-7.99 ug/g), in contrast, were all outside the ranges for *Fucus* (although not widely so) and indicates the possible association with particles of these metals also.

3.1.3 *Cerastoderma edule*

This organism has historically only been collected from one site in South Wales (Burry Inlet, 1986-1988). Two extra nearby sites were included in the 1993 sampling programme at Jersey Marine and Trostre. There was little spatial variation between these three sites, and Jersey Marine was not sampled in '94 or '95 and no samples were collected from Trostre in '95 (Figs. 18-25). Copper, Zinc, Cadmium, Mercury, Lead and Arsenic concentrations within *Cerastoderma edule* are all within the range measured in *Mytilus edulis* from around the Welsh coastline. At all 3 sites, especially Jersey Marine, Nickel is outside the range previously recorded for both *Fucus* and *Mytilus* from around the Welsh coastline (maximum 90 ug/g compared with 10 ug/g for *Mytilus* and 25 ug/g for *Fucus*). This must indicate a high level of nickel in sediment as *C. edule* is indicative of sediment load. Similarly, historical data from Burry Inlet gives a higher concentration of Chromium in cockle than has previously been recorded in *Fucus* and *Mytilus*, but this is now declining.

3.1.4 Total metal burdens at sampling sites

By adding all the metals for every site during 1993 for each species, the percentage contribution that each site made to the total amount of metals was calculated for that year. 1993 *Fucus spp.* data was chosen because it represents the most complete dataset, thus allowing for valid inter-site comparisons throughout Wales. *Fucus spp.* were present at twenty five sites and the data are presented graphically in terms of the lowest to the highest metals-contaminated sites in Wales during 1993 (Fig. 26). The least contaminated sites in any one particular area were those located along the Pembrokeshire coastline, followed by west and north west Wales and finally to the most contaminated sites along the Bristol Channel and Severn and Dee estuaries. There are exceptions to this, notably Castlerocks (this site is located at the mouth of a catchment draining a metalliferous mining area) and Tywyn (possibly due to an elevated lead concentration).

The data for *Mytilus edulis* is more limited in geographical area as it occurs at fewer sites than *Fucus*. Castlerocks is the most contaminated site, possibly for the reasons explained above. This site accounted for over 18% of the total metals determined for 10 sites (Fig. 27). Again, the Pembrokeshire sites are the least contaminated followed by the heavier industrial areas of Swansea Bay and Cardiff Flats.

3.2 Temporal trends

Because of natural between year variability and the incomplete data set, temporal trends can only be evaluated by comparing bulked historical information ('82-'88 on the histograms in Figs. 2-25) to 5 years ('91-'95) recent data. These complete data sets are only available for South Wales (Swansea Bay and Severn Estuary). Because of this limited information any trends shown in the data can only be indicative.

i) *Fucus vesiculosus*

Trends in concentration from '82-'88 to the recent data ('91-'95) are summarised:

Copper shows a downward trend in concentration (Fig. 2)

Cadmium - downward at sites within the Severn Estuary (Fig. 4)

Lead - downward at sites within the Severn Estuary and Swansea Bay (Fig. 6)

Chromium - downward at sites within the Severn Estuary (Fig. 8)

ii) *Mytilus edulis*

Copper - higher levels for 1995 only were recorded at most sites (Fig. 10)

Zinc - downward (Fig. 11) e.g. at Burry Port Jetty levels fell from 136 to 63 ug/g from '82-'88 to 1995 and in Swansea Bay fell from 219 to 94 ug/g over the same period

Cadmium - downward at Cardiff Flats (Fig. 12)

Chromium - downward in Swansea Bay and Burry Port (Fig. 16)

Nickel - higher levels for 1995 only were recorded at most sites (Fig. 17)

iii) *Cerastoderma edule* (Burry Inlet and Swansea Bay only)

Copper - at Burry Inlet from '94-'95 levels of copper rose sharply to a peak of 60.2 ug/g in 1994 and then fell to 30.2 ug/g in '95 (Fig. 18). All previous values were <5 ug/g.

Zinc - downward (Fig. 19). At Burry Inlet a decline from 201 ug/g (mean '86-'88) to 66.8 ug/g (mean '91-'95) occurred.

Cadmium - downward (Fig. 20)

Lead - at Burry Inlet from '94-'95 lead levels rose sharply to a peak of 5.47 ug/g in 1994 (Fig. 22).

Arsenic - upward trend from 1991 onwards to a peak of 17.28 ug/g in 1994 (Fig. 23).

Chromium - downward (Fig. 24)

Nickel - levels of Nickel rose sharply in 1994 at the Burry Inlet site (71.1 ug/g) to above the previous maximum (50.8 ug/g).

There is a close correlation between the downward trends shown in *M. edulis* and *C. edule*. As both species reflect the particulate and sediment metals loadings respectively, there is some evidence that these must be reducing.

The sharp rise in concentration that was observed in 1994 for Copper, Lead, Arsenic and Nickel at Burry Inlet needs to be investigated. These huge increases were sustained, although they dropped slightly, in 1995. It does appear to be a real increase rather than spurious results.

4.0 ORGANICS RESULTS

A suite of organics was analysed on each of the target species from 1991 onwards at a limited number of sites (mainly those sampled for the Baseline Estuary Monitoring Programme which became the National Monitoring Programme). From 1993 onwards the suite of organics was measured at all sites around the coastline from each species.

Early results ('91-'93), showed low levels of organics at all sites with almost all values recorded as being below the limits of detection for each determinand. Detection limits vary between samples for any particular determinand, according to the amount of tissue that was available for analysis. The various detection limit ranges for each species during 1992-1995 at most sites were as follows:

	M. edulis	F. vesiculosus	C. edule
	1992-1995	1992-1995	1992-1995
	ug/kg	ug/kg	ug/kg
ALDRIN	0.9-54	1-22.7	2.2-18
HCH ALPHA	0.9-54	1-22.7	2.2-18
HCH GAMMA	0.9-54	1-22.7	2.2-18
DIELDRIN	0.9-54	1-22.7	2.2-18
DDT (PP')	0.9-54	1-22.7	2.2-18
DDT (OP')	0.9-54	1-22.7	2.2-18
DDE (PP')	0.9-54	1-22.7	2.2-18
DDE (OP')	0.9-54	1-22.7	2.2-18
TDE (PP')	0.9-54	1-22.7	2.2-18
ENDRIN	1.8-108	2-45.4	4.4-36
HEXACHLOROBENZENE	0.9-12	0.9-22.7	2.2-18
HEXACHLOROBUTADIENE	1-8	1-22.7	2.2-18
CHLOROFORM	5-100	7-100	7-100
CARBON TETRACHLORIDE	5-100	7-100	7-100
PENTACHLOROPHENOL	5-100	7-100	10-100
PCB 28	0.9-54	0.9-22.7	2.2-18
PCB 52	0.9-54	0.9-22.7	2.2-18
PCB 101	0.9-54	0.9-22.7	2.2-18
PCB 118	0.9-54	0.9-22.7	2.2-18
PCB 138	0.9-54	0.9-22.7	2.2-18
PCB 153	0.9-54	0.9-22.7	2.2-18
PCB 180	0.9-54	0.9-22.7	2.2-18

During 1991, the 1st year of organics analysis, the detection limits were even wider.

Some positive values were recorded from around the Welsh Coastline for certain organics during '94 - '95. These are tabulated below:

Positive organics values (ug/kg dry weight)

Species	Location	Date	Determinand	Value	D.L.
F. vesiculosus	Rhyl	21.2.94	Chloroform	71.33	<11.61
F. vesiculosus	Nolton Haven	2.2.95	Chloroform	46.00	<10.00
M. edulis	Hilbre Island	27.1.95	pp'- TDE	11.80	< 4.10
M. edulis	Hilbre Island	27.1.95	PCB 153	21.60	< 4.10
M. edulis	Thurstaston	27.1.95	pp'- TDE	9.30	< 2.30
M. edulis	Thurstaston	27.1.95	PCB 153	20.80	< 2.30
M. edulis	Caernarfon	27.1.95	PCB 153	11.60	< 5.60
M. edulis	Swansea Bay	2.2.95	PCB 153	55.70	< 0.90

D.L. (Detection Limit)

5.0 DISCUSSION

5.1 Spatial variations in metals

Elevations of Copper, Zinc, Mercury, Lead and Nickel, as measured by bioaccumulation around the Welsh coastline, associated with the industrial embayments such as Swansea Bay and within the two major estuaries of Wales - the Dee and the Severn are to be expected given the industrial history of these sites. In comparison with the earlier Welsh Water Authority Tidal Waters Bioaccumulation Programme 1978/1979 data (Welsh Water Authority, 1982; Appendix V), the spatial variations found in this report are very similar and can be linked mainly to anthropogenic inputs from the heavy industries, such as metal refining and coal-mining. 'Natural' inputs associated with the old metalliferous mining areas and discharged via rivers draining these areas are also a factor and give rise to localised elevations in otherwise clean areas e.g. the levels of lead in *M. edulis* at Castlerocks which is affected by the Ystwyth and Rheidol catchments, that drain old metalliferous mining areas.

Metals distribution in the Severn Estuary is particularly well understood (Apte *et al.*, 1990), with Copper, Nickel and Zinc entering mainly from riverine sources, but with a mid-estuarine point source input for Cadmium and Chromium. The major input of Cadmium to the Severn is from the Avonmouth incinerator (Scott, 1987). There are also known point sources of Cadmium that discharge to the Severn Estuary at or near Cardiff. Cynon Valley STW, Lavernock Outfall and Cardiff Eastern District Pumping Station all discharge Cadmium into the Severn Estuary and are monitored under the Dangerous Substances Directive.

The most recent study on aerial inputs to the Severn Estuary (NRA R&D ref.; published as Harrison, Vale and Watts, 1991) concludes that of the aerial emissions, the Avonmouth area is a major source of Cadmium, Copper, Lead and Zinc. Secondary sources of Copper and Nickel may originate from the South Wales coast and are associated with metalliferous industries on this shore of the Estuary.

The Dee catchment management plan (NRA, 1994) cites as an issue the problem of elevated Copper and Zinc in the Dee Estuary which approach (and sometimes exceed) the Environmental Quality Standards (EQS) for these metals within the water column. Copper, Zinc and Nickel are the legacy of historic industrial activity which has left large areas of contaminated land in the catchment. Mining activity, in particular, has left behind large areas of spoil and contaminated land. Old lead mines are known to cause metals elevation of some tributaries in the catchment. A point source discharge from a textiles factory gave the maximum values of Zinc recorded in Wales for this catchment (>1600 ug/g in *F. vesiculosus*; WWA, 1982[a]) but the factory closed in the mid eighties and the discharge stopped. The recent data show much lower concentrations (197-675 ug/g) within the Dee Estuary.

Swansea Bay, because of metal refining and petro-chemical plants that discharge to the Bay, has a history of metals contamination e.g. in 1983, 41 sewage and industrial effluents discharged into the Bay, of which 7 were major industrial inputs. There is also considerable secondary input from the rivers which discharge into the Bay, because of industrial and mining impacts. In the early '80s a point source discharge of Mercury from a chlor-alkali plant was studied (Tidal Waters Report, 1982) but this discharge has stopped. The distribution of trace metals in sediments from the Bay has been reported by a number of authors (Cotsifis, 1993). In the Inner Bay (the most contaminated area), trace metals loadings, which are elevated compared to other UK estuaries, can be explained generally by industrial input, but only Chromium and Mercury distribution can be explained in relation to the known point source discharges. Due to an industrial point source at British Steel Trostre works, which discharges to the Loughor Estuary, Burry Inlet was particularly contaminated by Chromium (Fig. 24), although recent levels show a decline as discussed later.

Of all the metals, the distribution of Arsenic has an odd spatial pattern, not linked apparently to the industrial embayments and estuaries (Figs. 7 and 15). There is little information in the literature on the sources and distribution of this element.

5.1.2 UK National Perspective

20 years data from around the UK coastline has been collated by the Plymouth Marine Laboratory (PML) (Burt et al., 1992). This data relates to metals levels in sediments and bioaccumulation levels in a number of target organisms including *F. vesiculosus* and *M. edulis*. Unfortunately, much of the data for the Welsh coastline is the original tidal waters data from the late 70's and early 80's. Nevertheless, the report is still useful to compare the most recent Welsh data to. There is no National data available for the bioaccumulation of Nickel or Arsenic.

Areas within Wales that had the maximum National concentrations (Burt et al., 1992) included:

i) Cadmium concentrations in the Severn e.g. at Shepperdine in F. vesiculosus were the maximum recorded (58.2 ug/g in 1976). In shellfish, the highest UK concentrations were reported from *Littorina littorea* (winkle) and *Scrobicularia plana* (clam) at Brean Down and Rhymney, both situated on the Severn Estuary;

ii) a maximum Lead concentration of 196 ug/g (*F. vesiculosus*) at Aberystwyth during 1985;

iii) in terms of sediment concentrations, the Loughor Estuary was reported as being one of the most Chromium-polluted estuaries in the United Kingdom, with levels as high as 826 ug/g recorded in 1979. Elevated Chromium levels in the Loughor Estuary are a result of tinplate production at Trostre (Chubb and Stoner, 1977). Nationally, the highest recorded concentrations in F. vesiculosus (max=53.3 ug/g) was from the Loughor Estuary in 1979 (Burt et al., 1992). However, levels of Chromium at Burry Inlet, within the Loughor Estuary, are reducing as discussed later.

For all other metals the highest levels were 'naturally' occurring, from the Cornwall metalliferous mining areas. These levels are orders of magnitude above the Welsh levels e.g. the highest concentration of 39.0 ug/g Copper at Beachley Point in 1991 within South Wales, was several orders of magnitude lower than Copper concentrations found in *F. vesiculosus* from the metalliferous mining areas of southwest England; with up to 1821 ug/g recorded at Restronguet Creek in 1976 (Burt et al., 1992). The mean Copper concentration in *F. vesiculosus* for the whole of Wales (all years, all sites) was 12.58 ug/g.

Similarly, the highest concentrations of Zinc in the U.K. appear to be in south-west England associated with metalliferous mining. In this area, levels have reached 3239 ug/g (Burt *et al.*, 1992) compared to the maximum concentration in Wales of 973 ug/g at Beachley Point in 1991.

5.1.3 Temporal trends in metals distribution

The measured decline in Zinc, Cadmium, and Nickel in *M. edulis* from South Wales and in C. edule from Burry Inlet and Swansea Bay for the same metals, must indicate a decline in the levels of those metals being discharged to those localities. This is probably linked to the decline in heavy industries, such as metal refining and coal-mining, in those areas. In the case of the Chrðmium discharge to the Loughor, it reflects the reduction of the point source input, following installation of a Chromium reduction plant at the British Steel works at Trostre (Cotsifis, 1994).

In the Inner Bristol Channel and Severn Estuary concentrations of Lead, Chromium, Nickel and Zinc have decreased in the muddy sediments since the 1970's (Little and Smith, 1994). This is thought to be in line with pollution abatement over the years.

Copper values were elevated in *Mytilus edulis* at many locations around the Welsh Coastline (Fig 10) during 1995 only. Levels were more than double the previously recorded values at Cardiff Flats, Southerndown, Burry Port Jetty, Ferryside, Nolton Haven, Castlerocks and Mostyn. As most of these sites are in the South and all of the mussels from those sites were cleansed in the same tank, then this may indicate a problem with the cleansing process that year. Unless sustained in future surveys, it does not seem to be a real increase as Copper in *Fucus* from the same sites was not elevated.

The sharp rise in concentration that was observed in 1994 for Copper, Lead, Arsenic and Nickel in *C. edule* at Burry Inlet needs to be investigated. These huge increases were sustained, although they dropped slightly, in 1995. This does therefore appear to be a real increase and it is recommended that a spatial survey is carried out in 1996, to determine whether or not there is a recent point source input of these metals to the Loughor Estuary.

Temporal trends are difficult to determine because of variability within the data from year to year that are not related necessarily to any real increase of that metal in the environment. Although the methods used attempt to reduce the variability as much as possible by:

i) the collection of individuals from a fixed size range;

ii) repeating the survey during the same time period each year;

It will still take about 5 years to build up enough data to compare future trends upon. It is important therefore, that the survey is continued on an annual basis within the same sampling window, in order to ensure that the quality of the data remains as high as possible.

5.2 Organics Levels

Recent data ('94-'95) has indicated the presence of chloroform (46-71.33 ug/kg) in *Fucus vesiculosus* from Nolton Haven and Rhyl, pp'-TDE (a DDT metabolite, ranging from 9.3-11.8 ug/kg) in *Mytilus edulis* from Hilbre Island and Thurstaston, within the Dee Estuary, and PCB congener 153 (11.6-55.7 ug/kg) from Hilbre Island, Thurstaston, Caernarfon and Swansea Bay. Previous data indicated that for all organic compounds analysed, in each species, the concentrations were below the routine analytical detection limits for those compounds. No firm conclusions can be drawn regarding the distribution of organics in biota from around the Welsh coastline, as most of the positive values were for 1995 only. Again, if the survey is repeated annually, then a long term data set can be built up in order to evaluate trends.

In an earlier Welsh Water Tidal Waters Unit study of chlorinated hydrocarbons in biota from around the Welsh Coastline (Welsh Water Authority, 1982[b]), the detection limits were even lower than in the present study and positive values were found. In this earlier work, the most useful indicator of organic compounds was also *M. edulis*, showing the association with particulate matter of organochlorine compounds.

PCBs were measured against *Arochlor* standards in the earlier study and not as ICES congeners measured in the present study, therefore the data is not directly comparable. However, elevations of PCBs in *Mytilus edulis* were recorded before, from sites in the industrialised areas of the Upper Severn Estuary, Swansea Bay, Burry Inlet and North Wales, similar to the distribution found in this study. DDT and its metabolites were recorded in *Mytilus edulis* from the Upper Severn Estuary and the Dee Estuary, in similar concentrations to that found in the present study in the Dee Estuary only. There is no historic data for Chloroform.

6.0 CONCLUSIONS

6.1 Spatial trends in metals bioaccumulation in the target organisms around the Welsh coastline reflect historical industrial inputs predominantly, but there are peaks of some metals in otherwise uncontaminated areas due to 'natural' sources from old metalliferous mining areas.

6.2 Because the conclusions about temporal trends can only be tentative, due to variability of bioaccumulation data, the Regional Permissive bioaccumulation programme needs to be continued at its current level annually and within the same time period each year.

6.3 Copper was found in higher concentration in *Mytilus edulis* than in previous years during 1995 only. As the levels of Copper in *Fucus spp* in 1995 were similar to previous years then may not reflect a real increase in the environment. However, a sharp rise in Copper, Lead, Arsenic and Nickel in *Cerastoderma edule* from the Burry Inlet site during '94 and '95 probably does reflect a real increase.

6.4 Concentrations of some organic compounds (Chloroform, pp'-TDE and PCB congener 153) above the routine analytical detection limits were recorded at some sites in *Fucus* vesiculosus and in Mytilus edulis in '94 and '95. All other data i.e. at all sites around the coastline for each species from '91-'95, was below the limits of detection for a suite of organic compounds.

7.0 RECOMMENDATIONS

7.1 Continue the Regional Permissive Bioaccumulation monitoring programme, as described, at its present annual frequency within the specified sampling window, in order to maintain consistency. If for any reason sampling has to be performed outside of the sampling window i.e. later than mid February, then it would be better to cancel the survey for that year, rather than collect data that may be spurious.

7.2 A spatial survey needs to be performed in '96 within the Loughor Estuary in relation to the elevated levels of some metals measured in *Cerastoderma edule* from the Burry Inlet site from '94-'95. The survey is needed in order to determine any recent point source input of these metals to the estuary.

8.0 REFERENCES

Apte, S.C., Gardner, M.J., Gunn, A.M., Ravenscroft, J.E. and Vale, J. (1990). Trace Metals in the Severn Estuary: a Reappraisal. Mar. Pollut. Bull. **21**, **No. 8**, 393-396.

Barnett, B.E. (1990). Guidelines for a Bio-accumulation Programme for the Monitoring of Persistent Contaminants in Estuaries and Coastal Waters. BB/NRA/NAT.90.

Brown, H.J. (1989). Bioaccumulation monitoring, Bristol Channel, 1982-1988. Summary of data. Welsh Water, EAL/E4.6.

Burt, G.R., Bryan, G.W., Langston, W.J. and Hummerstone, L.G. (1992). Mapping the Distribution of Metal Contamination in United Kingdom Estuaries. Final Report on DoE Contract PECD 7/7/280. Plymouth Marine Laboratory.

Chubb, C.J. and Stoner, J.H. (1977). Discharges to the Loughor Estuary and Burry Inlet. In: Problems of a Small Estuary: Proceedings of a Symposium, 13th-14th September 1976, p4:1/1:4:1/4. University College Swansea, Institute of Marine Studies.

Cotsifis, P.A. (1993). An Evaluation of Marine Benthic Sampling Strategies in Swansea Bay and the Loughor Estuary. NRA, South-West EAU, Penyfai House, Llanelli.

Cotsifis, P.A. (1994). Proposal: A Biological Assessment on BS Trostre Works in 1994. NRA, South-West EAU. Tech. Memo. No.TM/EAW/94/05.

Davies, G.L. (1992). 1992 Severn Estuary Bioaccumulation Monitoring. NRA, South-East EAU. Tech. Memo. No.EAE/91/1.

Little, D.I. and Smith, J. (1994). Appraisal of contaminants in sediments of the Inner Bristol Channel and Severn Estuary. Biological Journal of the Marine Biological Association UK **51:** 55-69.

National Rivers Authority (1994). The River Dee Catchment Management Plan Consultation Report: June 1994. NRA, Welsh Region, Rivers House, St Mellons, Cardiff.

Scott, D.W. (1987). The measurement of suspended particulate material, heavy metals and selected organic emissions at the Avonmouth Municipal Incinerator. Warren Spring Lab. Report LR 614 (PA).

Tidal Waters Report (1982). Inputs and Distribution of Mercury in Swansea Bay - A study of the principal discharges of mercury and it's distribution in surface waters, sediments, indigenous mussels and transplanted mussels. Tidal Waters Report No. TW.82/3. Tidal Waters Section, Tremains House, Bridgend.

Vale, J.A., Harrison, S.J. and Watts, C.D. (1991). Aerial Inputs to the Severn Estuary. Report for the NRA, No.NR 2748. WRc, Medmenham, Buckinghamshire.

Welsh Water Authority (1982). Investigations into the Methodology of Bioaccumulation Studies. Tidal Waters Report No. 82/4.

Welsh Water Authority (1982[a]). Welsh Water Authority Bioaccumulation Programme 1978/79 Data Summary. Tidal Waters Report No. 82/13.

Welsh Water Authority (1982[b]). Chlorinated Hydrocarbons in Water and the Tissues of some Flora and Fauna from the Welsh Coast. Tidal Waters Report No. 82/9/17.

TABLE 1 - List of species collected from each sampling point location

SITE DESCRIPTION	MENSAR SPT No	NATIONAL GRID REF	SPECIES COLLECTED AT SITE
Beachley Point	50453	ST5530090700	*F. vesiculosus*
Goldcliff	41169	ST3830082200	*F. vesiculosus*
Cardiff Flats *	68827	ST2050073700	*F. vesiculosus, M. edulis*
Southerndown *	19103	SS8840072600	*M. edulis*
Afan Estuary	19050	SS7445088950	*M. edulis*
Swansea Bay	74060	SS6530092000	*F. vesiculosus, M. edulis*
Jersey Marine	39153	SS7040092500	*C. edule*
Burry Inlet	74058	SS4900092000	*C. edule*
Trostre	30537	SS5156096940	*C. edule*
Burry Port Jetty	74059	SN4450000200	*F. vesiculosus, M. edulis*
Ferryside	39229	SN3630007600	*F. vesiculosus, M. edulis*
Lawrenny	32734	SN0110006100	*F. vesiculosus, M. edulis*
Dale	39228	SM8140006100	*F. vesiculosus, M. edulis*
Nolton Haven	39046	SM8570018400	*F. vesiculosus, M. edulis*
Goodwick	39059	SM9490037900	*F. vesiculosus, M. edulis*
Castlerocks	39091	SN5790081400	*F. vesiculosus, M. edulis*
Tywyn	20019	SH5767000320	*F. spiralis*
Barmouth	20014	SH6084015900	*F. spiralis*
Porthmadog	22595	SH5693038330	*F. spiralis*
Pwllheli	22589	SH3710034070	*F. spiralis*
Caernarfon	22568	SH4737062850	*F. vesiculosus*
Beaumaris	27828	SH6050075800	*F. vesiculosus*
Conwy	25291	SH7825077680	*F. vesiculosus*
Penrhyn Bay	25045	SH8312081630	*F. spiralis*
Rhyl	4500	SJ0000082500	*F. vesiculosus*
Mostyn *	4501	SJ1600081700	*F. vesiculosus, F. spiralis, M. edulis*
Greenfield *	4502	SJ2070077200	*F. vesiculosus, M. edulis*
Shotton	4503	SJ2750072300	*F. spiralis*
Thurstaston	4504	SJ2290083800	*F. vesiculosus, F. spiralis, F. serratus, M. edulis*
Hilbre Island	4505	SJ1870017400	*F. vesiculosus, F. spiralis, M. edulis*

*** National Marine Monitoring Programme Sites for *Mytilus edulis* collection**

Fig. 1 Bioaccumulation sites

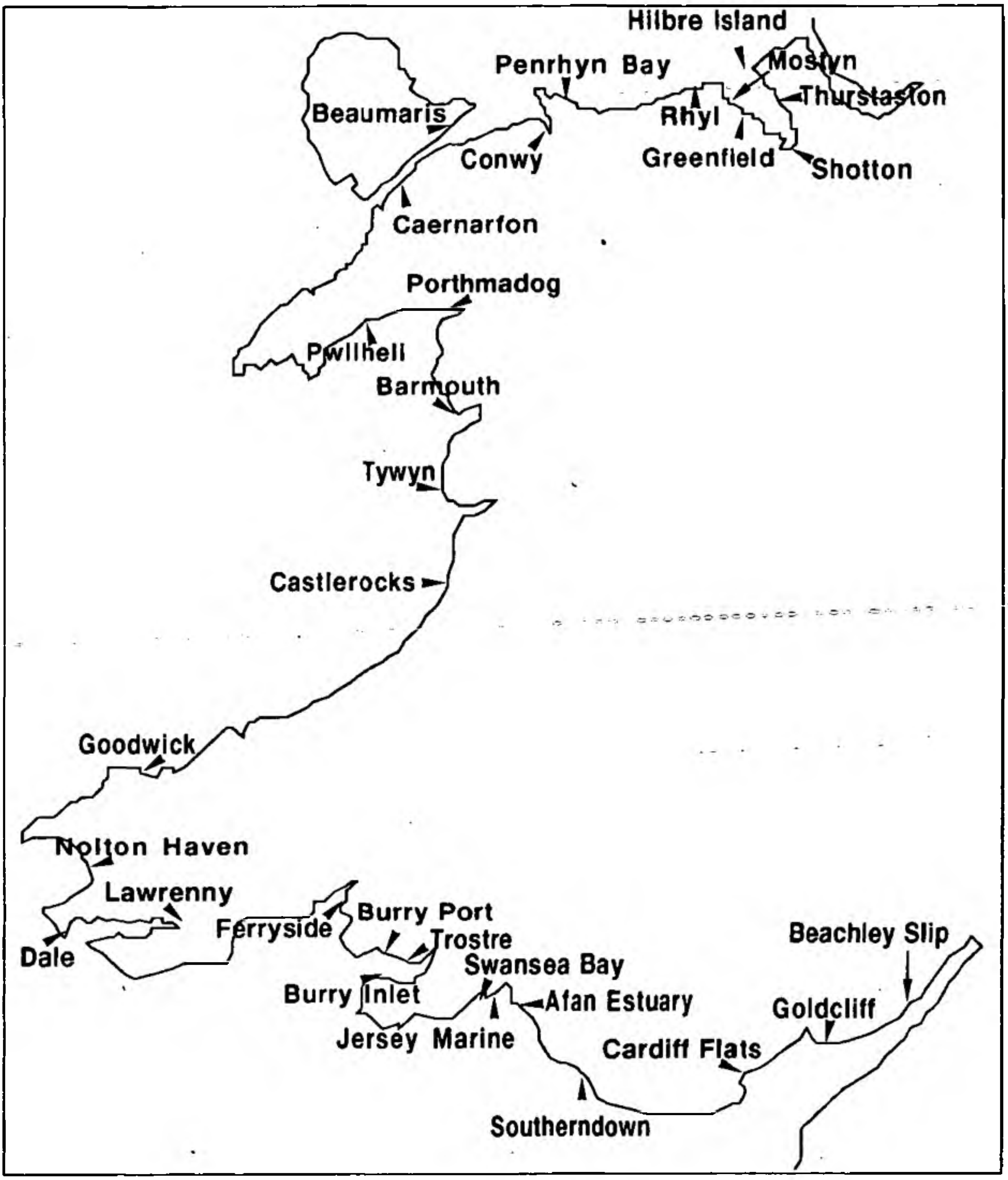


Fig. 2 COPPER concentrations (ug/g dry weight) in Fucus spp.

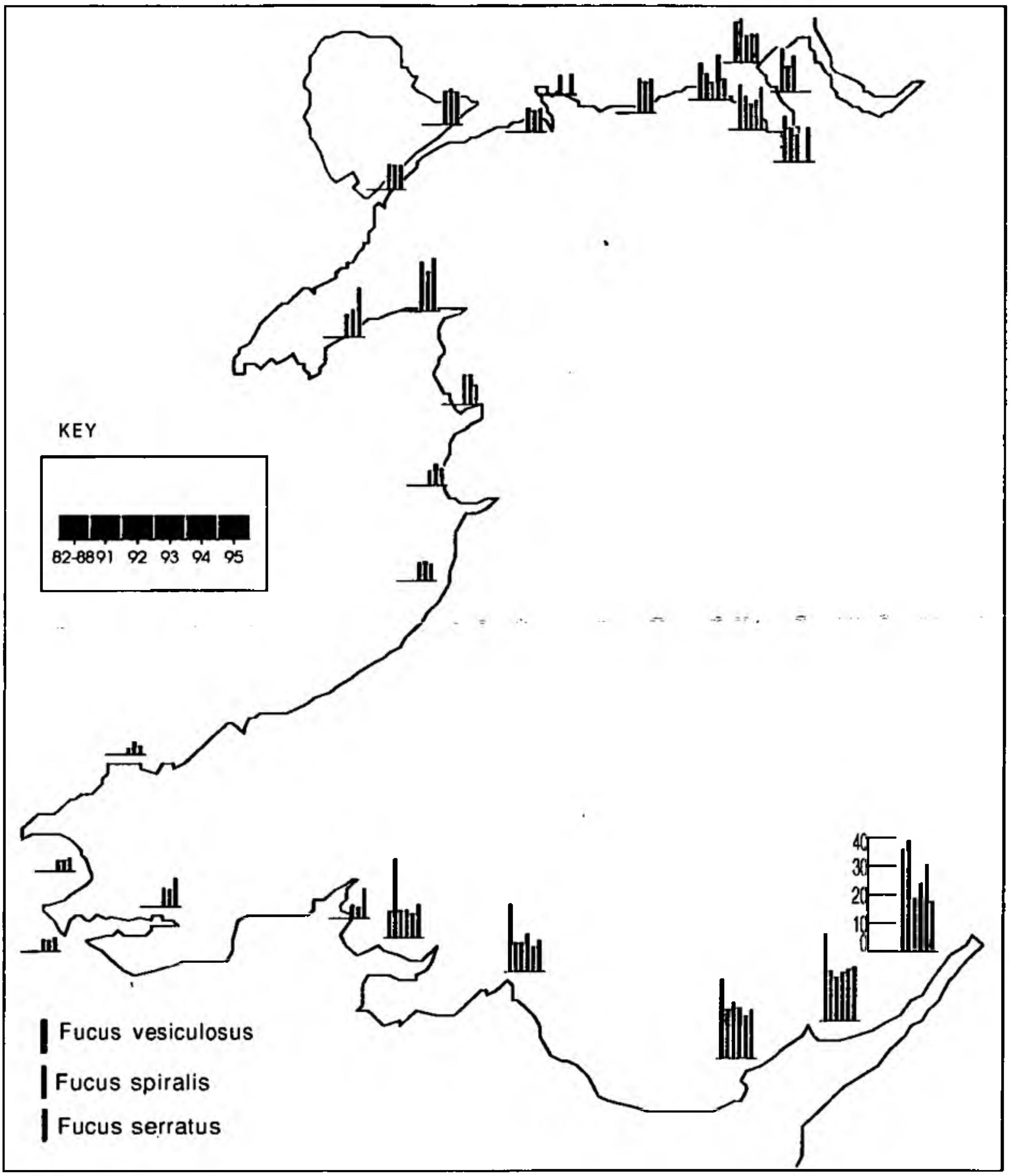


Fig. 3 ZINC concentrations (ug/g dry weight) in Fucus spp.

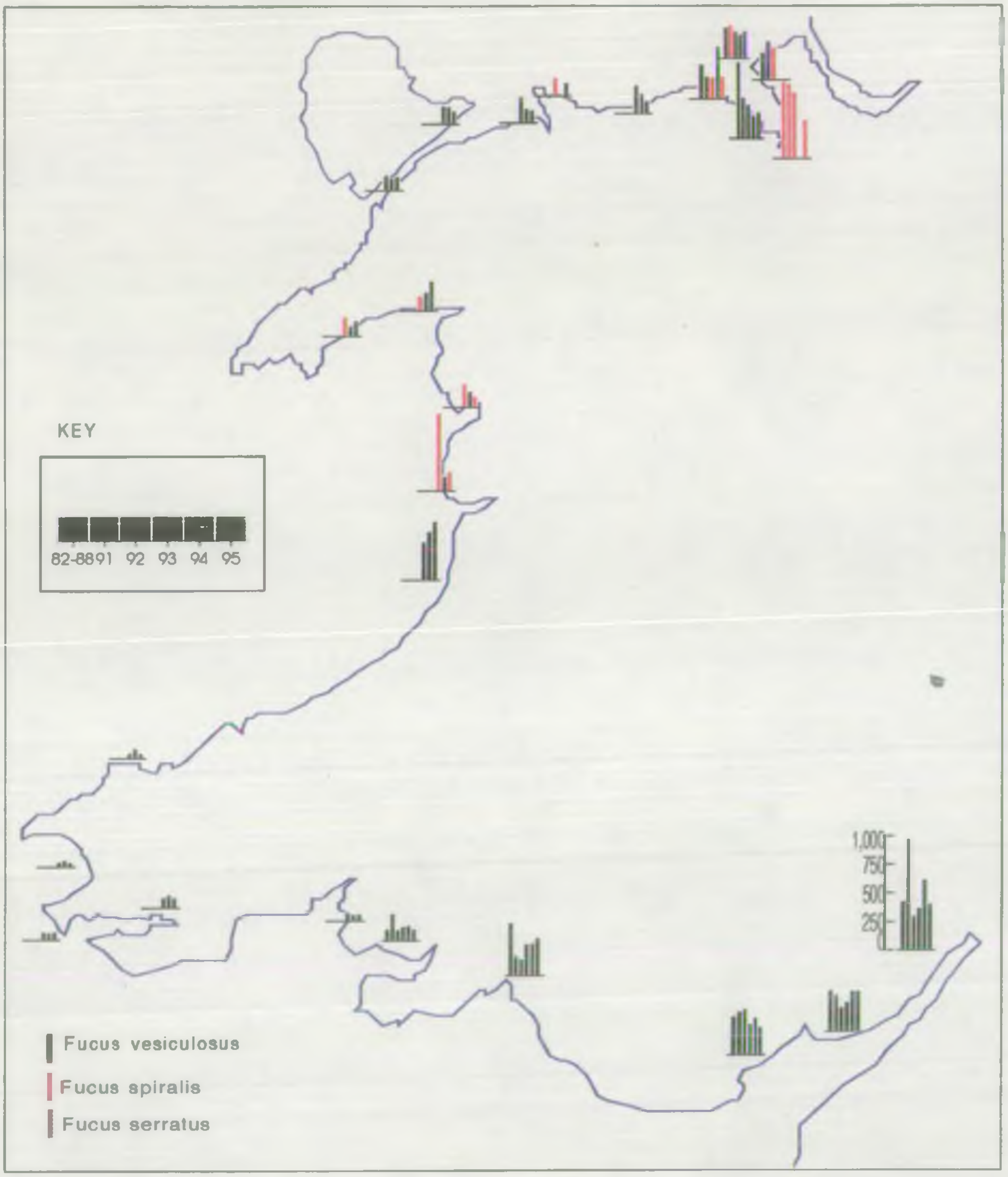


Fig. 4 CADMIUM concentrations (ug/g dry weight) in Fucus spp.

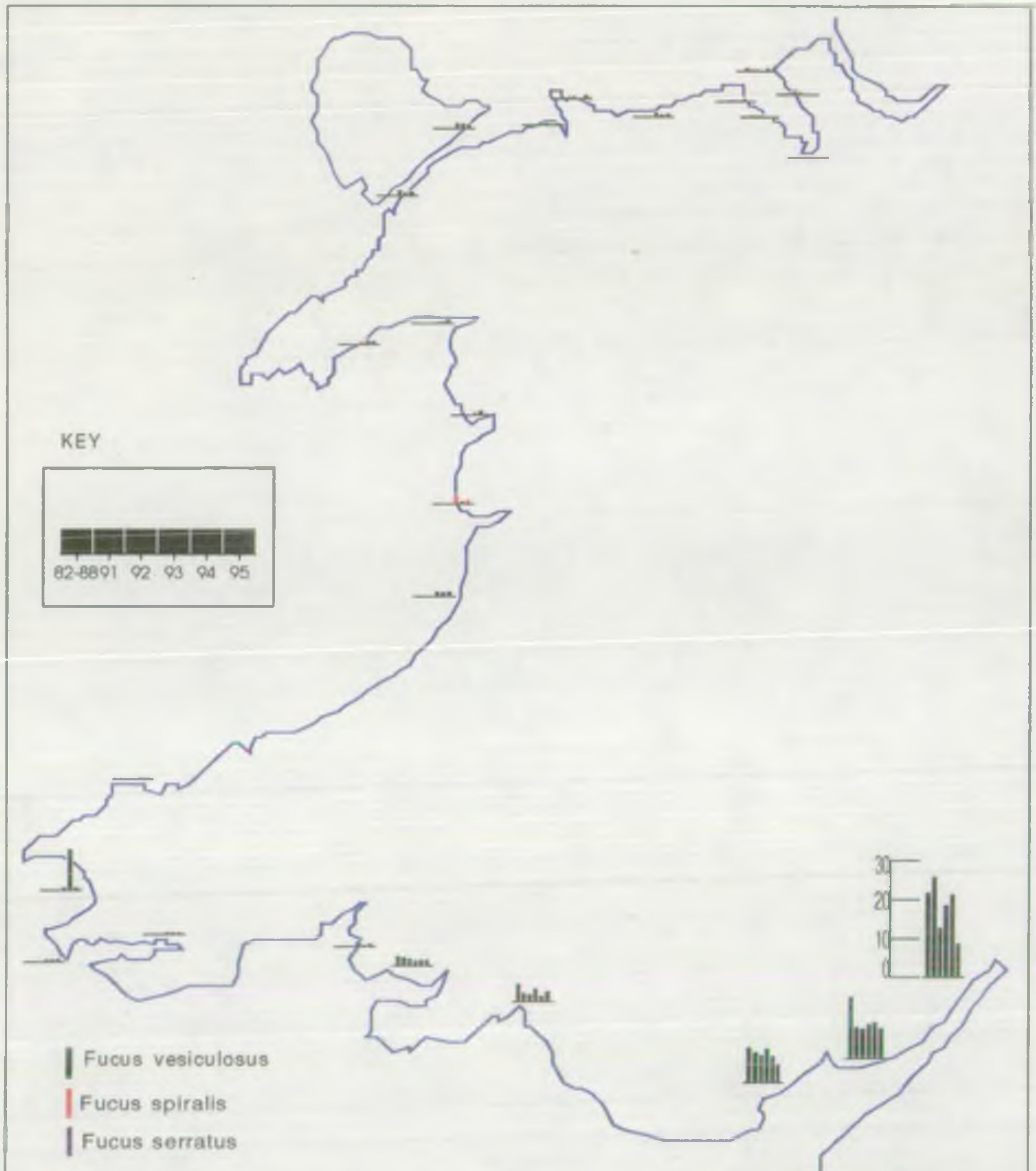


Fig. 5 MERCURY concentrations (ug/g dry weight) in Fucus spp.

Fig. 6 LEAD concentrations (ug/g dry weight) in Fucus spp.

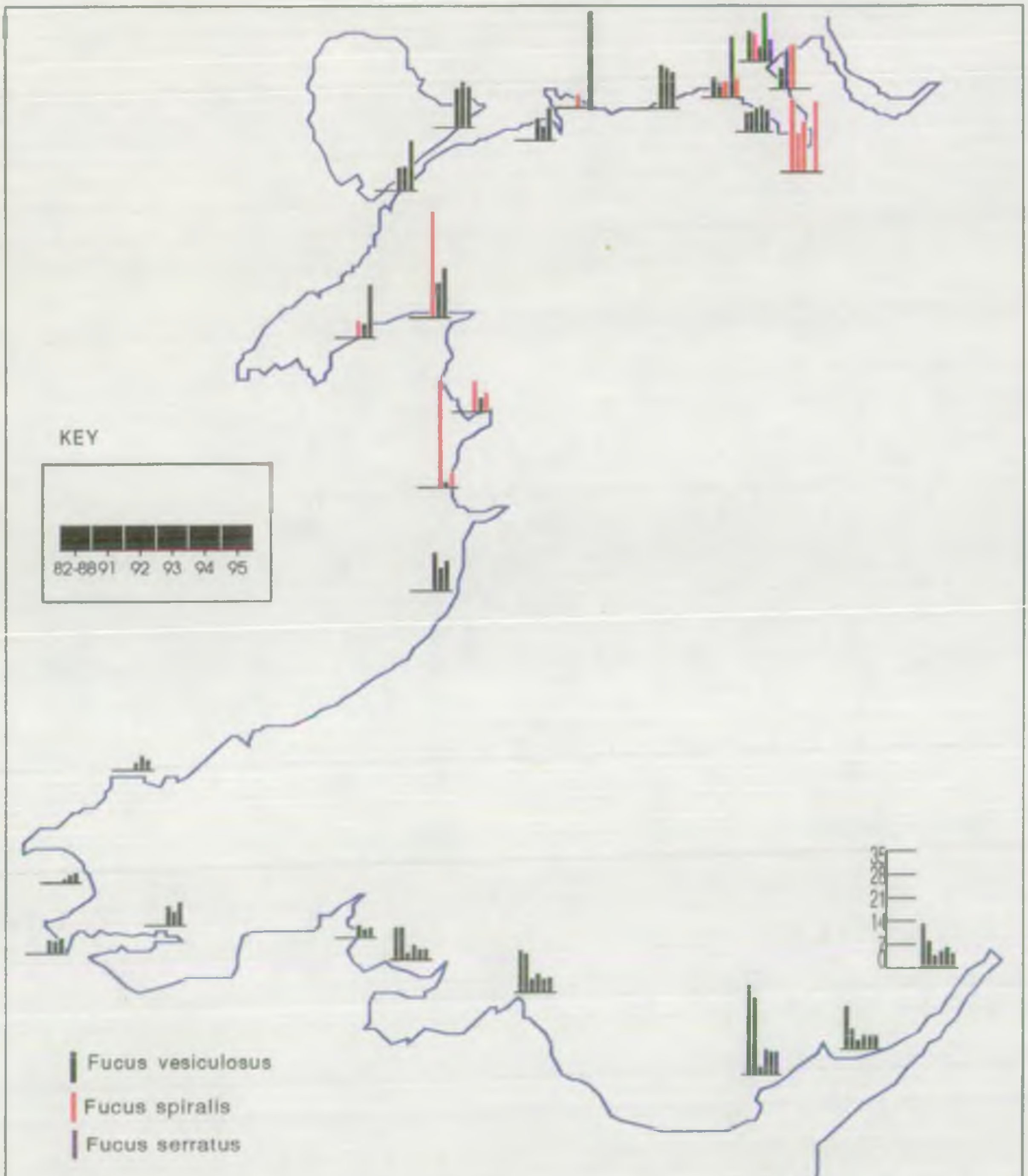


Fig. 7 ARSENIC concentrations (ug/g dry weight) in Fucus spp.

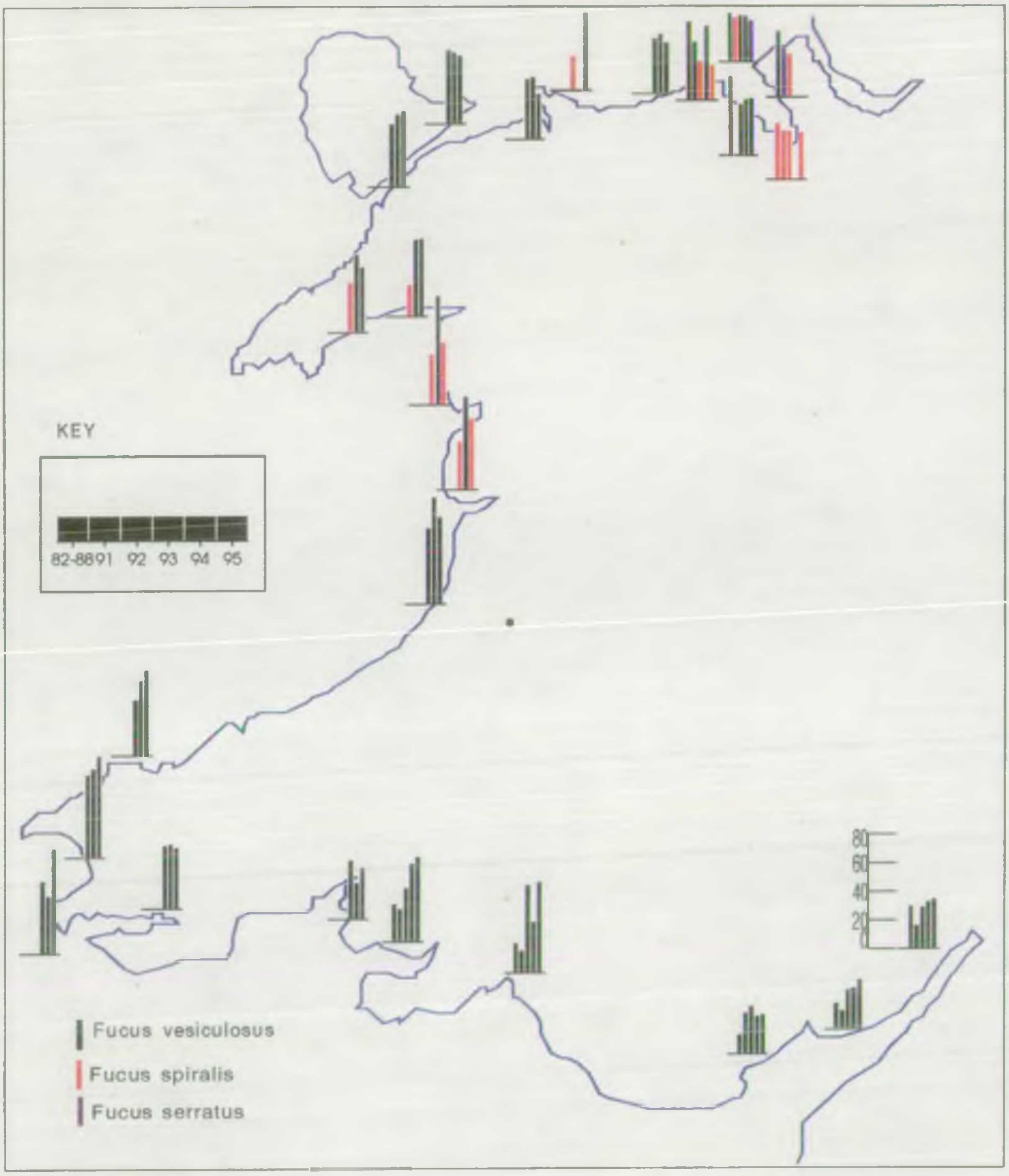


Fig. 8 CHROMIUM concentrations (ug/g dry weight) in Fucus spp.

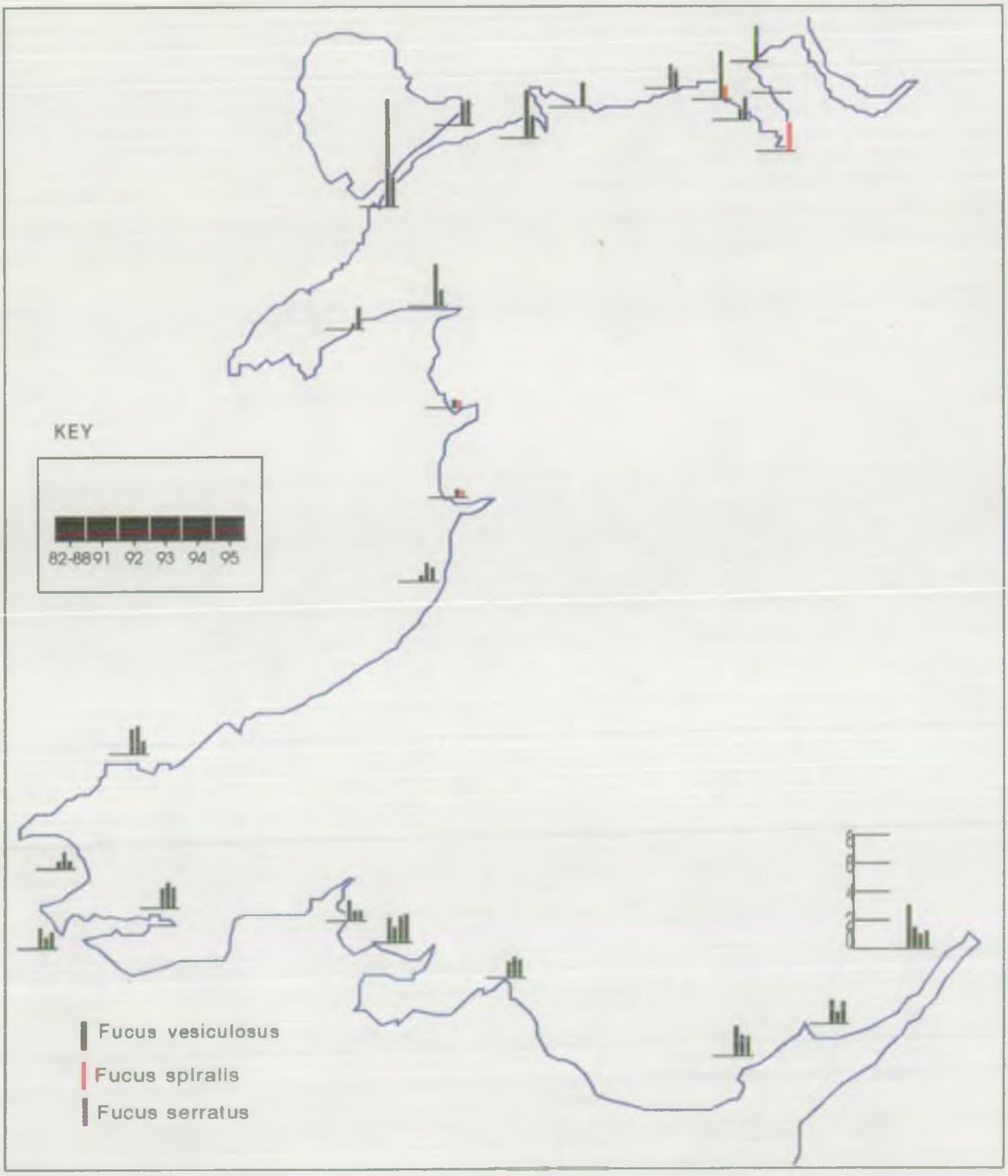


Fig. 9 NICKEL concentrations (ug/g dry weight) in Fucus spp.

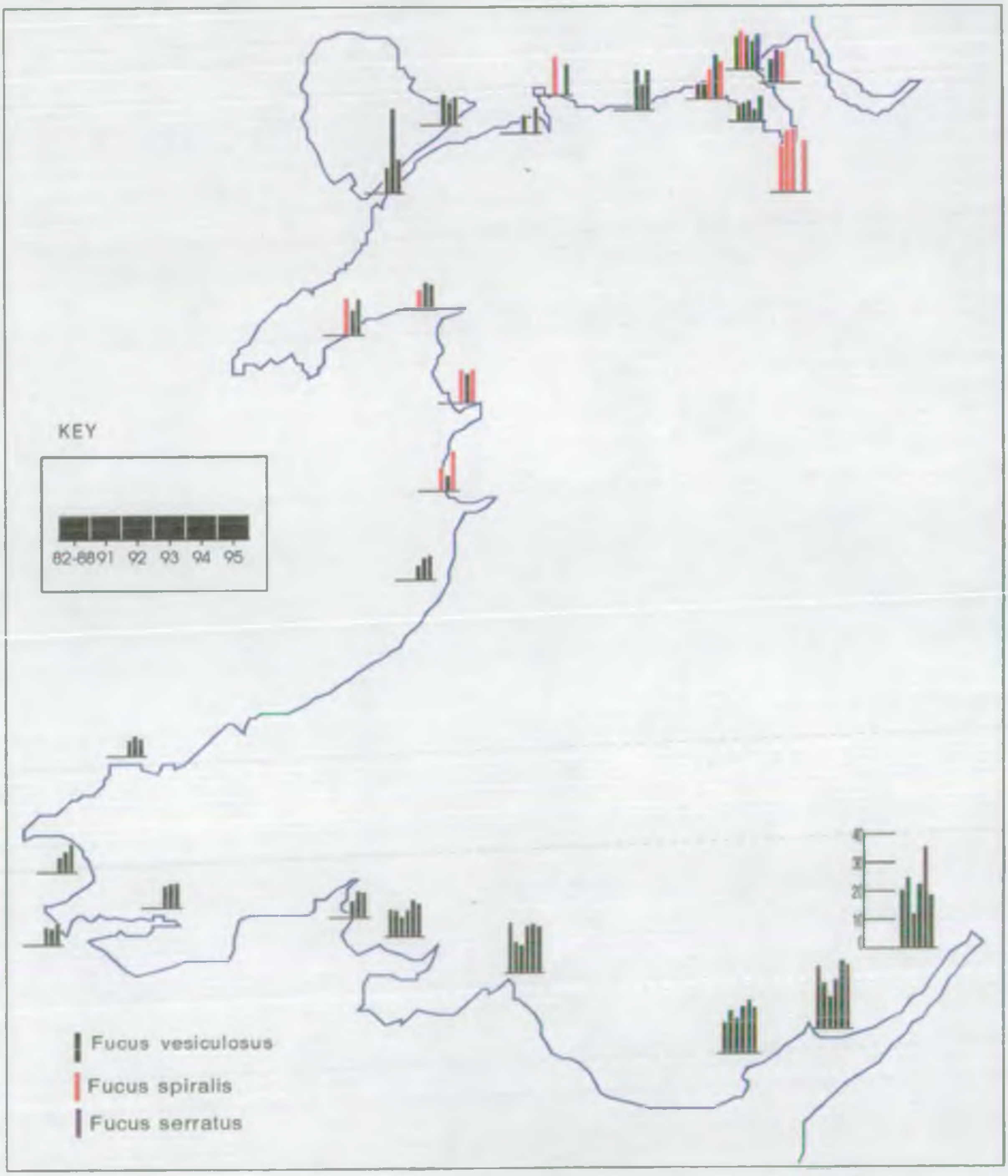


Fig. 10 COPPER concentrations (ug/g dry weight) in Mytilus edulis

Fig. 11 ZINC concentrations (ug/g dry weight) in Mytilus edulis

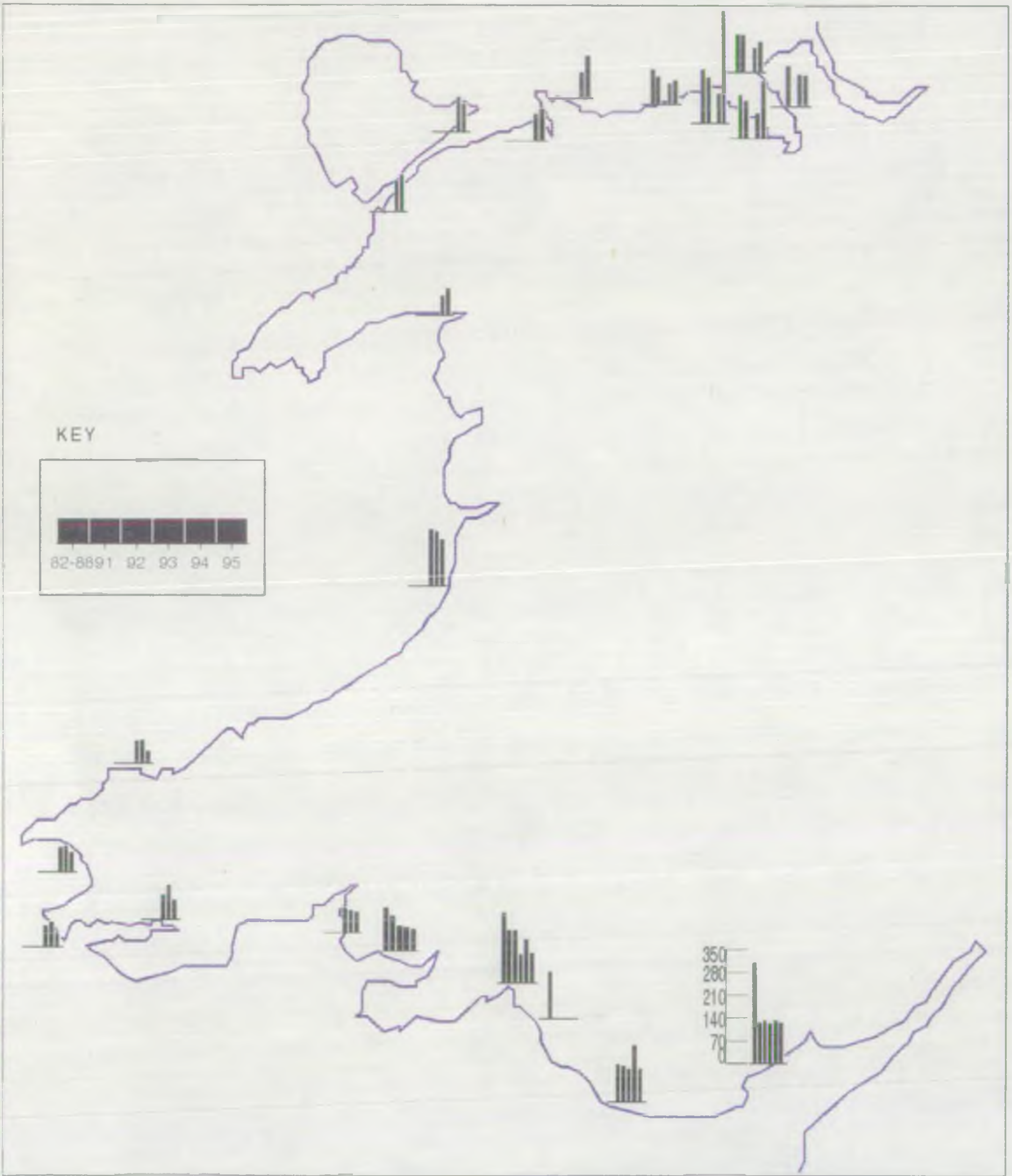


Fig. 12 CADMIUM concentrations (ug/g dry weight) in Mytilus edulis

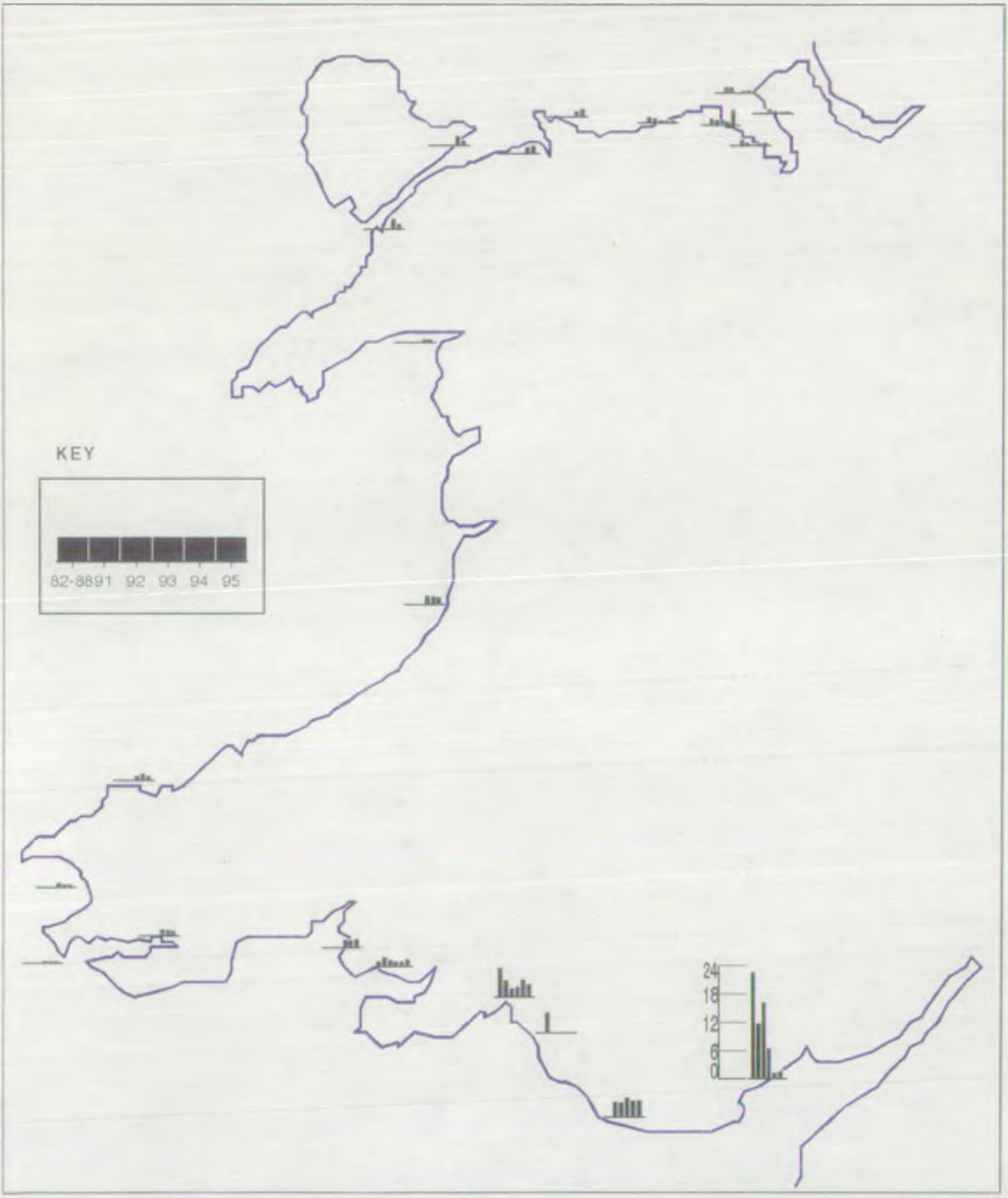


Fig. 13 MERCURY concentrations (ug/g dry weight) in Mytilus edulis

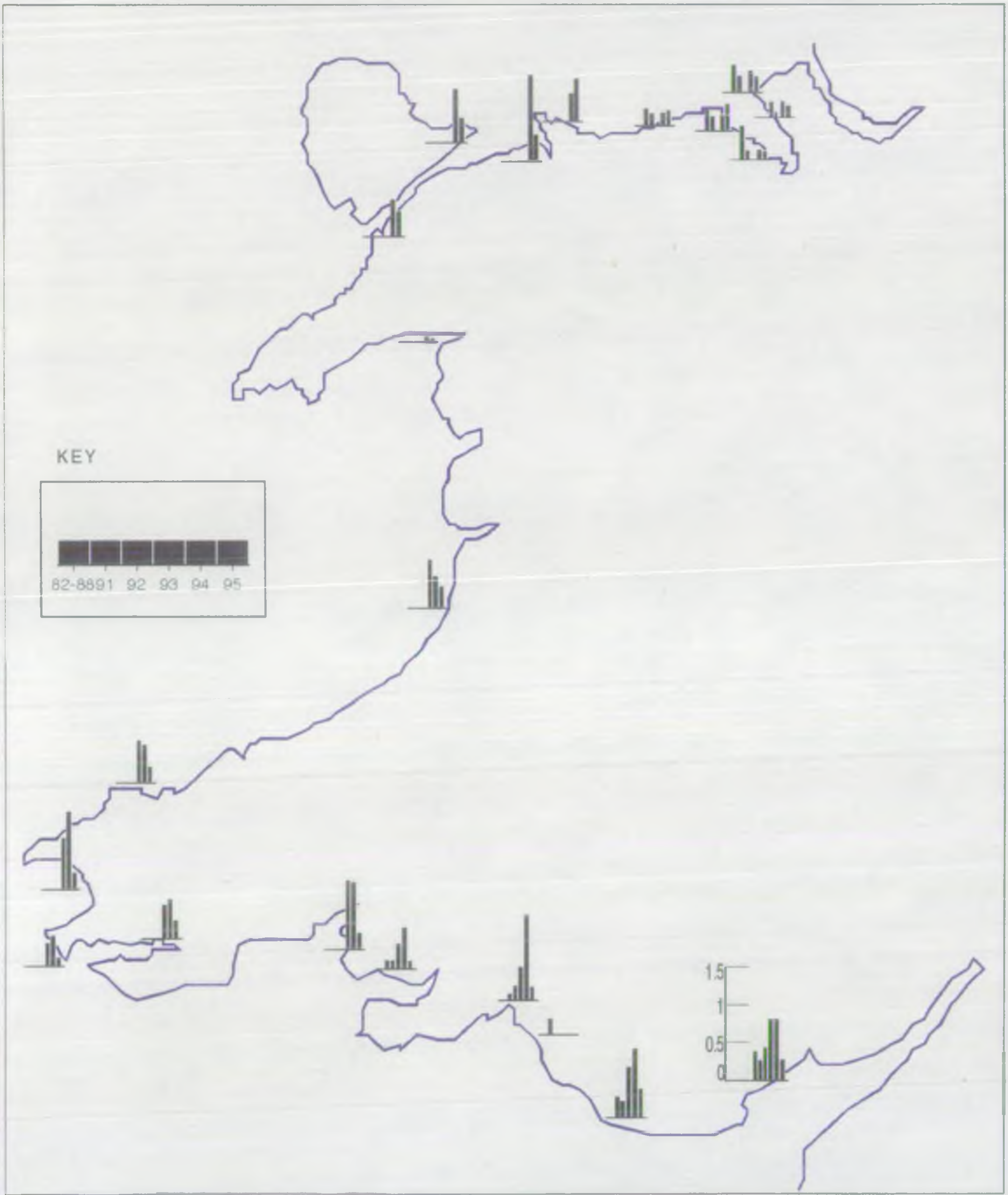


Fig. 14 LEAD concentrations (ug/g dry weight) in Mytilus edulis

Fig. 15 ARSENIC concentrations (ug/g dry weight) in Mytilus edulis

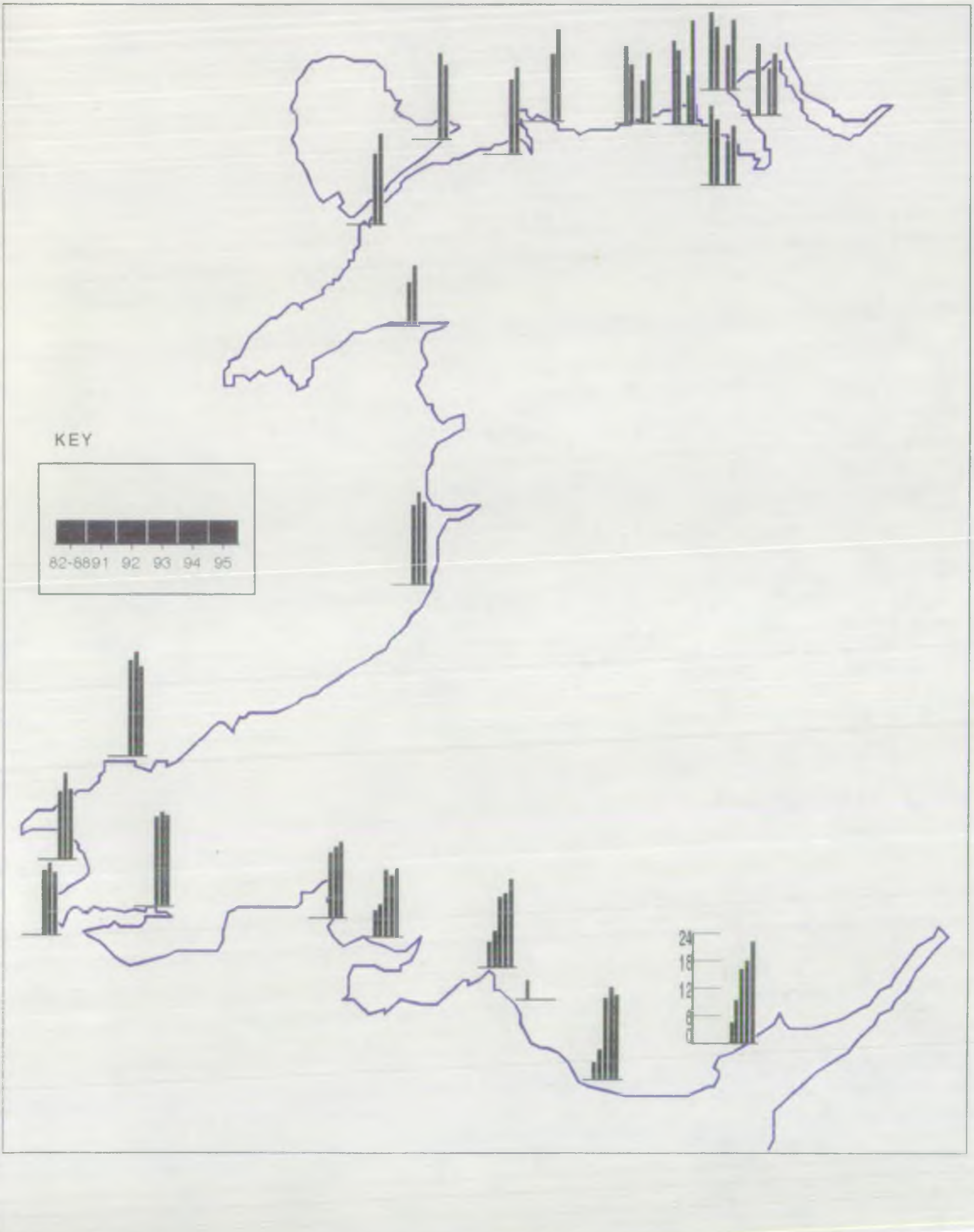
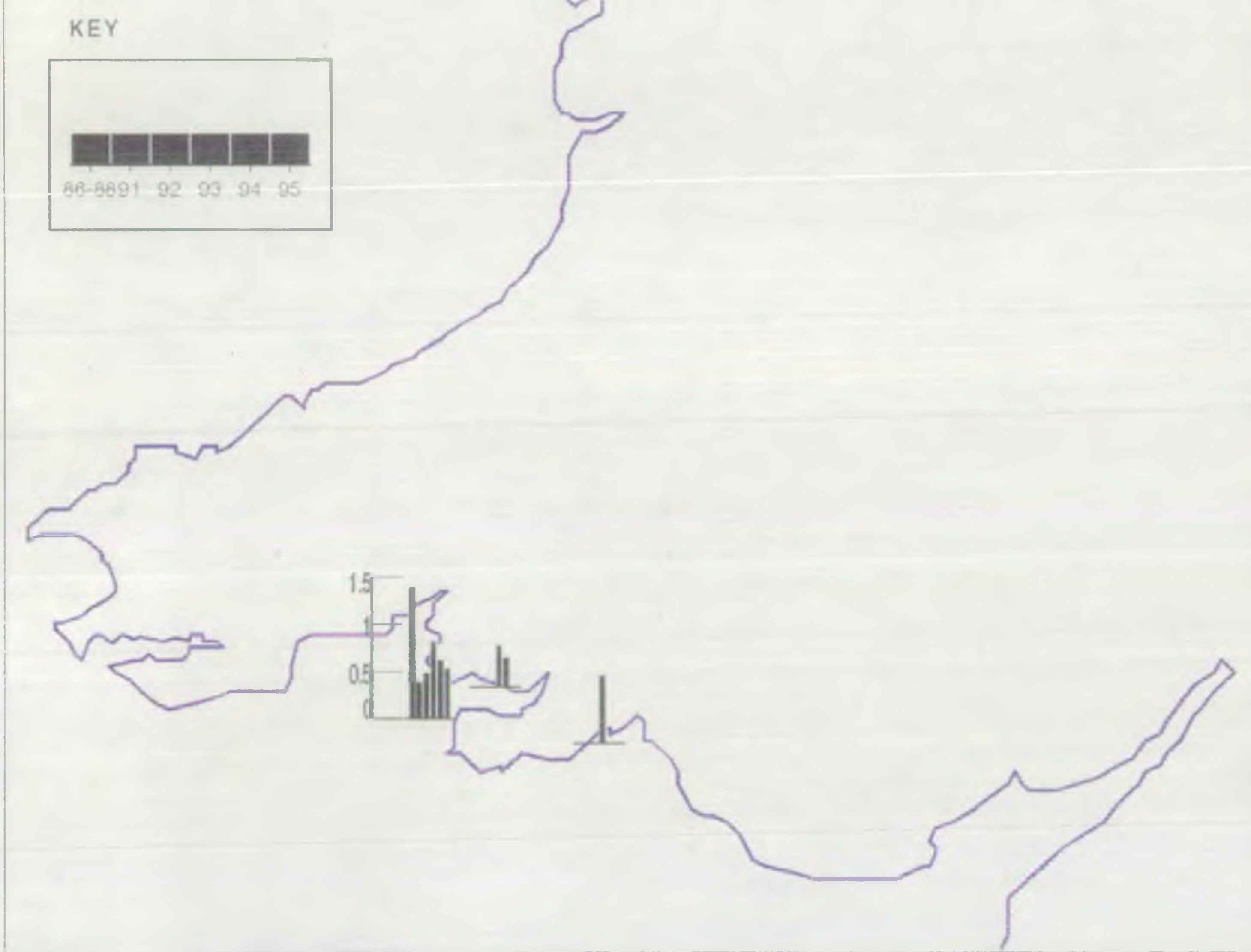


Fig. 16 CHROMIUM concentrations (ug/g dry weight) in Mytilus edulis

Fig. 17 NICKEL concentrations (ug/g dry weight) in Mytilus edulis

Fig. 18 COPPER concentrations (ug/g dry weight) in Cerastoderma edule

Fig. 19 ZINC concentrations (ug/g dry weight) in Cerastoderma edule


KEY
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92
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Fig. 20 CADMIUM concentrations (ug/g dry weight) in Cerastoderma edule

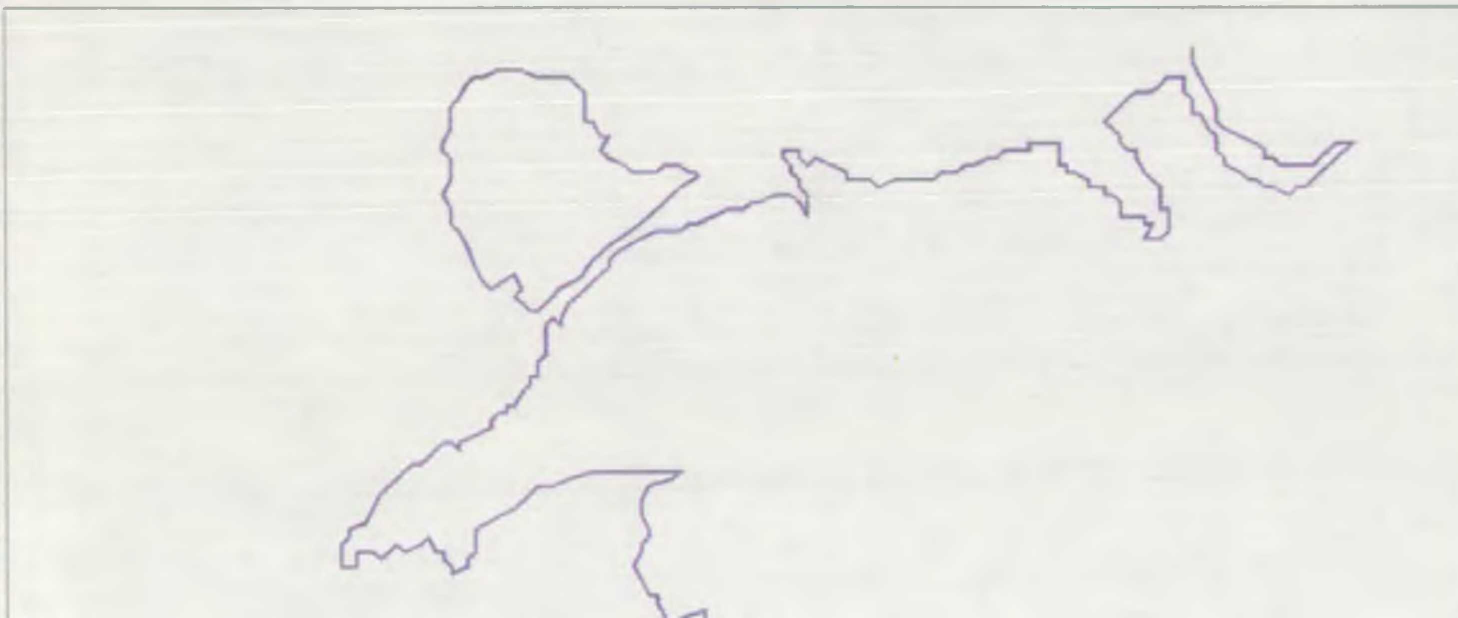


Fig. 21 MERCURY concentrations (ug/g dry weight) in Cerastoderma edule

Fig. 22 LEAD concentrations (ug/g dry weight) in Cerastoderma edule

Fig. 23 ARSENIC concentrations (ug/g dry weight) in Cerastoderma edule

Fig. 24 CHROMIUM concentrations (ug/g dry weight) in Cerastoderma edule

Fig. 25 NICKEL concentrations (ug/g dry weight) in Cerastoderma edule

Fig. 26 Distribution of metals in Fucus spp. for each site in 1993 expressed as a percentage of the total.

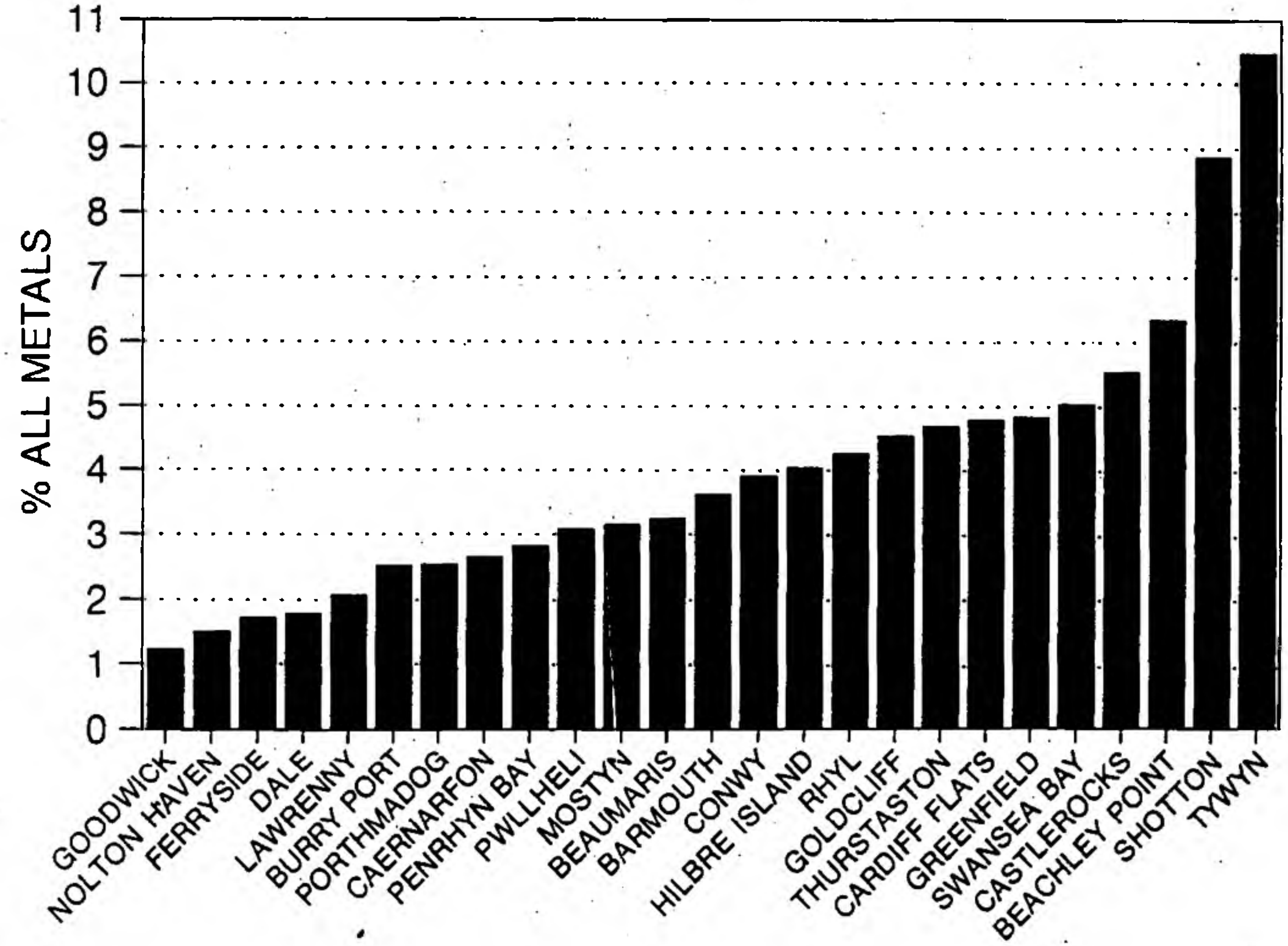
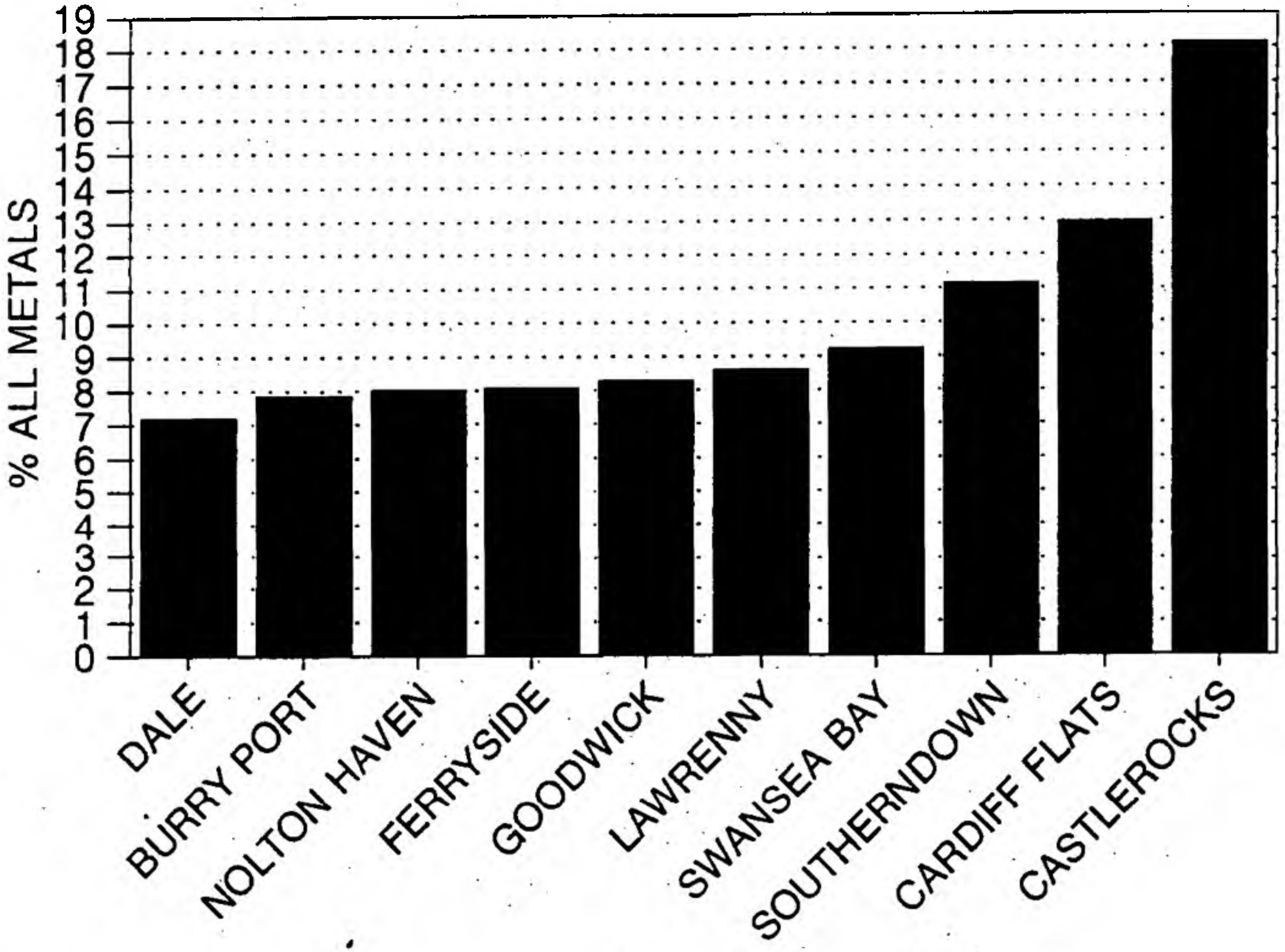


Fig. 27 Distribution of metals in Mytilus edulis for each site in 1993 expressed as a percentage of the total.



APPENDIX I - Sample collection and preparation

(a) Sample collections

Collections will be made as recommended by Barnett, 1990 in his guidelines for a standardised NRA bioaccumulation programme and summarised in the table below:

Target Species	No. of Specimens	Size (range) mm	Time for Collection	Shore Position
Fucus vesiculosus	25-30	250-300	February	Mid-shore
Mytilus edulis	50	25-45	Mid. Jan.- Mid. Feb.	Mid-shore
Cerastoderma edule	50	25-40	Jan-Mar	Mid-shore

Seaweed and shellfish can be collected by hand and placed into a clearly labelled plastic bag. Samples should be returned to the laboratory in cooled containers.

(b) Sample preparation

This will be performed by the South West EAU at Llanelli, as the facilities exist on site, and is summarised in the table:

Target Species	Storage prior to cleansing/ preparation	Cleansing	Depuration	Storage Prior to dissection	Tissue Selection
F. vesiculosus	Refrigeration (up to 10 days)	scrubbing/ washing	N/A	No, but can be deep frozen after (-18°C)	Old Thallus only
M. edulis	No	scrape off growth on shells and scrub clean	48 hours	Deep frozen (-18°C)	Remove shells
C. edule	Kept cool in sediment (up to 24 hrs)	scrubbing/ washing	3-4 days	Deep frozen (-18°C)	Remove shells

In practice samples will be transported to the laboratory as soon as possible, when samples will be washed immediately.

F. vesiculosus should be washed thoroughly in running tap water, followed by distilled water. Tips of the thallus (the 1st 5cm) and the stipes (including the last 5cm of the thallus which is likely to be worn) should be removed and discarded prior to storage. If the thallus is smooth without too many air bladders then the air bladders should be removed (this may not be practicable in specimens which have many air bladders).

M. edulis should be cleansed of as much extraneous material as possible, washed with settled seawater and placed in clean tanks containing aerated settled seawater for at least 48 hours. The tank should be fitted with a recirculation pump and the seawater continuously filtered through an activated carbon filter. The system should be set up at least 24 hours in advance. The seawater should be collected from a clean site as far west as possible and kept as close to the ambient sea temperature as possible (the garage area will be suitable). Ideally, the seawater should match the salinity of the locality in which organisms are collected from, but this will be difficult as the organisms are from differing salinity regimes and the local seawater will probably be of poor quality. A difference in salinity of +/- 5 ppt should not unduly stress the organisms (Brian Barnett pers. comm.).

During depuration, organisms sometimes will not begin to evacuate their gut contents for several days, therefore they should be observed and left for longer than 48 hours if necessary. The same procedure should be followed for *C. edule* but the recommended time is 3-4 days.

APPENDIX II - Fucus spp. Metals Concentrations

II.1 Copper concentrations (ug g⁻¹) in *Fucus* spp.

SITE	1982-1988	1991	1992	1993	1994	1995
Beachley Point	35.80	39.00	18.80	24.10	30.60	18.00
Goldcliff	31.30	18.00	15.62	17.30	18.50	19.20
Cardiff Flats	28.10	17.55	20.03	18.15	15.30	17.40
Swansea Bay	24.10	10.90	10.90	13.90	9.38	11.60
Burry Port Jetty	9.70	28.00	10.04	10.20	8.87	12.00
Ferryside	--	--	--	5.10	4.25	10.70
Lawrenny	--	--	--	6.80	6.52	10.30
Dale	--	--	--	4.70	4.32	5.16
Nolton Haven	--	--	--	4.10	4.31	5.21
Goodwick	--	--	--	2.80	4.87	3.71
Castlerocks	--	--	--	6.90	7.26	6.26
Tywyn	--	--	--	**5.58**	7.90	**6.31**
Barmouth	--	--	--	**10.90**	10.90	**7.29**
Porthmadog	--	--	--	**17.40**	14.10	18.87
Pwllheli	--	--	--	**8.32**	10.00	17.58
Caernarfon	--	--	--	9.28	9.10	8.88
Beaumaris	--	--	--	11.90	12.70	11.80
Conwy	--	--	--	8.52	7.60	8.47
Penrhyn Bay	--	--	--	**7.19**	--	7.97
Rhyl	--	--	--	12.40	11.30	12.43
Mostyn	--	13.70	9.70	**6.43**	16.40	**7.72**
Greenfield	--	16.20	12.10	9.46	10.80	15.31
Shotton	--	**16.20**	**12.30**	**9.72**	--	**12.36**
Thurstaston	--	16.10	<u>**9.68**</u>	**13.30**	--	--
Hilbre Island	--	14.60	**15.50**	9.68	10.20	<u>**10.03**</u>

Values in **bold** are concentrations in *Fucus spiralis*
Values in <u>**bold and underline**</u> are concentrations in *Fucus serratus*

II.2 **Zinc concentrations (ug g^{-1}) in *Fucus* spp.**

SITE	1982-1988	1991	1992	1993	1994	1995
Beachley Point	430	973	302	372	617	410
Goldcliff	365	321	214	262	361	361
Cardiff Flats	339	382	408	274	333	250
Swansea Bay	458	170	145	277	278	326
Burry Port Jetty	103	239	101	127	138	103
Ferryside	--	--	--	75	55	62
Lawrenny	--	--	--	94	118	93
Dale	--	--	--	71	64	75
Nolton Haven	--	--	--	46	59	41
Goodwick	--	--	--	43	86	45
Castlerocks	--	--	--	340	435	523
Tywyn	--	--	--	**690**	132	**176**
Barmouth	--	--	--	**208**	141	**100**
Porthmadog	--	--	--	**131**	168	261
Pwllheli	--	--	--	**171**	92	138
Caernarfon	--	--	--	132	112	124
Beaumaris	--	--	--	163	157	121
Conwy	--	--	--	231	127	115
Penrhyn Bay	--	--	--	**163**	--	114
Rhyl	--	--	--	246	180	113
Mostyn	--	305	198	**189**	456	**197**
Greenfield	--	675	362	303	203	237
Shotton	--	**675**	**658**	**583**	--	**341**
Thurstaston	--	245	**<u>343</u>**	**288**	--	--
Hilbre Island	--	275	**296**	244	216	**<u>245</u>**

Values in **bold** are concentrations in *Fucus spiralis*
Values in **<u>bold and underline</u>** are concentrations in *Fucus serratus*

II.3 Cadmium concentrations (ug g^{-1}) in *Fucus* spp.

SITE	1982-1988	1991	1992	1993	1994	1995
Beachley Point	21.90	26.00	12.89	18.60	21.50	8.82
Goldcliff	16.10	8.40	7.97	9.20	9.62	8.04
Cardiff Flats	9.30	8.03	7.39	9.03	7.12	4.93
Swansea Bay	4.80	2.40	1.99	3.49	1.64	2.78
Burry Port Jetty	2.70	2.30	1.99	1.51	1.76	1.76
Ferryside	--	--	--	1.35	0.66	0.90
Lawrenny	--	--	--	0.65	0.68	0.67
Dale	--	--	--	0.85	0.77	0.96
Nolton Haven	--	--	--	1.03	10.70	0.93
Goodwick	--	--	--	0.50	0.76	0.70
Castlerocks	--	--	--	1.41	1.22	1.35
Tywyn	--	--	--	**2.20**	0.87	**1.22**
Barmouth	--	--	--	**0.99**	1.34	**0.70**
Porthmadog	--	--	--	**0.52**	0.70	1.38
Pwllheli	--	--	--	**0.96**	1.35	1.10
Caernarfon	--	--	--	1.54	0.95	1.28
Beaumaris	--	--	--	1.52	1.33	1.19
Conwy	--	--	--	0.70	0.52	0.76
Penrhyn Bay	--	--	--	**1.01**	--	1.19
Rhyl	--	--	--	1.25	0.91	1.05
Mostyn	--	0.63	0.53	**0.54**	0.90	**0.43**
Greenfield	--	0.58	0.67	0.61	0.53	0.51
Shotton	--	**0.58**	**0.54**	**0.53**	--	**0.51**
Thurstaston	--	0.70	<u>**0.92**</u>	**0.95**	--	--
Hilbre Island	--	1.04	**0.86**	0.74	0.38	<u>**1.02**</u>

Values in **bold** are concentrations in *Fucus spiralis*
Values in <u>**bold and underline**</u> are concentrations in *Fucus serratus*

II.4 Mercury concentrations (ug g^{-1}) in *Fucus* spp.

SITE	1982-1988	1991	1992	1993	1994	1995
Beachley Point	--	0.086	0.036	0.024	0.070	0.042
Goldcliff	--	0.076	0.035	0.025	0.086	0.063
Cardiff Flats	--	0.054	0.051	0.033	0.025	0.039
Swansea Bay	--	0.079	0.035	0.191	0.066	0.058
Burry Port Jetty	--	0.093	0.027	0.023	0.059	0.036
Ferryside	--	--	--	0.026	0.012	0.023
Lawrenny	--	--	--	0.029	0.043	0.027
Dale	--	--	--	0.029	0.031	0.025
Nolton Haven	--	--	--	0.030	0.048	0.031
Goodwick	--	--	--	0.017	0.060	0.023
Castlerocks	--	--	--	0.032	0.055	0.025
Tywyn	--	--	--	**0.025**	0.035	**0.040**
Barmouth	--	--	--	**0.035**	0.035	**0.022**
Porthmadog	--	--	--	**0.024**	0.031	0.026
Pwllheli	--	--	--	**0.035**	0.081	0.043
Caernarfon	--	--	--	0.085	0.071	0.036
Beaumaris	--	--	--	0.090	0.080	0.063
Conwy	--	--	--	0.068	0.076	0.063
Penrhyn Bay	--	--	--	**0.042**	--	0.069
Rhyl	--	--	--	0.102	0.103	0.089
Mostyn	--	0.100	0.078	**0.032**	0.112	**0.027**
Greenfield	--	0.066	0.088	0.082	0.116	0.075
Shotton	--	**0.066**	**0.065**	**0.057**	--	**0.055**
Thurstaston	--	0.110	**<u>0.036</u>**	**0.131**	--	--
Hilbre Island	--	0.071	**0.086**	0.051	0.090	**<u>0.071</u>**

Values in bold are concentrations in *Fucus spiralis*
Values in **<u>bold and underline</u>** are concentrations in *Fucus serratus*

II.5 Lead concentrations (ug g^{-1}) in *Fucus* spp.

SITE	1982-1988	1991	1992	1993	1994	1995
Beachley Point	4.60	2.80	1.34	1.79	2.18	1.59
Goldcliff	4.50	2.20	1.03	1.59	1.52	1.54
Cardiff Flats	9.30	8.03	0.82	2.64	2.39	2.41
Swansea Bay	4.40	4.10	1.50	2.02	1.48	1.58
Burry Port Jetty	3.40	3.40	0.78	1.59	1.17	1.17
Ferryside	--	--	--	1.35	0.93	1.03
Lawrenny	--	--	--	2.08	1.53	2.46
Dale	--	--	--	1.48	1.38	1.63
Nolton Haven	--	--	--	0.50	0.86	1.08
Goodwick	--	--	--	0.86	1.56	1.12
Castlerocks	--	--	--	4.02	2.45	3.19
Tywyn	--	--	--	**32.40**	1.80	**4.60**
Barmouth	--	--	--	**3.19**	1.50	**2.09**
Porthmadog	--	--	--	**11.10**	3.70	5.22
Pwllheli	--	--	--	**1.80**	1.50	5.49
Caernarfon	--	--	--	2.46	2.60	5.29
Beaumaris	--	--	--	4.14	4.80	4.30
Conwy	--	--	--	2.42	1.60	3.48
Penrhyn Bay	--	--	--	**1.36**	--	10.05
Rhyl	--	--	--	4.51	4.20	3.79
Mostyn	--	2.10	1.22	**1.67**	6.36	**1.99**
Greenfield	--	2.10	2.20	2.62	2.80	2.39
Shotton	--	**7.70**	**4.10**	**5.35**	--	**7.47**
Thurstaston	--	2.20	**<u>4.00</u>**	**4.65**	--	--
Hilbre Island	--	3.20	**2.90**	1.53	5.03	**<u>2.29</u>**

Values in **bold** are concentrations in *Fucus spiralis*
Values in **<u>bold and underline</u>** are concentrations in *Fucus serratus*

II.6 Arsenic concentrations (ug g^{-1}) in *Fucus* spp.

SITE	1982-1988	1991	1992	1993	1994	1995
Beachley Point	--	28.40	15.68	27.80	31.60	33.10
Goldcliff	--	17.60	12.58	26.10	27.20	32.60
Cardiff Flats	--	13.00	27.32	31.45	25.20	26.30
Swansea Bay	--	19.80	15.13	57.90	33.90	60.00
Burry Port Jetty	--	25.30	22.30	35.80	51.70	56.40
Ferryside	--	--	--	38.90	24.40	34.20
Lawrenny	--	--	--	41.40	42.70	40.60
Dale	--	--	--	48.20	38.50	69.50
Nolton Haven	--	--	--	55.60	59.40	67.90
Goodwick	--	--	--	37.10	50.20	57.10
Castlerocks	--	--	--	51.20	71.60	58.70
Tywyn	--	--	--	**32.40**	61.90	**47.40**
Barmouth	--	--	--	**33.80**	71.90	**41.48**
Porthmadog	--	--	--	**21.40**	50.70	51.35
Pwllheli	--	--	--	**33.30**	51.60	43.25
Caernarfon	--	--	--	42.20	48.60	50.86
Beaumaris	--	--	--	49.40	47.60	45.46
Conwy	--	--	--	40.60	41.80	30.71
Penrhyn Bay	--	--	--	**23.00**	--	51.94
Rhyl	--	--	--	37.10	40.10	34.19
Mostyn	--	52.70	39.20	**25.80**	49.70	**23.35**
Greenfield	--	52.70	314.00	34.40	37.60	38.55
Shotton	--	**38.00**	**32.90**	**32.50**	--	**32.00**
Thurstaston	--	44.00	<u>**32.50**</u>	**29.00**	--	--
Hilbre Island	--	32.50	**29.80**	31.10	30.80	<u>**27.68**</u>

Values in **bold** are concentrations in *Fucus spiralis*
Values in <u>**bold and underline**</u> are concentrations in *Fucus serratus*

II.7 Chromium concentrations ($\mu g\ g^{-1}$) in *Fucus* spp.

SITE	1982-1988	1991	1992	1993	1994	1995
Beachley Point	--	<1.50	2.94	1.49	1.03	1.24
Goldcliff	--	<1.50	<1.50	1.64	0.84	1.52
Cardiff Flats	--	<1.50	<1.50	1.99	1.43	1.35
Swansea Bay	--	<1.50	<1.50	1.07	1.40	1.24
Burry Port Jetty	--	<1.50	1.69	1.07	1.79	1.92
Ferryside	--	--	--	1.39	0.74	0.74
Lawrenny	--	--	--	1.37	1.73	1.42
Dale	--	--	--	1.41	0.79	1.15
Nolton Haven	--	--	--	0.56	1.19	0.59
Goodwick	--	--	--	1.68	1.90	0.90
Castlerocks	--	--	--	0.47	1.30	0.99
Tywyn	--	--	--	--	0.60	**0.54**
Barmouth	--	--	--	--	0.60	**0.54**
Porthmadog	--	--	--	--	2.80	1.10
Pwllheli	--	--	--	--	0.40	1.50
Caernarfon	--	--	--	--	7.10	1.99
Beaumaris	--	--	--	--	1.50	1.69
Conwy	--	--	--	--	3.20	1.50
Penrhyn Bay	--	--	--	--	--	1.69
Rhyl	--	--	--	--	1.60	1.23
Mostyn	--	--	--	--	3.24	**0.93**
Greenfield	--	--	--	--	0.80	1.52
Shotton	--	--	--	--	--	**1.90**
Thurstaston	--	--	--	--	--	--
Hilbre Island	--	--	--	--	2.41	<u>**0.10**</u>

Values in **bold** are concentrations in *Fucus spiralis*
Values in <u>**bold and underline**</u> are concentrations in *Fucus serratus*

II.8 Nickel concentrations (ug g^{-1}) in *Fucus* spp.

SITE	1982-1988	1991	1992	1993	1994	1995
Beachley Point	20.60	25.00	12.28	22.70	35.80	18.90
Goldcliff	22.30	16.40	11.64	17.60	24.30	22.80
Cardiff Flats	11.50	15.58	12.94	17.08	19.30	16.70
Swansea Bay	17.60	10.90	9.90	16.50	17.36	16.30
Burry Port Jetty	9.70	9.40	7.03	9.60	13.15	11.80
Ferryside	--	--	--	6.00	9.39	8.82
Lawrenny	--	--	--	7.80	8.59	8.84
Dale	--	--	--	6.60	6.06	8.09
Nolton Haven	--	--	--	5.30	7.38	10.30
Goodwick	--	--	--	5.80	7.29	6.03
Castlerocks	--	--	--	5.20	8.12	8.80
Tywyn	--	--	--	**8.20**	5.70	**14.19**
Barmouth	--	--	--	**11.90**	10.50	**12.06**
Porthmadog	--	--	--	**7.10**	9.90	8.98
Pwllheli	--	--	--	**13.10**	9.10	12.98
Caernarfon	--	--	--	9.20	29.80	11.94
Beaumaris	--	--	--	11.00	8.10	10.35
Conwy	--	--	--	6.40	0.50	9.24
Penrhyn Bay	--	--	--	**13.90**	--	11.03
Rhyl	--	--	--	14.40	9.20	14.31
Mostyn	--	5.70	5.50	**10.70**	15.80	**13.30**
Greenfield	--	5.70	6.70	7.40	4.50	9.27
Shotton	--	**16.30**	**21.90**	**22.40**	--	**18.22**
Thurstaston	--	8.30	**<u>11.70</u>**	**10.90**	--	--
Hilbre Island	--	11.70	**13.70**	12.20	10.01	**<u>12.54</u>**

Values in bold are concentrations in *Fucus spiralis*
Values in **<u>bold and underline</u>** are concentrations in *Fucus serratus*

APPENDIX III - **Mytilus edulis metals concentrations**

III.1 Copper concentrations (ug g^{-1} dry weight) in *Mytilus edulis*.

SITE	1982-1988	1991	1992	1993	1994	1995
Cardiff Flats	10.90	8.03	10.89	7.41	8.86	34.90
Southerndown	--	9.40	10.47	9.10	8.63	63.80
Afan Estuary	--	5.00	--	--	--	--
Swansea Bay	7.60	6.50	8.45	6.30	11.00	15.00
Burry Port Jetty	6.50	5.40	7.96	7.50	6.50	26.90
Ferryside	--	--	--	6.40	6.54	15.60
Lawrenny	--	--	--	7.04	7.61	12.60
Dale	--	--	--	6.60	7.82	13.50
Nolton Haven	--	--	--	6.60	11.00	35.20
Goodwick	--	--	--	6.00	6.43	8.51
Castlerocks	--	--	--	6.30	7.33	40.90
Porthmadog	--	--	--	--	7.08	8.39
Caernarfon	--	--	--	--	9.88	11.76
Beaumaris	--	--	--	--	8.49	9.57
Conwy	--	--	--	--	7.76	14.81
Penrhyn Bay	--	--	--	--	7.08	10.88
Rhyl	--	10.20	7.80	--	5.80	9.16
Mostyn	--	9.50	8.30	--	6.89	26.06
Greenfield	--	9.60	9.60	--	6.87	13.26
Thurstaston	--	--	10.00	--	7.21	10.24
Hilbre Island	--	10.60	10.80	--	6.92	11.39

III.2 Zinc concentrations (ug g[-1] dry weight) in *Mytilus edulis*.

SITE	1982-1988	1991	1992	1993	1994	1995
Cardiff Flats	313	129	135	126	136	128
Southerndown	--	118	112	104	176	105
Afan Estuary	--	148	--	--	--	--
Swansea Bay	219	165	165	89	138	94
Burry Port Jetty	136	110	79	75	71	63
Ferryside	--	--	--	77	71	67
Lawrenny	--	--	--	79	108	62
Dale	--	--	--	68	78	45
Nolton Haven	--	--	--	78	82	62
Goodwick	--	--	--	73	74	41
Castlerocks	--	--	--	176	170	144
Porthmadog	--	--	--	--	63	85
Caernarfon	--	--	--	--	102	121
Beaumaris	--	--	--	--	112	92
Conwy	--	--	--	--	86	102
Penrhyn Bay	--	--	--	--	82	132
Rhyl	--	109	87	--	68	76
Mostyn	--	169	143	--	93	348
Greenfield	--	135	118	--	80	178
Thurstaston	--	--	128	--	100	99
Hilbre Island	--	120	118	--	80	98

III.3 Cadmium concentrations (ug g^{-1} dry weight) in *Mytilus edulis.*

SITE	1982-1988	1991	1992	1993	1994	1995
Cardiff Flats	22.60	11.85	16.36	6.55	1.33	1.75
Southerndown	--	3.40	3.31	4.30	3.63	3.74
Afan Estuary	--	4.40	--	--	--	--
Swansea Bay	6.27	3.70	1.99	2.35	3.81	2.88
Burry Port Jetty	1.30	2.20	1.49	1.31	1.31	1.75
Ferryside	--	--	--	1.81	1.59	1.98
Lawrenny	--	--	--	1.55	1.37	1.13
Dale	--	--	--	0.65	0.55	0.59
Nolton Haven	--	--	--	0.98	0.75	0.75
Goodwick	--	--	--	1.10	1.44	1.03
Castlerocks	--	--	--	2.04	1.94	1.75
Porthmadog	--	--	--	--	0.80	0.74
Caernarfon	--	--	--	--	2.30	1.16
Beaumaris	--	--	--	--	2.18	1.20
Conwy	--	--	--	--	1.50	1.80
Penrhyn Bay	--	--	--	--	1.50	1.85
Rhyl	--	1.31	0.99	--	0.60	0.60
Mostyn	--	1.45	1.14	--	0.80	3.31
Greenfield	--	1.38	0.87	--	0.70	0.84
Thurstaston	--	--	1.00	--	0.50	0.60
Hilbre Island	--	1.36	1.42	--	0.60	0.86

III.4 Mercury concentrations (ug g^{-1} dry weight) in *Mytilus edulis*.

SITE	1982-1988	1991	1992	1993	1994	1995
Cardiff Flats	0.39	0.28	0.44	0.82	0.82	0.29
Southerndown	--	0.29	0.23	0.68	0.92	0.39
Afan Estuary	--	0.22	--	--	--	--
Swansea Bay	--	0.09	0.20	0.45	1.13	0.19
Burry Port Jetty	--	0.13	0.12	0.35	0.56	0.12
Ferryside	--	--	--	0.92	0.90	0.23
Lawrenny	--	--	--	0.45	0.53	0.25
Dale	--	--	--	0.32	0.41	0.12
Nolton Haven	--	--	--	0.68	1.03	0.23
Goodwick	--	--	--	0.58	0.52	0.22
Castlerocks	--	--	--	0.65	0.43	0.30
Porthmadog	--	--	--	--	0.08	0.06
Caernarfon	--	--	--	--	0.49	0.34
Beaumaris	--	--	--	--	0.72	0.33
Conwy	--	--	--	--	1.16	0.37
Penrhyn Bay	--	--	--	--	0.39	0.58
Rhyl	--	0.24	0.17	--	0.18	0.21
Mostyn	--	0.28	0.20	--	0.22	0.36
Greenfield	--	0.46	0.13	--	0.14	0.12
Thurstaston	--	--	0.22	--	0.23	0.17
Hilbre Island	--	0.37	0.23	--	0.29	0.22

III.5 **Lead concentrations (ug g-1 dry weight) in *Mytilus edulis*.**

SITE	1982-1988	1991	1992	1993	1994	1995
Cardiff Flats	10.10	3.71	4.21	7.22	8.43	9.72
Southerndown	--	5.40	2.94	5.24	13.90	10.13
Afan Estuary	--	10.20	--	--	--	--
Swansea Bay	11.50	1.50	3.88	5.00	6.38	9.06
Burry Port Jetty	4.10	5.70	1.88	2.48	2.71	4.05
Ferryside	--	--	--	3.01	4.50	5.73
Lawrenny	--	--	--	3.13	6.50	4.47
Dale	--	--	--	3.30	3.19	3.25
Nolton Haven	--	--	--	2.14	3.08	3.16
Goodwick	--	--	--	4.47	6.13	3.99
Castlerocks	--	--	--	32.10	36.80	32.20
Porthmadog	--	--	--	--	3.00	3.39
Caernarfon	--	--	--	--	7.46	10.49
Beaumaris	--	--	--	--	9.59	9.47
Conwy	--	--	--	--	8.63	6.89
Penrhyn Bay	--	--	--	--	10.14	7.98
Rhyl	--	5.40	3.90	--	3.20	3.58
Mostyn	--	8.70	7.00	--	5.30	20.18
Greenfield	--	5.50	5.70	--	3.61	4.99
Thurstaston	--	--	5.70	--	3.82	4.39
Hilbre Island	--	4.80	5.20	--	3.60	4.58

III.6 Arsenic concentrations (ug g^{-1} dry weight) in *Mytilus edulis*.

SITE	1982-1988	1991	1992	1993	1994	1995
Cardiff Flats	--	4.83	9.75	16.53	18.30	22.50
Southerndown	--	4.00	6.73	18.20	20.50	18.78
Afan Estuary	--	4.50	--	--	--	--
Swansea Bay	--	5.70	8.20	15.50	16.30	19.38
Burry Port Jetty	--	6.00	7.26	14.70	13.59	15.13
Ferryside	--	--	--	14.40	15.60	16.77
Lawrenny	--	--	--	19.60	20.78	19.89
Dale	--	--	--	14.30	15.80	13.82
Nolton Haven	--	--	--	14.90	18.90	15.42
Goodwick	--	--	--	21.20	22.92	19.69
Castlerocks	--	--	--	17.60	20.40	18.19
Porthmadog	--	--	--	--	9.69	13.48
Caernarfon	--	--	--	--	15.80	20.04
Beaumaris	--	--	--	--	18.90	16.25
Conwy	--	--	--	--	16.48	19.08
Penrhyn Bay	--	--	--	--	14.77	20.11
Rhyl	--	16.90	12.90	--	9.58	15.35
Mostyn	--	18.40	16.20	--	10.77	22.91
Greenfield	--	17.40	14.40	--	9.76	13.05
Thurstaston	--	--	15.70	--	10.37	13.49
Hilbre Island	--	17.10	13.90	--	9.92	15.46

III.7 Chromium concentrations (ug g^{-1} dry weight) in *Mytilus edulis*.

SITE	1982-1988	1991	1992	1993	1994	1995
Cardiff Flats	--	4.13	7.99	3.36	6.55	6.09
Southerndown	--	3.90	3.11	2.43	3.98	2.56
Afan Estuary	--	5.50	--	--	--	--
Swansea Bay	--	4.40	2.68	1.31	2.61	2.48
Burry Port Jetty	3.75	3.00	2.19	1.01	1.23	2.03
Ferryside	--	--	--	1.25	1.56	2.38
Lawrenny	--	--	--	0.84	1.68	2.27
Dale	--	--	--	0.66	1.11	1.09
Nolton Haven	--	--	--	1.03	1.25	1.90
Goodwick	--	--	--	1.24	2.28	1.78
Castlerocks	--	--	--	1.25	1.82	2.02
Porthmadog	--	--	--	--	0.80	0.80
Caernarfon	--	--	--	--	2.89	1.79
Beaumaris	--	--	--	--	2.40	1.70
Conwy	--	--	--	--	2.00	2.89
Penrhyn Bay	--	--	--	--	1.63	2.99
Rhyl	--	--	--	--	1.35	1.19
Mostyn	--	--	--	--	1.39	3.78
Greenfield	--	--	--	--	1.03	1.29
Thurstaston	--	--	--	--	0.79	1.00
Hilbre Island	--	--	--	--	0.91	1.49

III.8 **Nickel concentrations (ug g^{-1} dry weight) in *Mytilus edulis*.**

SITE	1982-1988	1991	1992	1993	1994	1995
Cardiff Flats	6.25	6.05	4.58	3.16	4.63	11.20
Southerndown	--	4.40	1.83	3.31	4.85	6.43
Afan Estuary	--	3.50	--	--	--	--
Swansea Bay	4.15	2.90	2.89	2.02	2.97	5.16
Burry Port Jetty	1.90	2.00	1.34	1.69	1.93	6.14
Ferryside	--	--	--	2.02	1.89	4.62
Lawrenny	--	--	--	2.28	3.18	3.97
Dale	--	--	--	1.59	1.32	1.85
Nolton Haven	--	--	--	1.89	4.79	3.95
Goodwick	--	--	--	1.99	2.63	2.76
Castlerocks	--	--	--	3.33	2.05	4.72
Porthmadog	--	--	--	--	1.40	3.49
Caernarfon	--	--	--	--	11.75	11.17
Beaumaris	--	--	--	--	2.70	4.57
Conwy	--	--	--	--	1.67	10.96
Penrhyn Bay	--	--	--	--	9.00	13.87
Rhyl	--	3.60	1.20	--	2.17	0.67
Mostyn	--	2.70	1.70	--	1.31	17.23
Greenfield	--	3.10	1.70	--	1.11	7.28
Thurstaston	--	--	3.30	--	1.38	3.09
Hilbre Island	--	1.40	2.10	--	1.09	2.99

APPENDIX IV - **Metal concentrations (ug g⁻¹ dry weight) in *Cerastoderma edule*.**

SITE	METAL	1986-1988	1991	1992	1993	1994	1995
Jersey Marine	Cu	--	--	--	4.54	--	--
Burry Inlet	Cu	4.60	3.00	3.47	3.90	60.20	30.20
Trostre	Cu	--	--	--	5.60	5.35	--
Jersey Marine	Zn	--	--	--	66	--	--
Burry Inlet	Zn	201	61	72	61	84	56
Trostre	Zn	--	--	--	49	51	--
Jersey Marine	Cd	--	--	--	0.73	--	--
Burry Inlet	Cd	1.40	0.40	0.49	0.83	0.63	0.55
Trostre	Cd	--	--	--	0.44	0.32	--
Jersey Marine	Hg	--	--	--	0.55	--	--
Burry Inlet	Hg	--	0.10	0.11	1.07	0.91	0.25
Trostre	Hg	--	--	--	0.44	0.75	--
Jersey Marine	Pb	--	--	--	1.70	--	--
Burry Inlet	Pb	2.50	0.68	0.82	0.86	5.47	2.20
Trostre	Pb	--	--	--	0.84	0.98	--
Jersey Marine	As	--	--	--	10.50	--	--
Burry Inlet	As	--	2.40	4.04	11.50	17.28	13.46
Trostre	As	--	--	--	11.20	11.17	--
Jersey Marine	Cr	--	--	--	1.29	--	--
Burry Inlet	Cr	24.10	2.00	2.24	2.95	9.07	2.35
Trostre	Cr	--	--	--	2.49	2.81	--
Jersey Marine	Ni	--	--	--	88.60	--	--
Burry Inlet	Ni	50.80	31.00	21.47	33.10	71.10	46.10
Trostre	Ni	--	--	--	41.00	35.70	--

APPENDIX V - Tidal Waters Bioaccumulation Programme

(a) Fucus vesiculosus

SITE	COPPER		CADMIUM		NICKEL	
	Tips	Stipes	Tips	Stipes	Tips	Stipes
Beachley Point	18.93	20.10	16.20	19.85	10.20	20.55
Goldcliff	29.16	34.55	16.66	16.25	14.96	18.95
Cardiff Flats	22.40	25.70	11.60	14.10	8.85	23.00
Swansea Flats	11.93	16.20	3.56	3.20	10.66	16.95
Nolton Haven	3.90	3.20	2.25	1.50	5.45	6.50
Aberystwyth	4.40	6.20	1.65	3.60	3.05	5.70
Tywyn	6.90	5.80	2.30	0.90	10.90	8.30
Barmouth	14.50	6.60	1.30	1.80	7.50	7.20
Porthmadog	22.05	12.40	1.25	2.20	10.15	11.30
Pwllheli	7.95	8.30	1.45	2.90	3.55	9.80
Caernarfon	7.55	8.50	1.70	2.10	5.65	7.80
Beaumaris	14.00	120.90	2.30	3.40	7.30	11.70
Conwy	7.90	10.00	1.20	2.10	3.40	11.80
Penrhyn Bay	8.50	8.60	2.60	2.00	9.70	12.80
Mostyn	10.65	12.80	0.65	0.60	2.60	6.90
Hilbre Island	16.10	17.80	1.90	1.10	8.60	16.80

APPENDIX V.1 continued...

SITE	ZINC		LEAD		CHROMIUM	
	Tips	Stipes	Tips	Stipes	Tips	Stipes
Beachley Point	489	395	1.72	0.02	0.36	0.45
Goldcliff	575	296	1.68	0.26	0.73	0.00
Cardiff Flats	618	666	0.52	2.60	0.55	0.80
Swansea Flats	327	235	2.47	0.73	0.46	1.15
Nolton Haven	76	53	2.55	0.00	0.20	0.00
Aberystwyth	452	448	3.25	4.60	0.00	0.00
Tywyn	600	265	5.20	7.20	0.00	0.10
Barmouth	169	161	12.40	0.90	2.65	0.10
Porthmadog	241	199	19.65	0.50	0.85	0.00
Pwllheli	137	106	5.55	4.90	0.35	0.20
Caernarfon	220	185	6.10	1.40	0.25	0.10
Beaumaris	463	160	3.20	3.70	0.80	1.20
Conwy	419	200	0.00	2.40	0.00	0.10
Penrhyn Bay	583	391	0.00	2.00	0.00	0.10
Mostyn	1111	1502	4.90	3.90	0.65	0.50
Hilbre Island	1649	1320	2.70	2.80	0.00	0.20