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Guardians of the Water Environment
Diogelwyr Amgylchedd Dŵr

Results of the NRA Welsh Regional

Marine Bioaccumulation Programme

1991-1993

SE/EAU/94/8

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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 have been carried out, but at a limited number of sites mainly in South Wales (Swansea Bay and the Severn Estuary). Bioaccumulation is a 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. Elevations 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 the maximum UK concentrations for some metals (Burt *et al.*, 1992) and include:

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 'naturally' occurring, 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, Lead, Chromium and Nickel in the shellfish species from Burry Inlet, Swansea Bay and the Severn Estuary has declined 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. Due to limited historical data, the conclusions about temporal trends can only be tentative at this stage and can only be drawn sensibly with reference to the South Wales sites that historical information is available for. The Regional Permissive bioaccumulation programme needs to be continued therefore at its current level, for *Fucus* and *Mytilus*.

7. *Cerastoderma edule*, should continue to be collected at Burry Inlet but does not need to be collected from the other 2 sites at Trostre and Jersey Marine, as concentrations measured in 1993 are similar from all 3 sites.

8. Concentrations of organic compounds were present at low levels i.e. less than the routine analytical detection limits at all sites for all species. Organic compounds are costly to determine and the frequency of analysis could be reduced at most sites to a rolling programme of a once in 3 year determination.

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 vesiculosus*, a brown alga that lives on rocky shores in the intertidal zone. It extracts nutrients etc. direct from the water column and the chemical loadings 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, 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 species from each site 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) 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 for each site by species for each metal (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 43.1 ug/g at Goodwick in 1993; 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).

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 0.50 ug/g measured at Goodwick in 1993, 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 0.017 ug/g at Goodwick in 1993 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 the mean value of 9.3 ug/g at Cardiff Flats from 1982-1988 (Fig. 6). Concentrations in *Fucus spiralis* in the Dee Estuary and Porthmadog exceed this but there is only one year's data for Porthmadog.

vi) Arsenic (As)

Arsenic levels in *F. vesiculosus* ranged from 13.0 ug/g at Cardiff Flats in 1991 to 341.0 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 2.94 ug/g at Beachley Slip in 1992. During 1991 levels less than the detection limit (<1.5 ug/g) were recorded at all sites. There was no particular spatial trend apparent (Fig. 8). No data were available for North Wales.

viii) Nickel (Ni)

Nickel levels in *F. vesiculosus* ranged from a minimum of 5.2 ug/g at Castlerocks (Aberystwyth) in 1993 to a maximum of 25.0 ug/g at Beachley Slip in 1991. 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 Slip) but with similar elevations in *Fucus spiralis* from the Dee Estuary (Fig. 9).

3.1.2 *Mytilus edulis*

The spatial trends described in the previous section with reference to *Fucus* spp, are similar in *Mytilus edulis* for Copper (Fig. 10), 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) (there is no Chromium data available from the North). For *Mytilus* only (Fig. 13) and based on just the 1993 samples, concentrations of

Mercury increase from Burry Port westwards to Pembrokeshire and Cardigan Bay. These increases are only small (<1.0 ug/g) and more data is needed before this observation can be confirmed.

Ranges for Copper (5.0-10.9 ug/g), Zinc (75-320 ug/g), Cadmium (0.65-22.6 ug/g), Arsenic (4-24 ug/g) and Nickel (1.2-6.5 ug/g) are all within the range of values recorded for *Fucus*. The metal concentration ranges are 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. Mercury (0.09-1.0 ug/g), Lead (1.5-32.1 ug/g) and Chromium (0.7-8.0 ug/g, in contrast, are all outside the ranges for *Fucus* (although not widely so) and indicates the possible association with particles of these metals.

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 is little spatial variation between these three sites, although the data is limited to just 1993 data for the 2 new sites (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*.

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 3 years ('91-'93) 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 at this stage.

i) *Fucus vesiculosus*

Trends in concentration from '82-'88 to the recent data ('91-'93) are summarised:

Copper shows a downward trend in concentration (Fig. 2)
Mercury - downward in the Severn Estuary (Fig. 6)
Chromium - upward (Fig. 8)

ii) *Mytilus edulis*

Zinc - downward (Fig. 11) e.g. at Burry Port levels fell from 136 to 75 ug/g from '82-'88 to 1993 and in Swansea Bay fell from 219 to 89 ug/g over the same period
Cadmium - downward (Fig. 12)
Lead - downward (Fig. 14)
Chromium - downward in Swansea Bay (Fig. 16) Nickel - downward (Fig. 17)

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

Zinc - downward (Fig. 19). At Burry Inlet a decline from 201 ug/g (mean '86-'88) to 64.6 ug/g (mean '91-'93) occurred.
Cadmium - downward (Fig. 20)
Lead - downward. The '91-'93 mean lead concentration at Burry Inlet (0.79 ug/g) contrasts with the higher mean '86-'88 level of 2.5 ug/g (Fig. 22)
Chromium - downward (Fig. 24)
Nickel - downward (Fig. 25). Levels at Burry Inlet have increased slightly since 1991 (2.0 - 2.95 ug/g), but are considerably less than the '86-'88 mean of 24.1 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.

4.0 ORGANICS RESULTS

The following organics were measured in tissue. All the samples for all species were less than the detection limits of those organic compounds. Detection limits vary slightly according to the amount of tissue that was available for analysis. The various detection limit ranges for each species during 1992 and 1993 were as follows:

	M. edulis 1992-1993 ug/kg	F. vesiculosus 1992-1993 ug/kg	C. edule 1992-1993 ug/kg
ALDRIN	6-21	4-17	8-15
HCH ALPHA	6-21	4-17	8-15
HCH GAMMA	6-21	4-17	8-15
DIELDRIN	6-21	4-17	8-15
DDT (PP')	6-21	4-17	8-15
DDT (OP')	6-21	4-17	8-15
DDE (PP')	6-21	4-17	8-15
DDE (OP')	6-21	4-17	8-15
TDE (PP')	6-21	4-17	8-15
ENDRIN	12-42	8-30	16-30
HEXACHLOROBENZENE	6-21	4-17	8-15

HEXACHLOROBUTADIENE	6-21	4-17	8-15
CHLOROFORM	5-10	7-18	7-11
CARBON TETRACHLORIDE	5-10	7-18	7-11
PENTACHLOROPHENOL	60-100	40-100	80
PCB 28	6-21	4-17	8-15
PCB 52	6-21	4-17	8-15
PCB 101	6-21	4-17	8-15
PCB 118	6-21	4-17	8-15
PCB 138	6-21	4-17	8-15
PCB 153	6-21	4-17	8-15
PCB 180	6-21	4-17	8-15

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 wich 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 Vale, Harrison 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 recently published 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 (198-675 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 is particularly contaminated by Chromium (Fig. 24).

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.

The two extra sites for *C. edule* at Trostre and Jersey Marine sampled from 1993 onwards, may be unecessary, as they are located very close together and show very similar metals levels from all 3 sites (Figs. 18-25). The site at Burry Inlet, for which historical information exists, should continue to be sampled.

5.2 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 have the maximum National concentrations (Burt *et al.*, 1992) include:

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 (nr Cardiff), 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 is 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).

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 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 15.15 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.

5.3 Temporal trends in metals distribution

The measured decline in Zinc, Cadmium, Lead, Chromium 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 localitites. This is probaly linked to the decline in heavy industries, such as metal refining and coal-mining, in those areas. In the case of the Chromium 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 concentraions of Lead, Copper, 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.

Because the conclusions about temporal trends can only be tentative at this stage and can only be drawn sensibly with reference to the South Wales sites that historical information is available for, the Regional Permissive bioaccumulation programme needs to be continued at its current level, for *Fucus* and *Mytilus*. *C. edule* should continue to be collected at Burry Inlet but does not need to be collected from the other 2 sites at Trostre and Jersey Marine, as concentrations measured in 1993 are similar from all 3 sites.

5.4 Organics Levels

No conclusions can be drawn regarding the distribution of organics around the coastline from the recent data, as for all organic compounds in all species the concentrations were below the routine analytical detection limits for those compounds. In an earlier Welsh Water Tidal Waters Unit study (Welsh Water Authority, 1982[b]) however, when the detection limits were even lower than in the present study, positive values were found. In this earlier work, the most useful indicator of organic compounds was *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. Elevations of PCBs in *Mytilus* were recorded before from sites in the industrialised areas of the Upper Severn Estuary, Swansea Bay, Burry Inlet and North Wales. These concentrations were all above the detection limits used in the present study and would have been detected in the present study if they were still present in the same concentrations. It would appear that the levels of PCBs in *Mytilus* in these areas has declined. Similarly, DDT and its metabolites were recorded in *Mytilus* from the Upper Severn Estuary and the Dee Estuary, in concentrations that would still have been picked up by the present study. These levels must have declined also.

6.0 Conclusions

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.
2. Because the conclusions about temporal trends can only be tentative at this stage and can only be drawn sensibly with reference to the South Wales sites that historical information is available for, the Regional Permissive bioaccumulation programme needs to be continued at its current level, for *Fucus* and *Mytilus*.
3. *C. edule* should continue to be collected at Burry Inlet but does not need to be collected from the other 2 sites at Trostre and Jersey Marine, as concentrations measured in 1993 are similar from all 3 sites.
4. Concentrations of organic compounds were present at low levels i.e. less than the routine analytical detection limits at all sites for all species.

7.0 Recommendations

1. Continue the Regional Permissive Bioaccumulation programme at its present annual freqency for metals determination in *F. vesiculosus* and *M. edulis* for all the sites that have been sampled in 1993 and 1994.

2. *C. edule* should only be sampled from the Burry Inlet site.

3. Organic compounds are costly to determine and the freqency of analysis could be reduced at most sites to a rolling programme of a once in 3 year determination. The National Marine Programme sites (Table 1) however, will have to be monitored every year as a requirement of that programme. The detail of which sites are to be sampled for organic compounds will be given prior to the 1995 sample collection.

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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 Fucus spp. COPPER (ug/g dry weight)

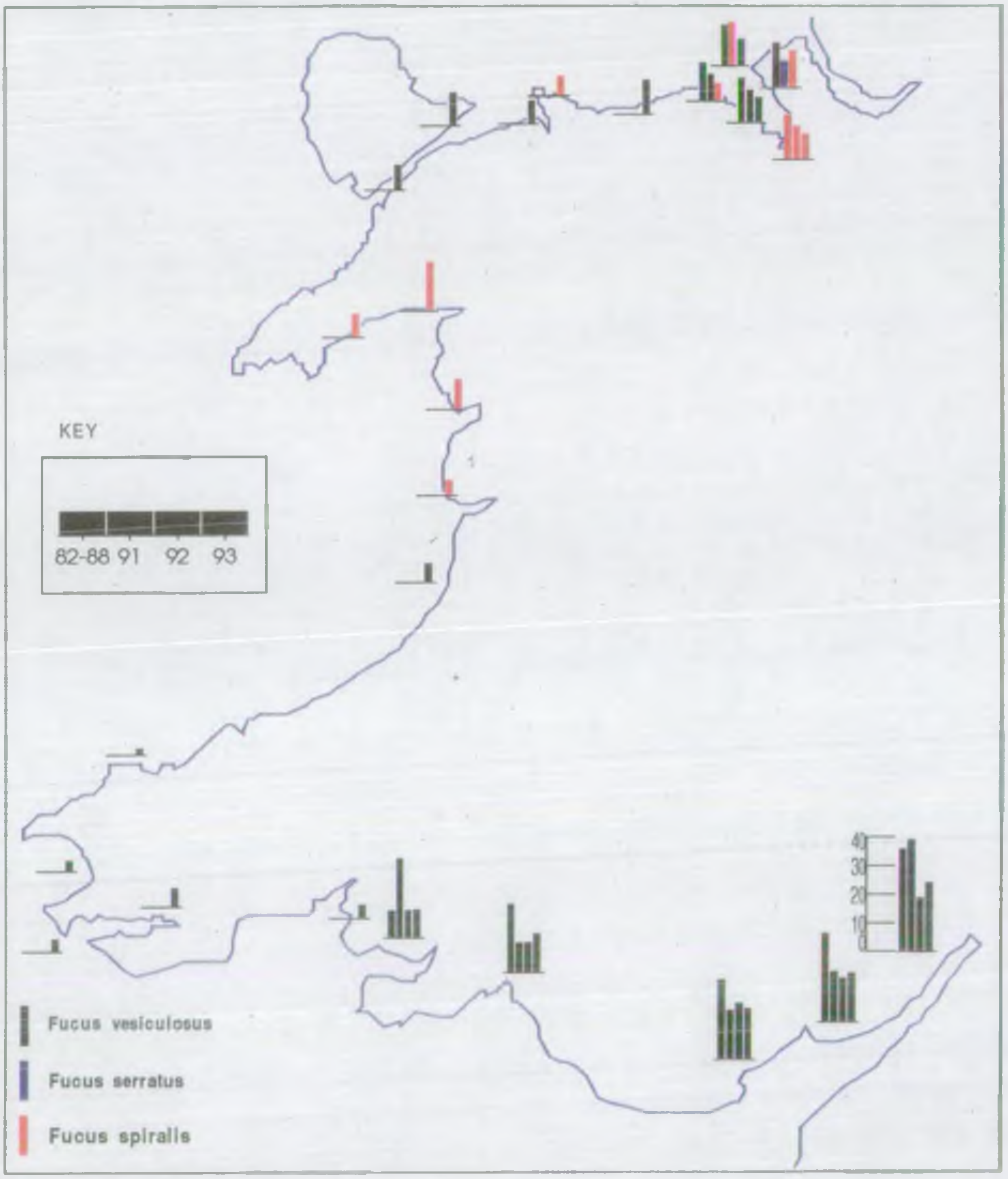


Fig. 3 Fucus spp. ZINC (ug/g dry weight)

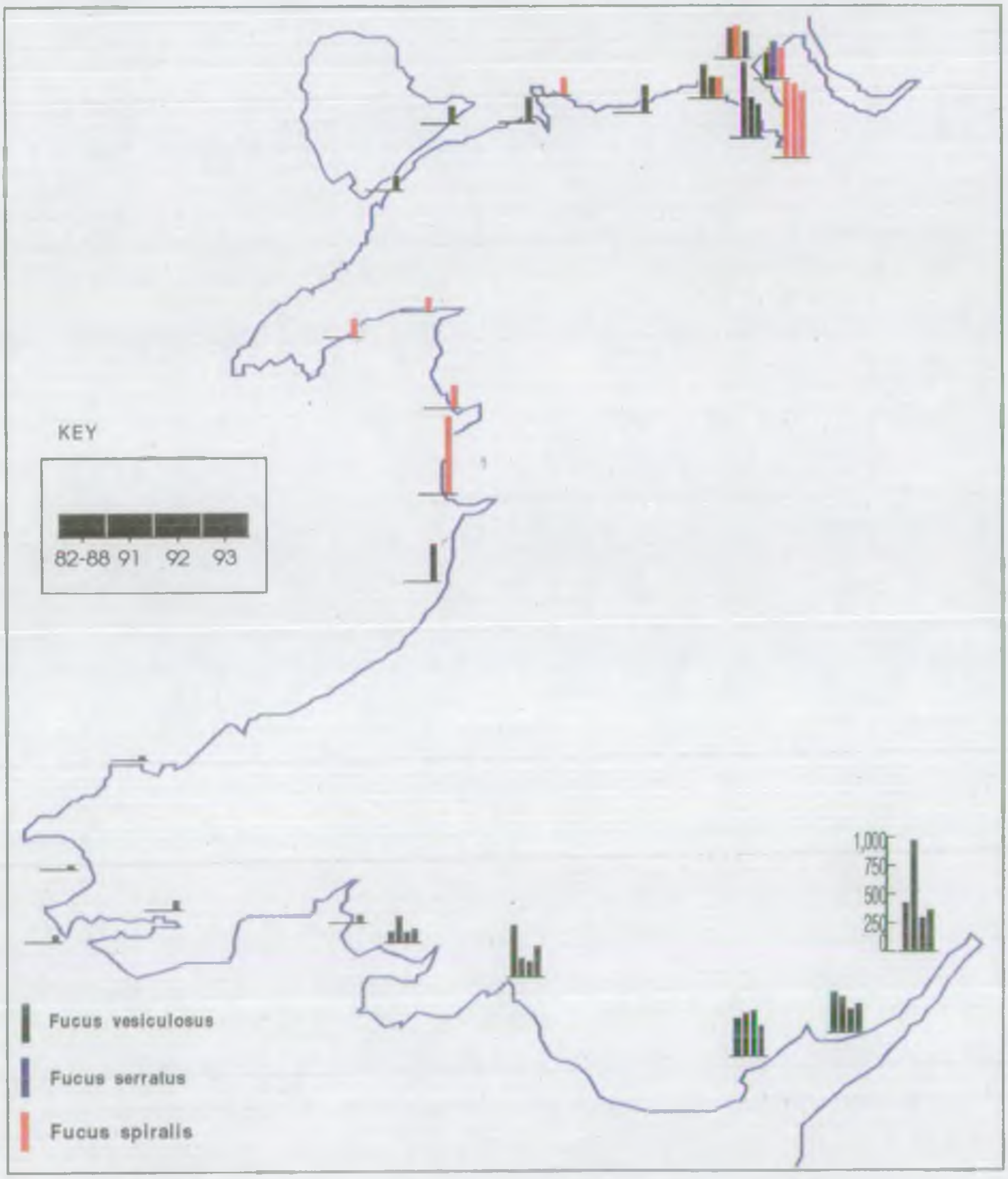


Fig. 4 Fucus spp. CADMIUM (ug/g dry weight)

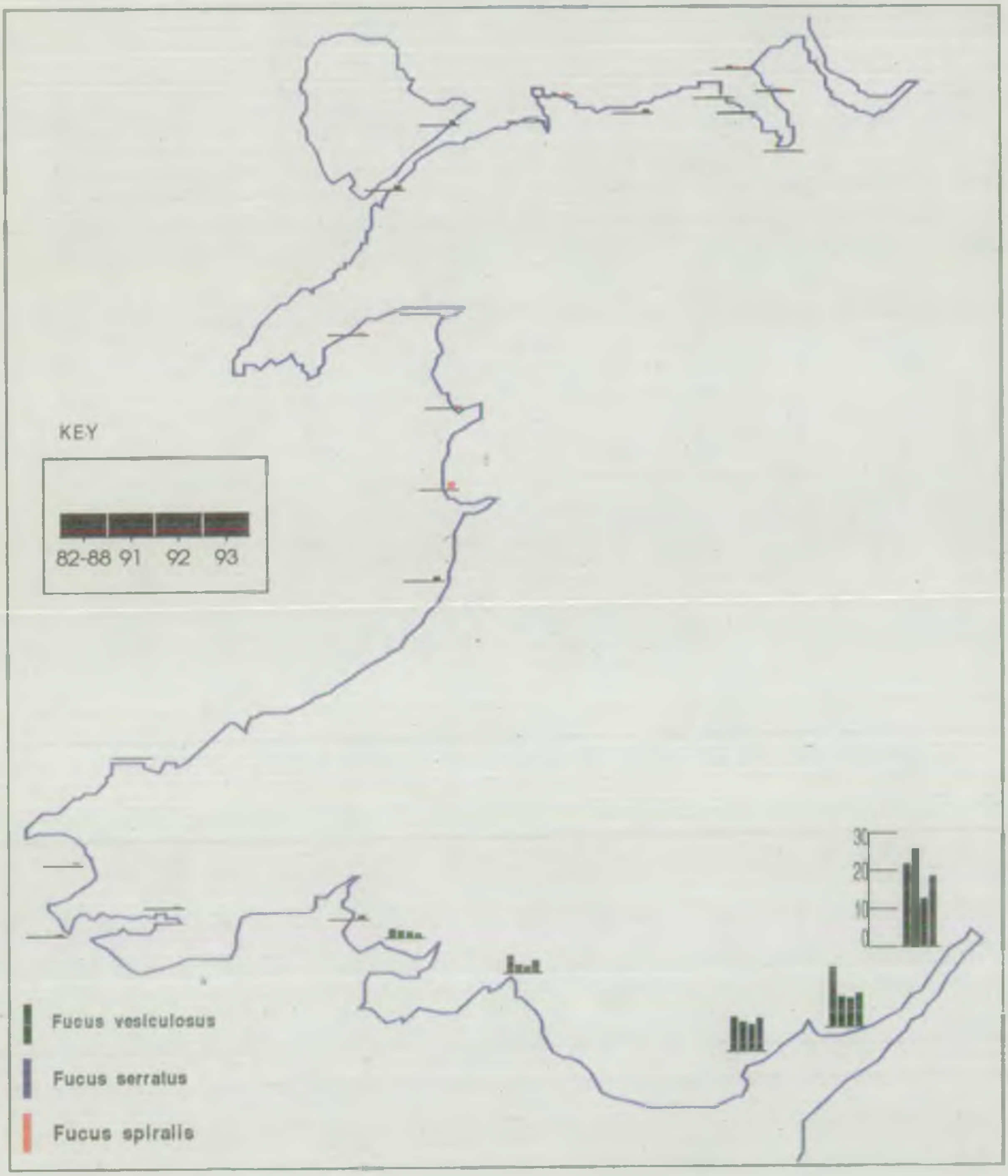


Fig. 5 Fucus spp. MERCURY (ug/g dry weight)

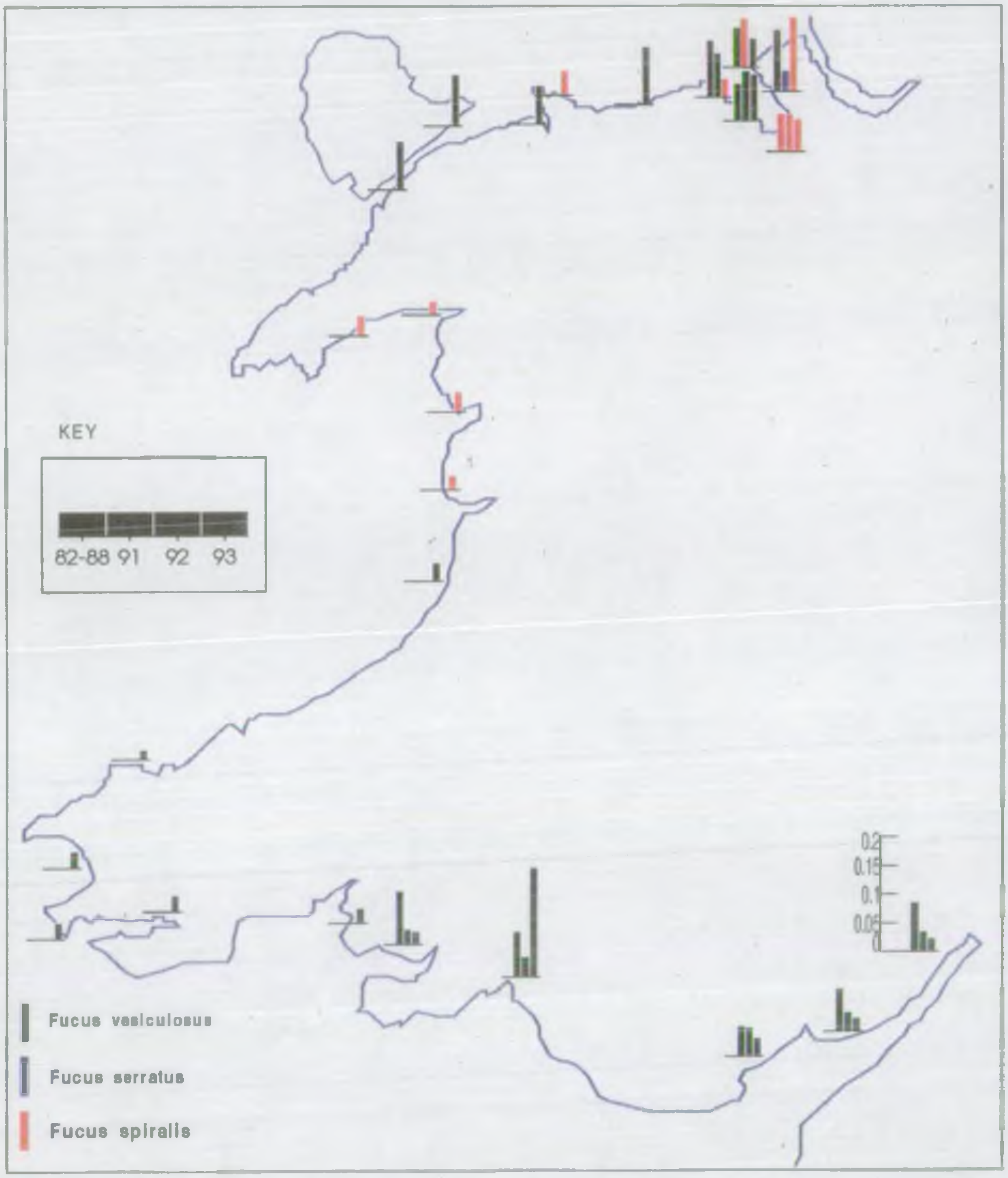


Fig. 6 Fucus spp. LEAD (ug/g dry weight)

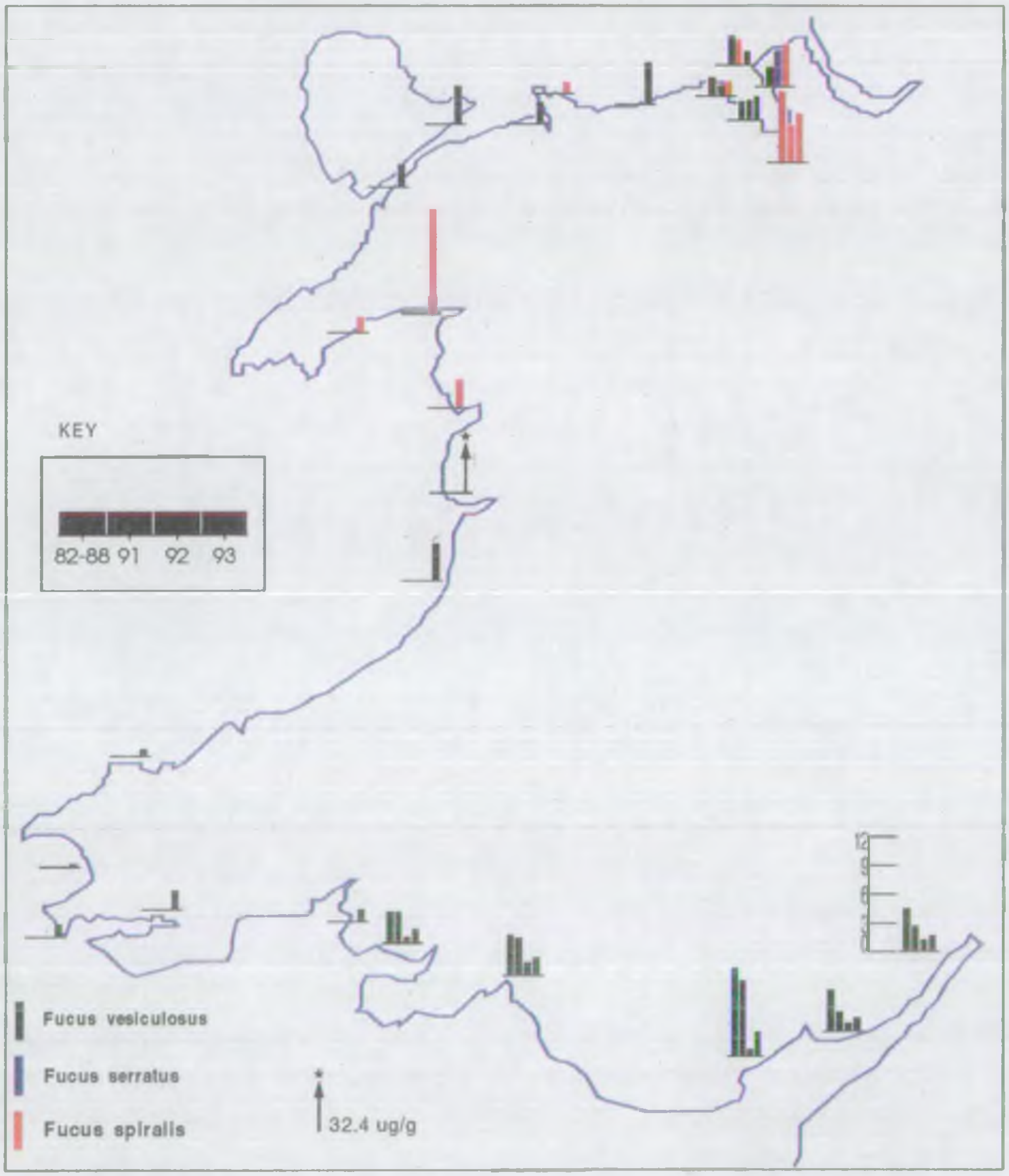


Fig. 7 Fucus spp. ARSENIC (ug/g dry weight)

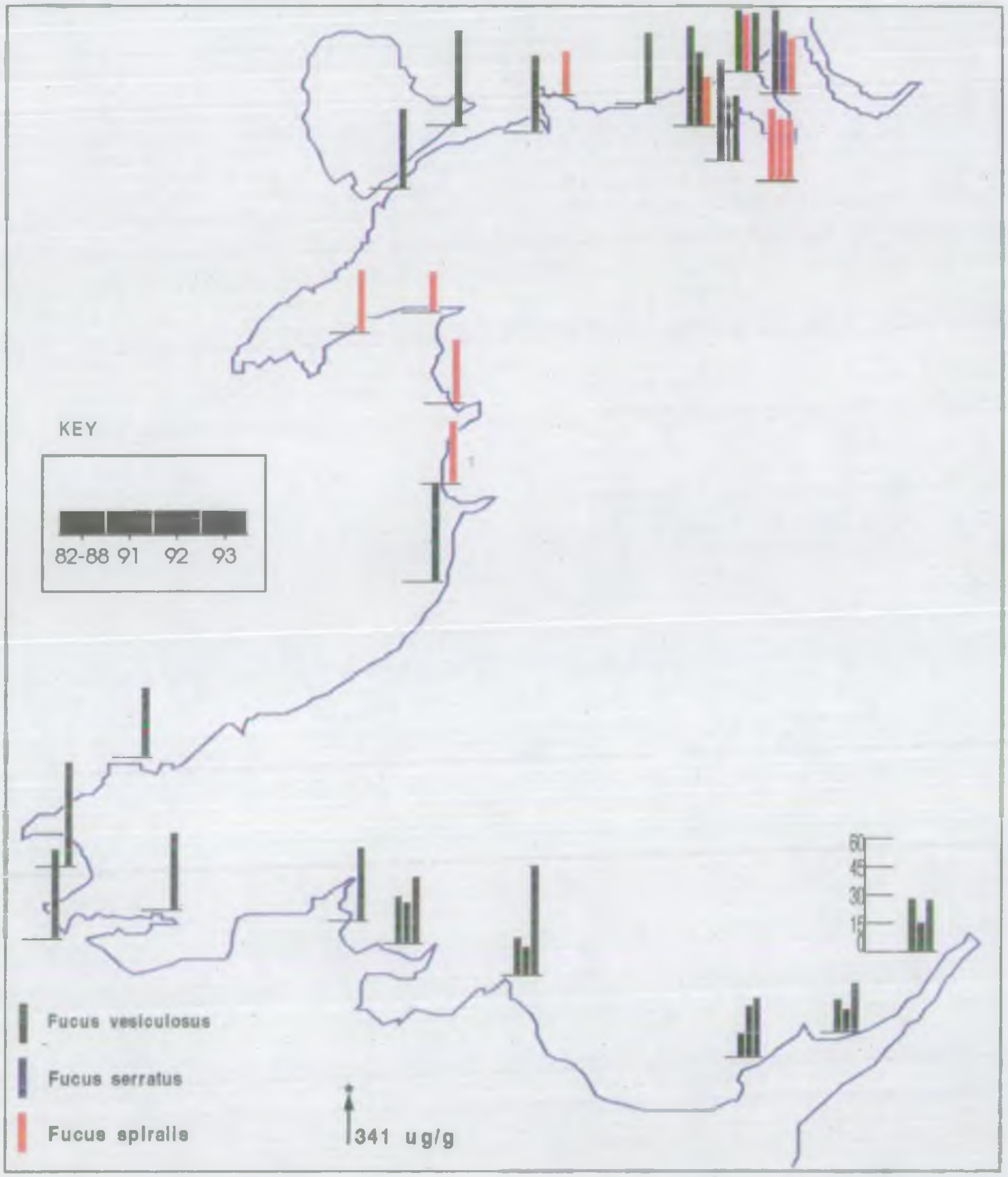


Fig. 8 Fucus spp. CHROMIUM (ug/g dry weight)

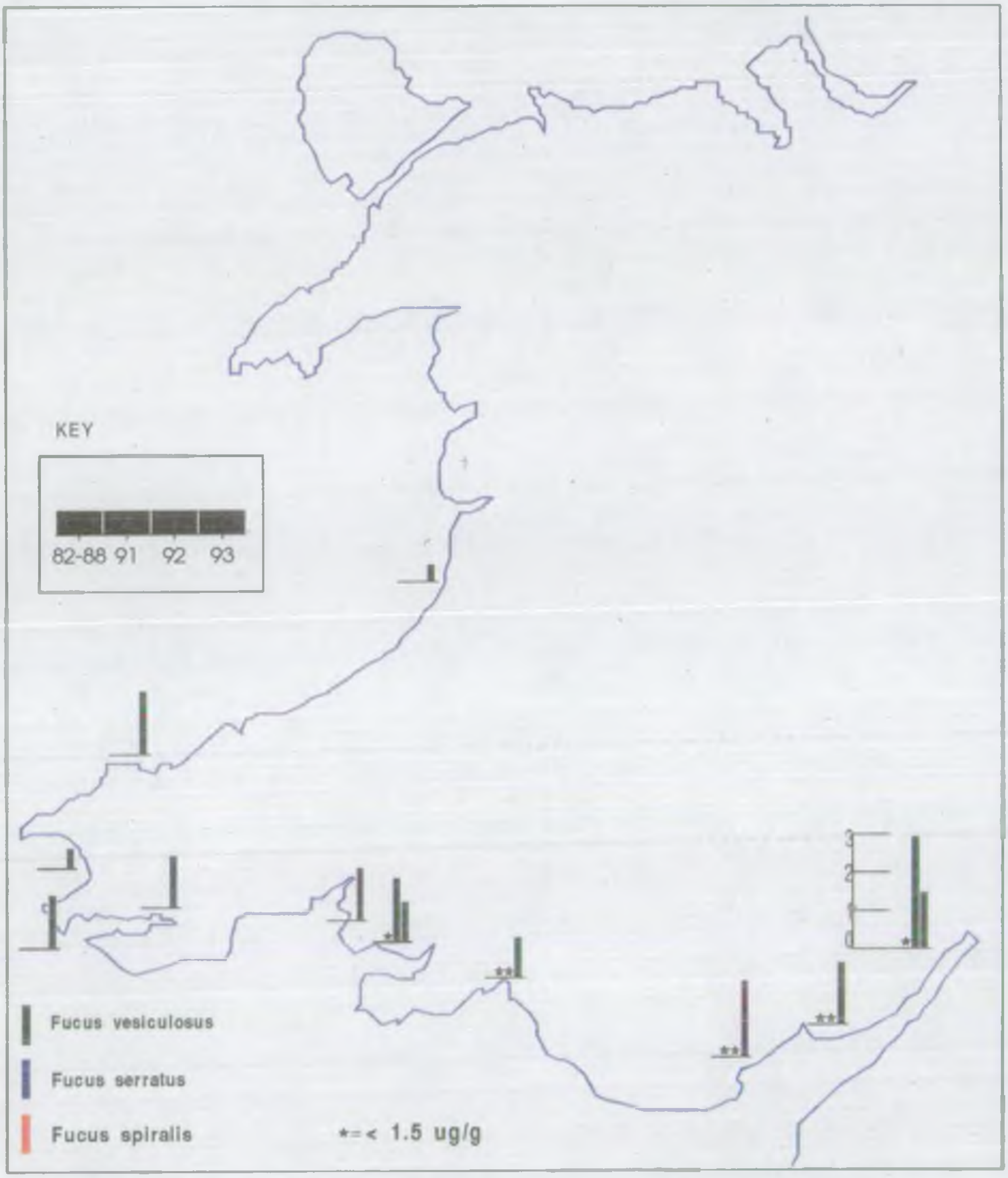


Fig. 9 Fucus spp. NICKEL (ug/g dry weight)

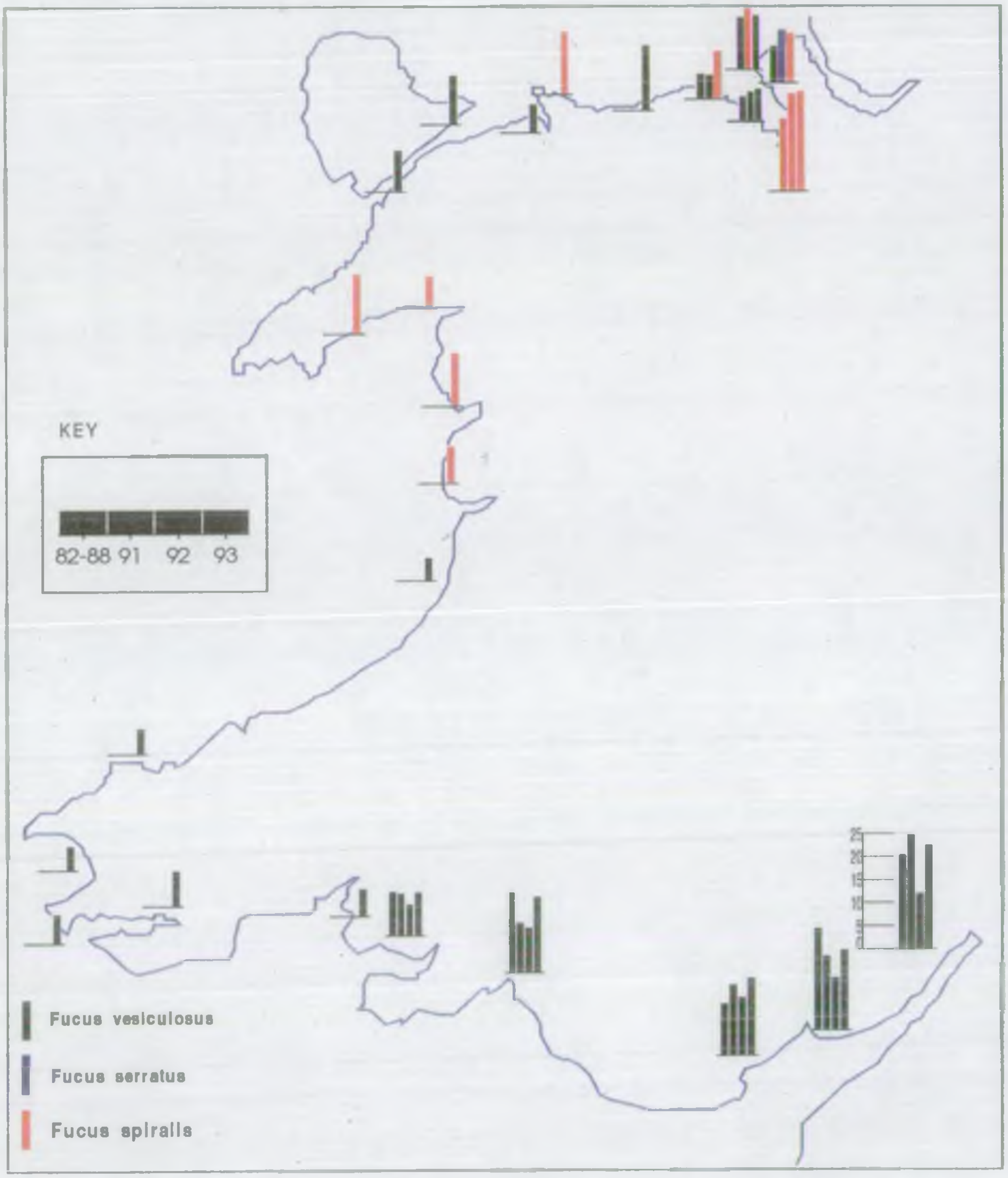


Fig. 10 Mytilus edulis. COPPER (ug/g dry tissue wt)

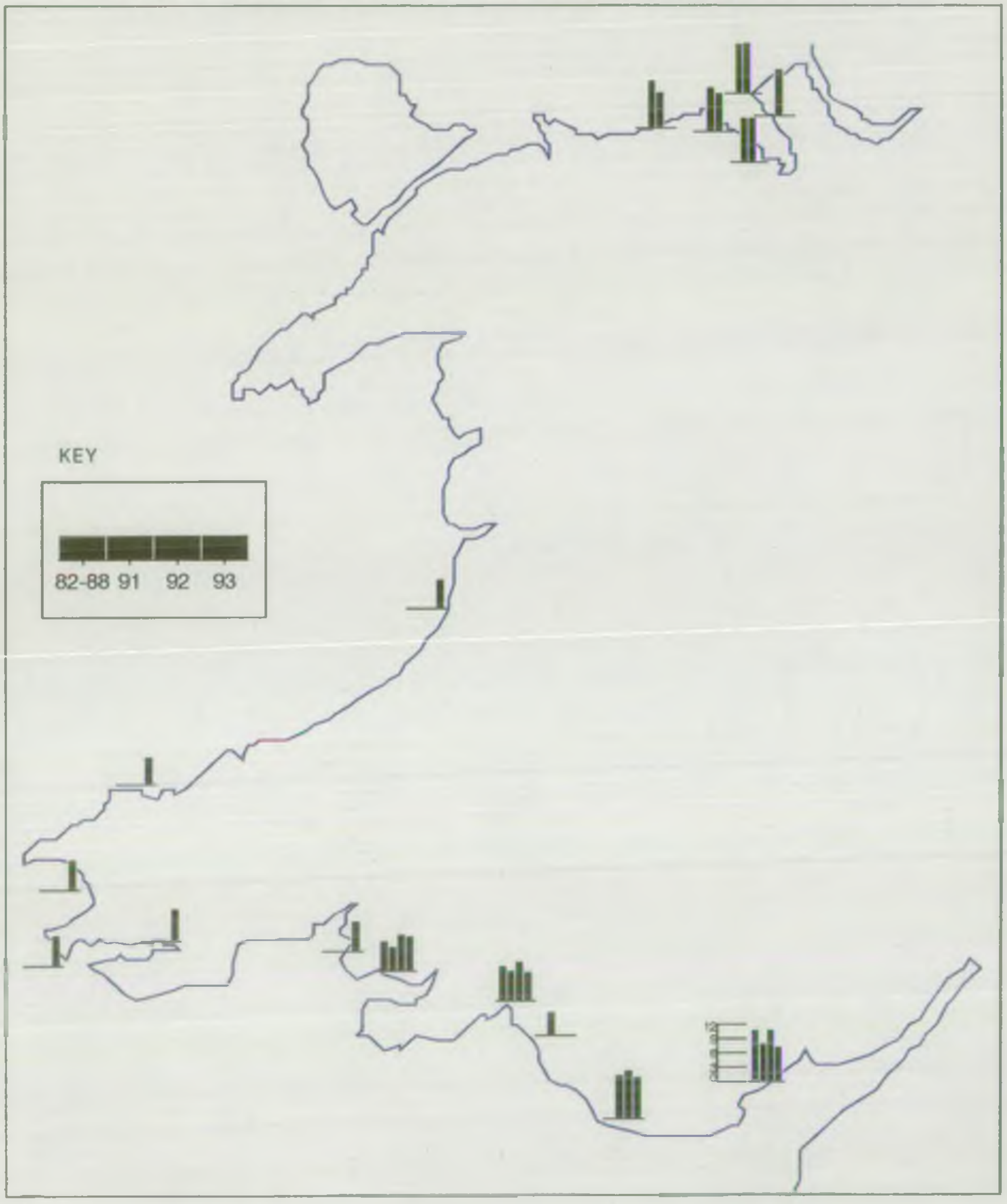


Fig. 11 Mytilus edulis. ZINC (ug/g dry tissue wt)

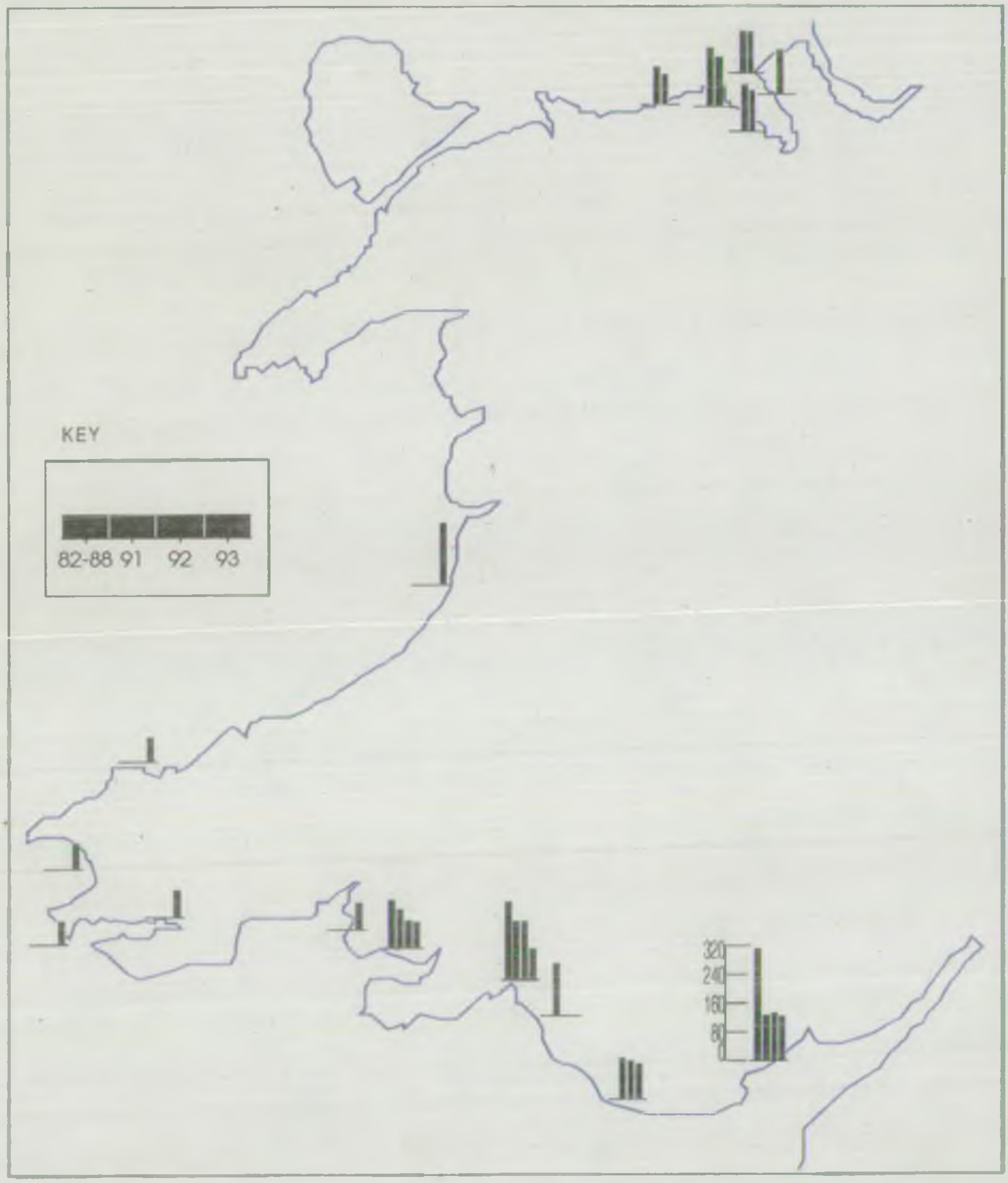


Fig. 12 Mytilus edulis. CADMIUM (ug/g dry tissue wt)

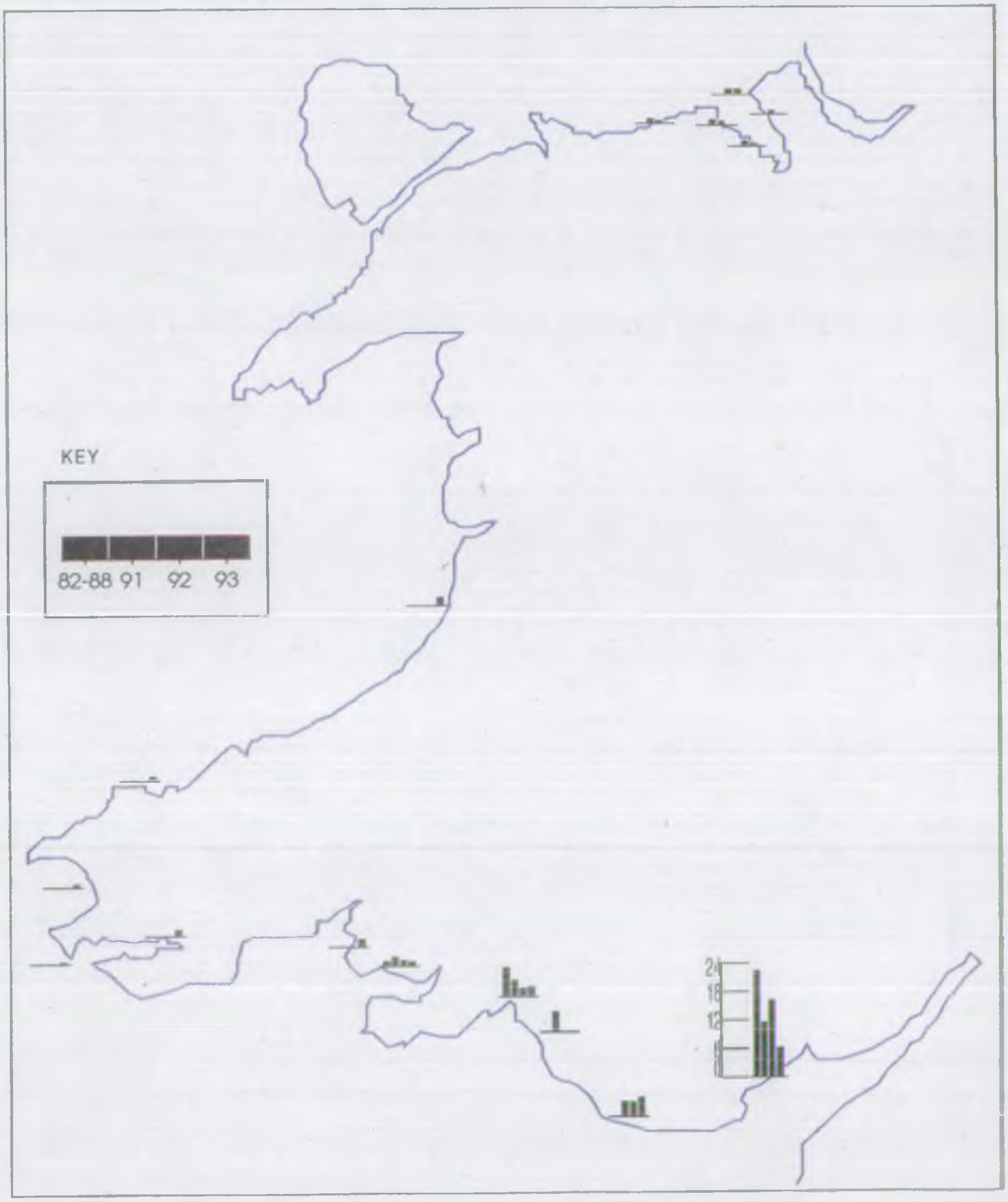


Fig. 13 Mytilus edulis. MERCURY (ug/g dry tissue wt)

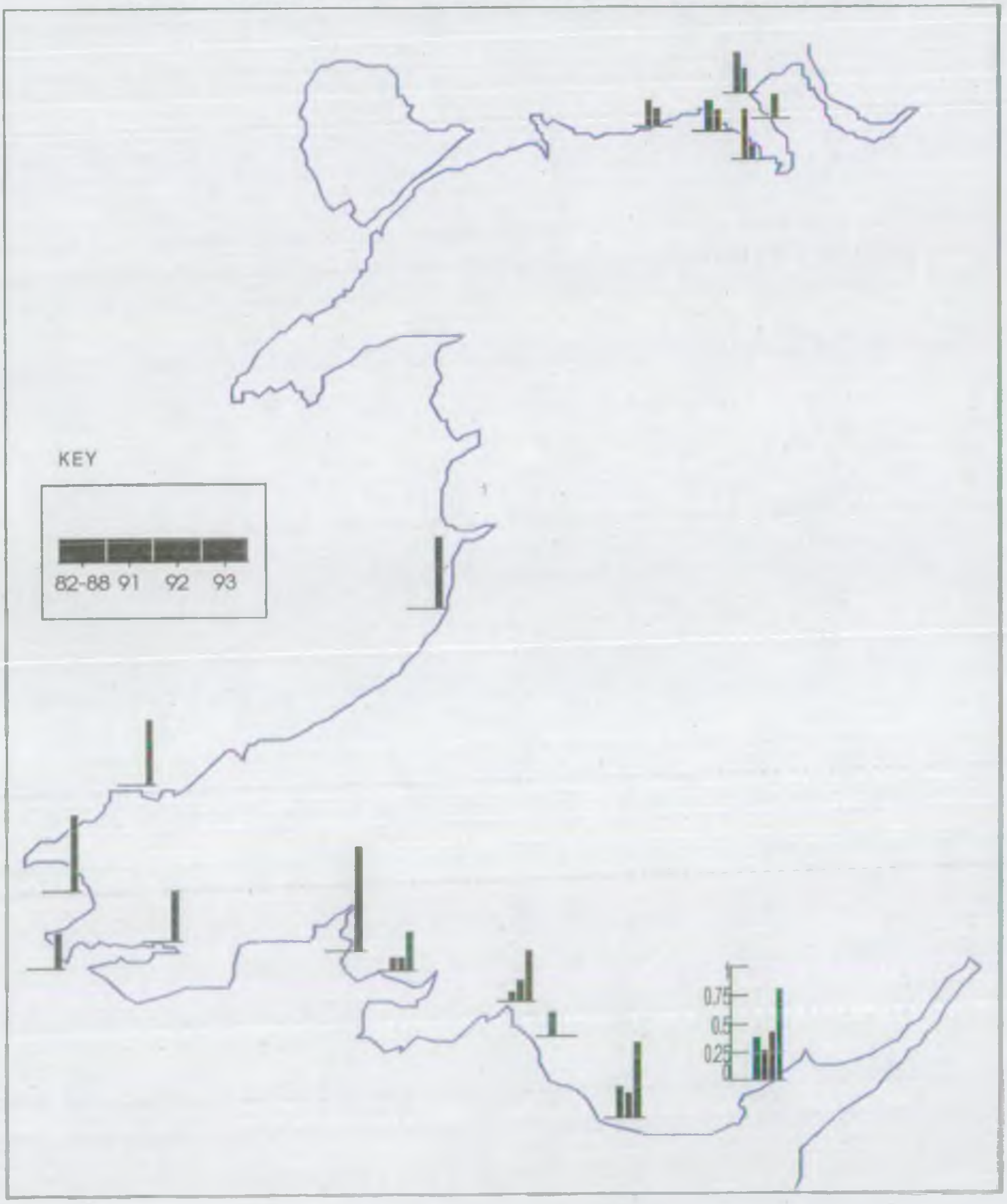


Fig. 14 Mytilus edulis. LEAD (ug/g dry tissue wt)

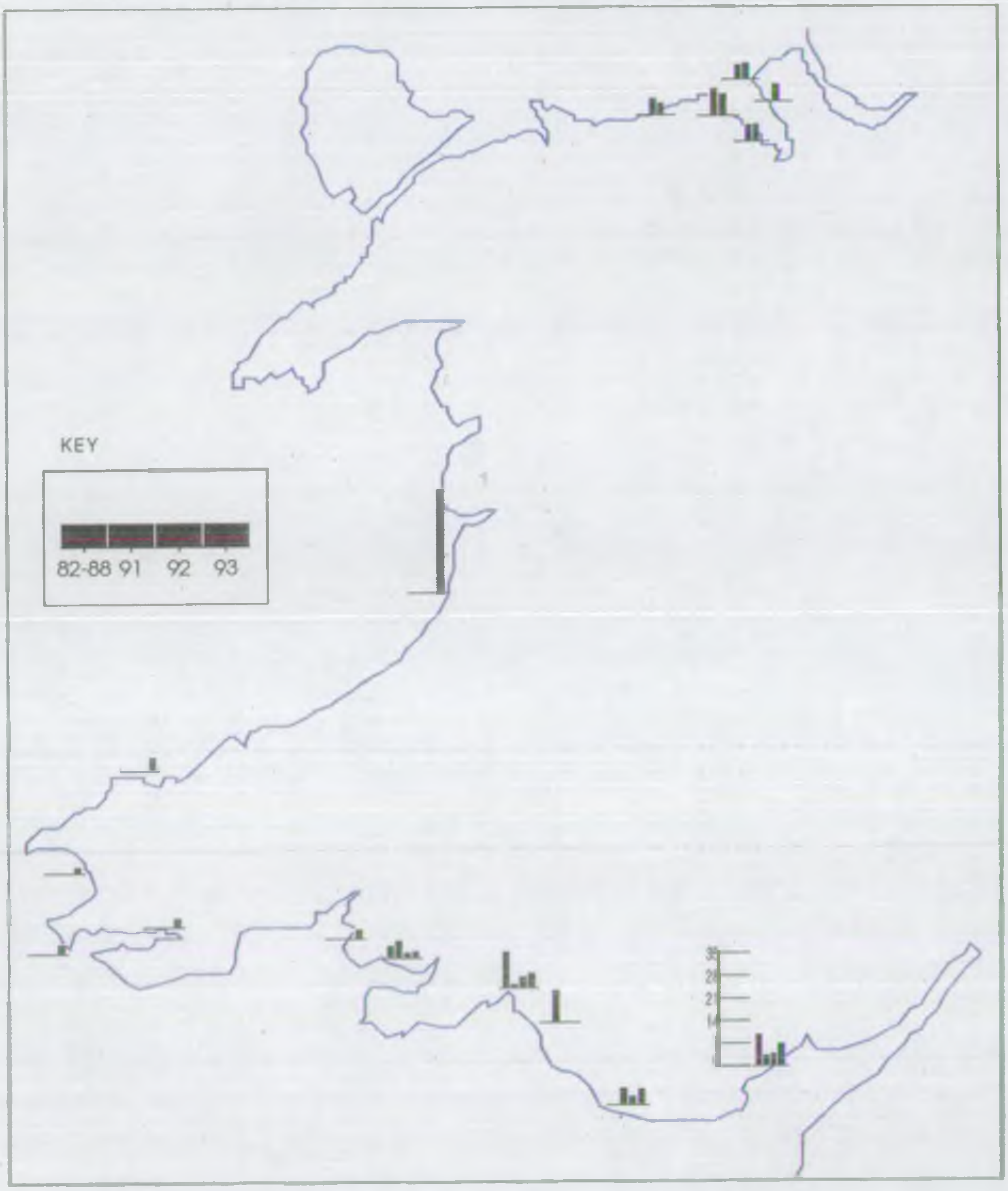


Fig. 15 Mytilus edulis. ARSENIC (ug/g dry tissue wt)

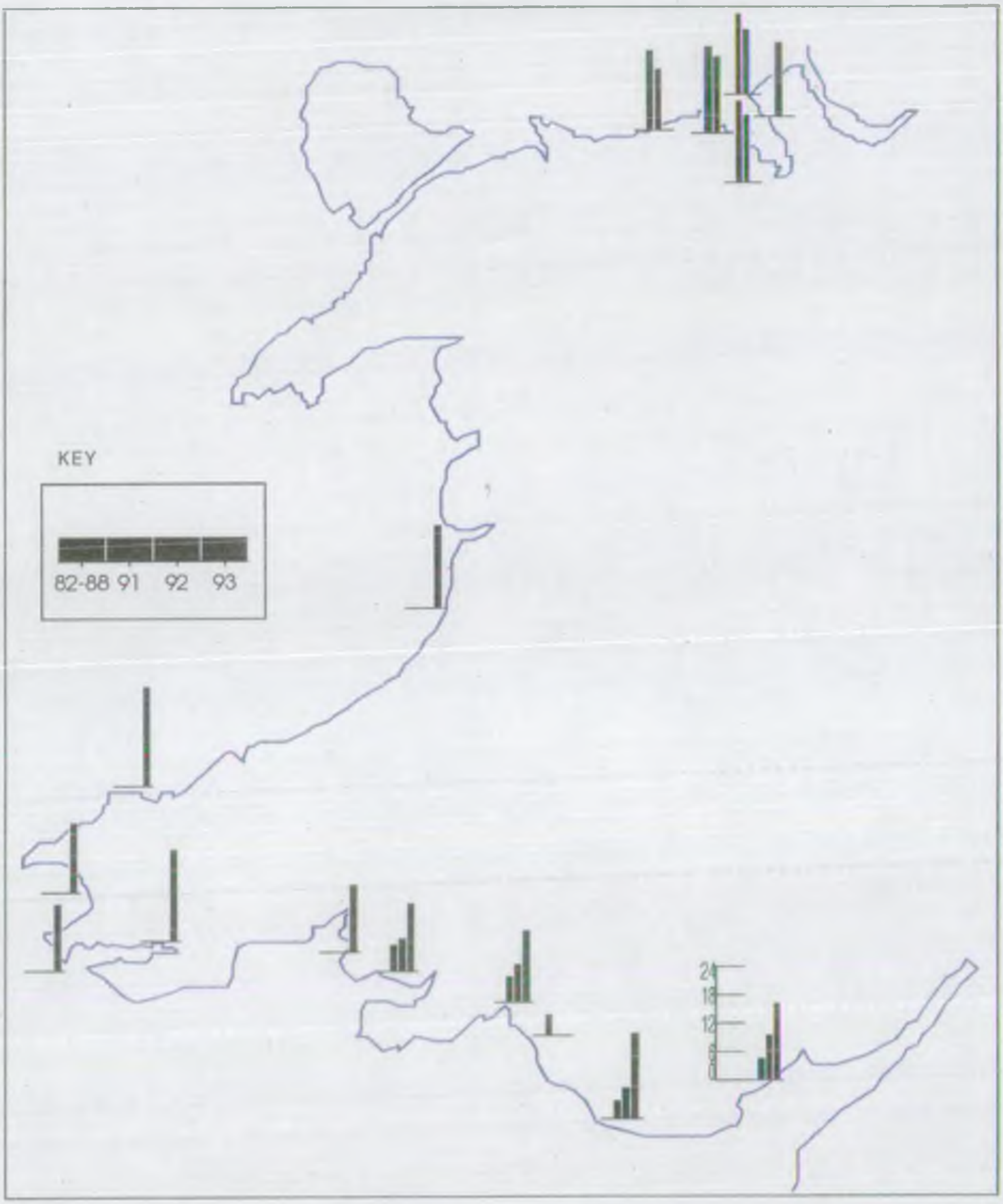


Fig. 16 Mytilus edulis. CHROMIUM (ug/g dry tissue wt)

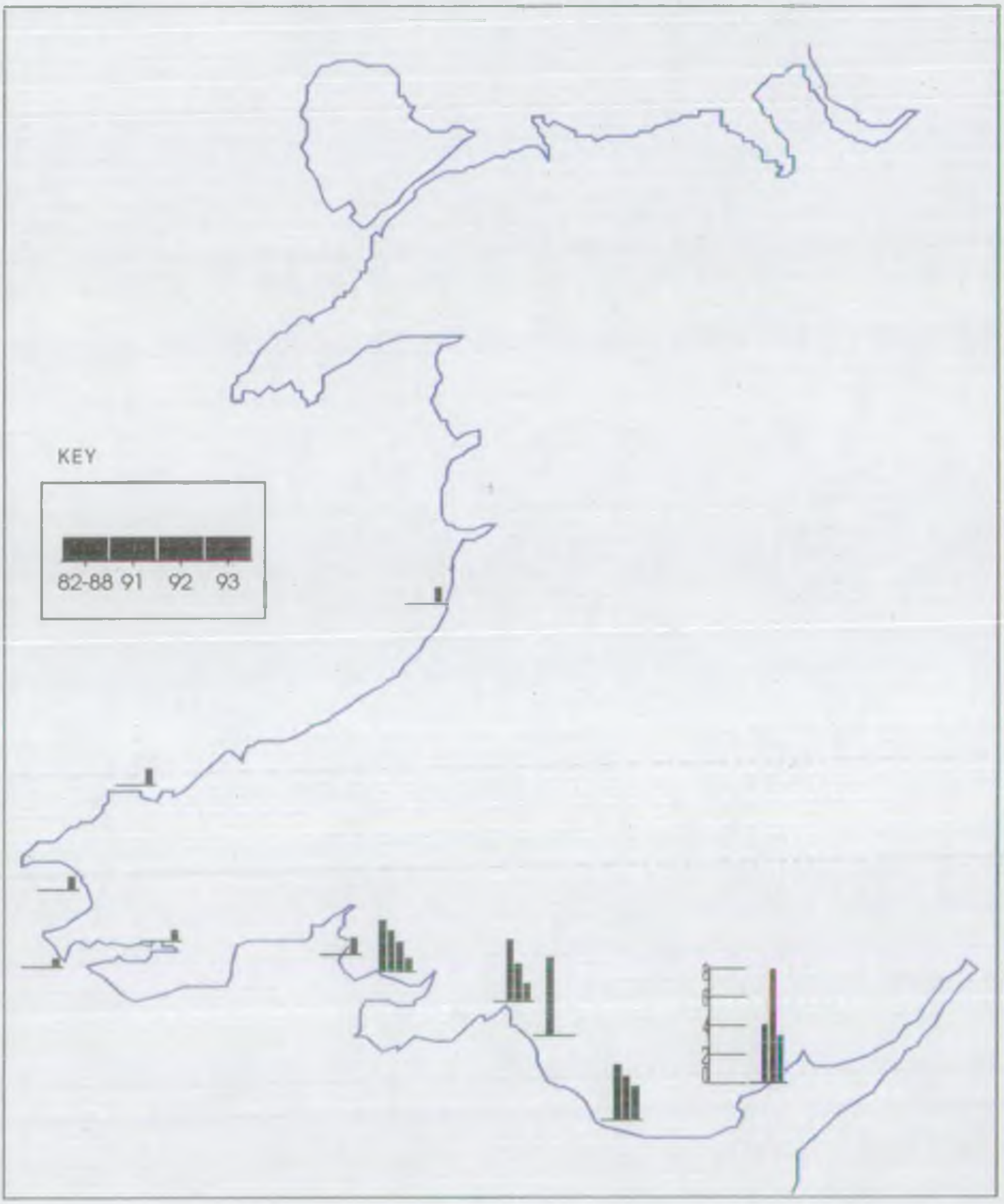


Fig. 17 Mytilus edulis. NICKEL (ug/g dry tissue wt)

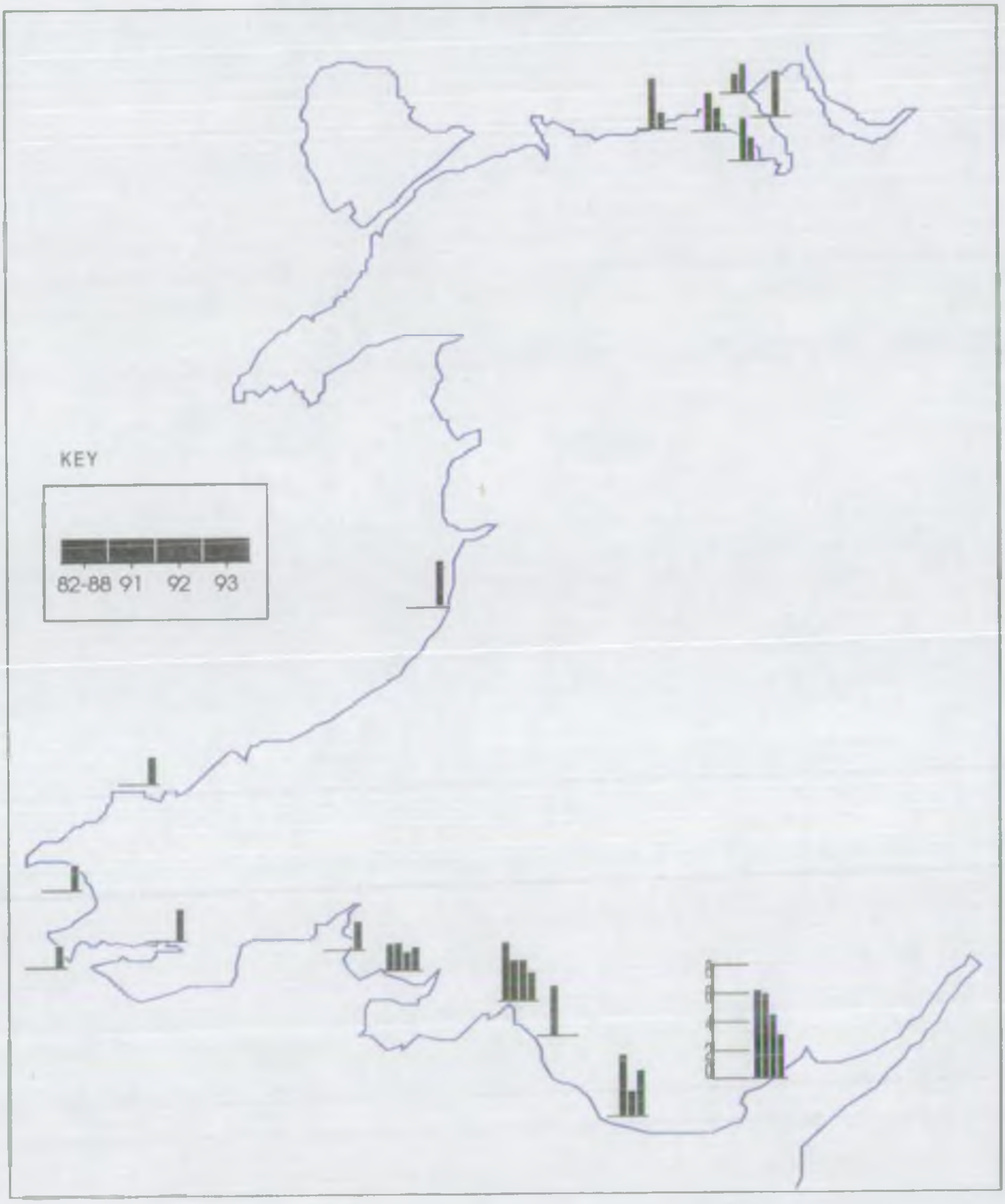


Fig. 18 Cerastoderma edule. COPPER (ug/g dry tissue wt)

Fig. 19 Cerastoderma edule. ZINC (ug/g dry tissue wt)

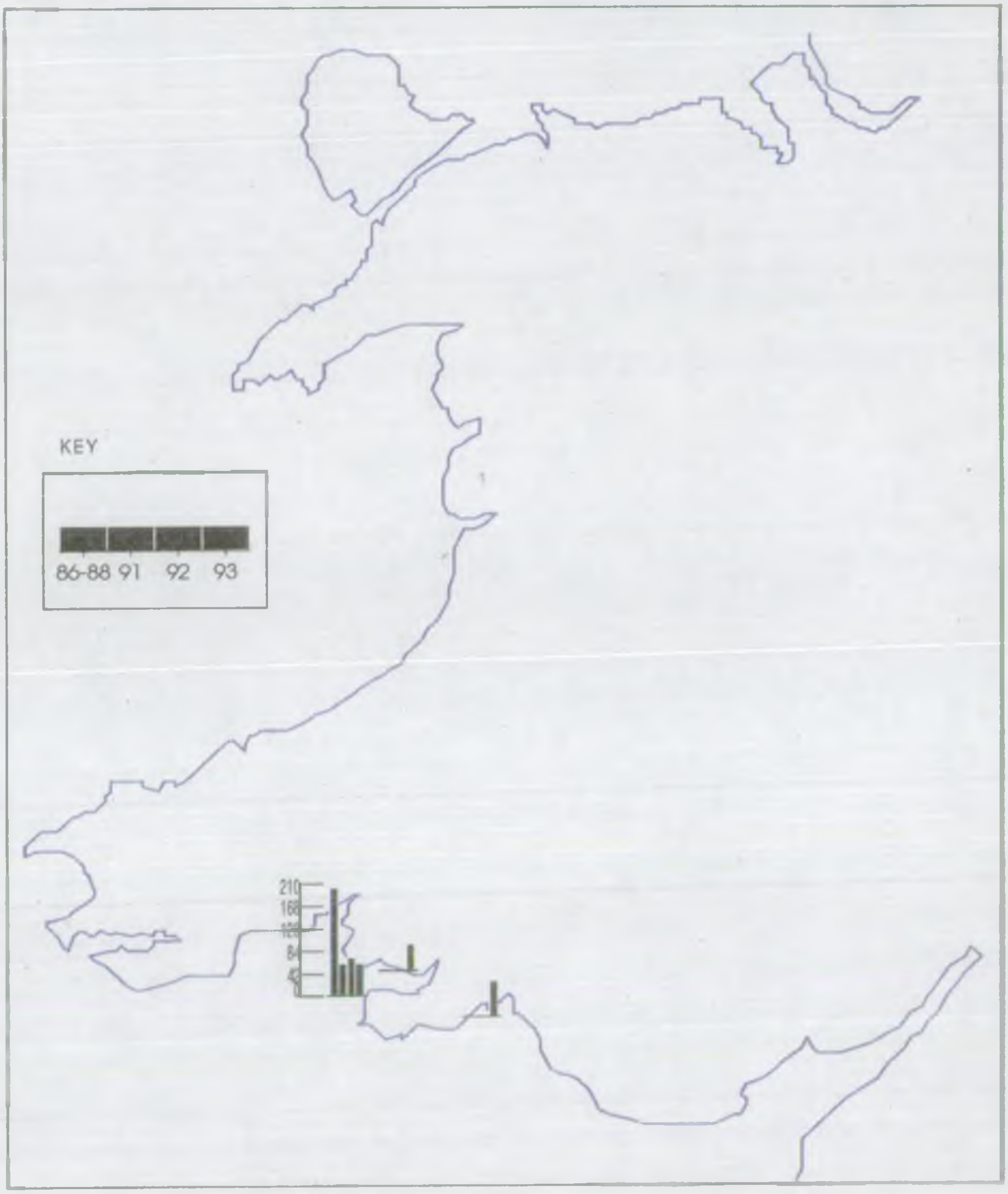


Fig. 20 Cerastoderma edule. CADMIUM (ug/g dry tissue wt)

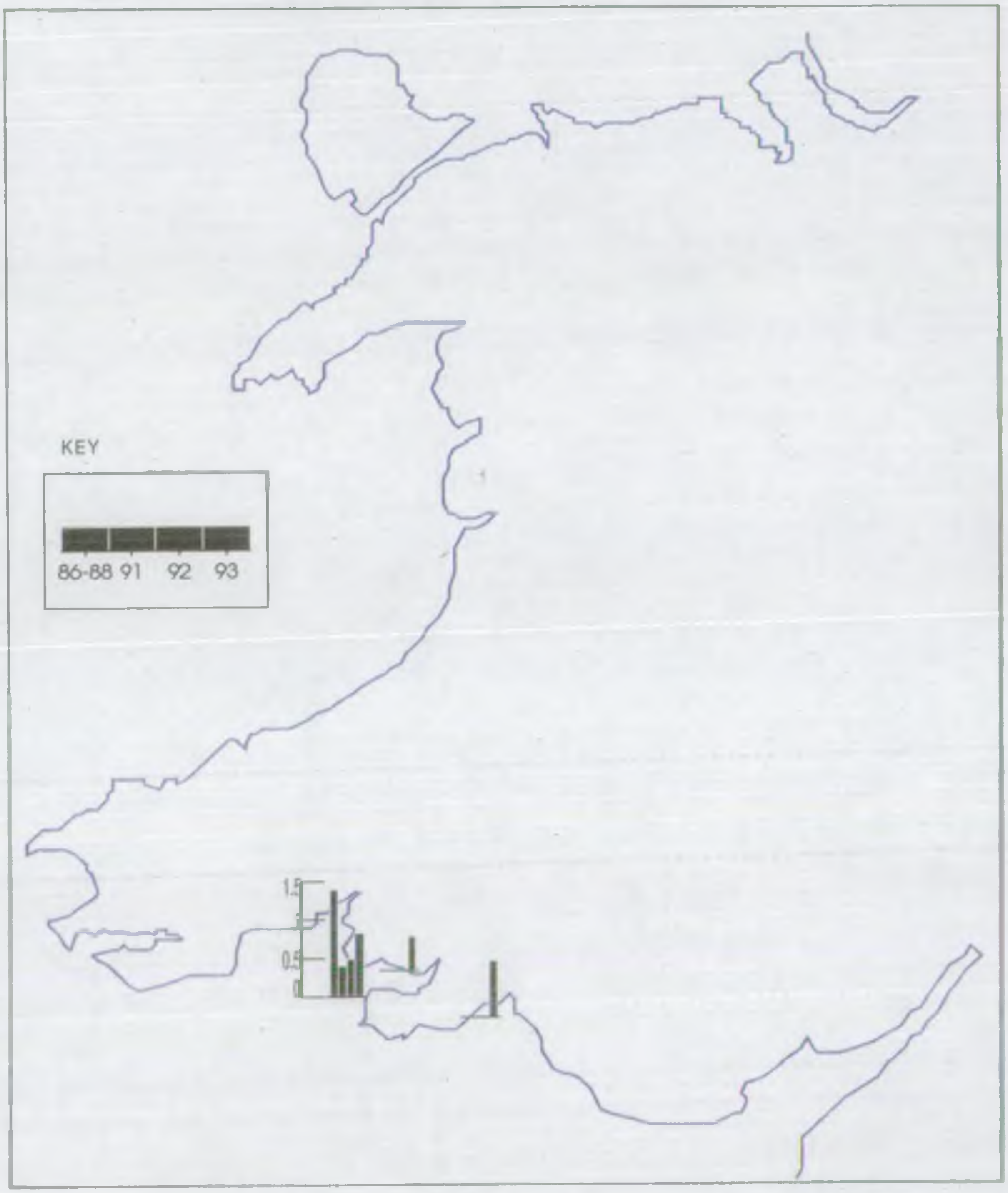


Fig. 21 Cerastoderma edule. MERCURY (ug/g dry tissue wt)

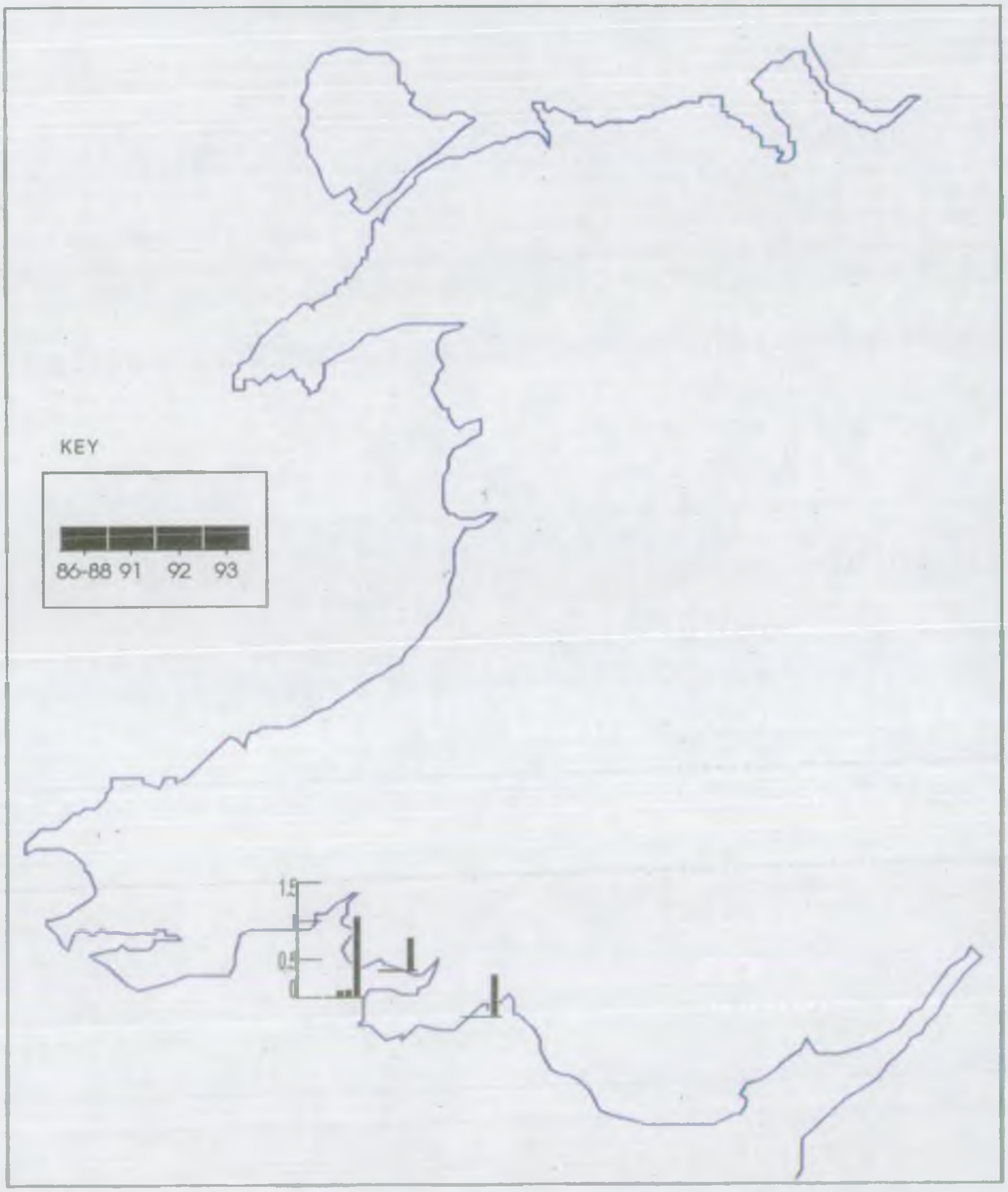


Fig. 22 Cerastoderma edule. LEAD (ug/g dry tissue wt)

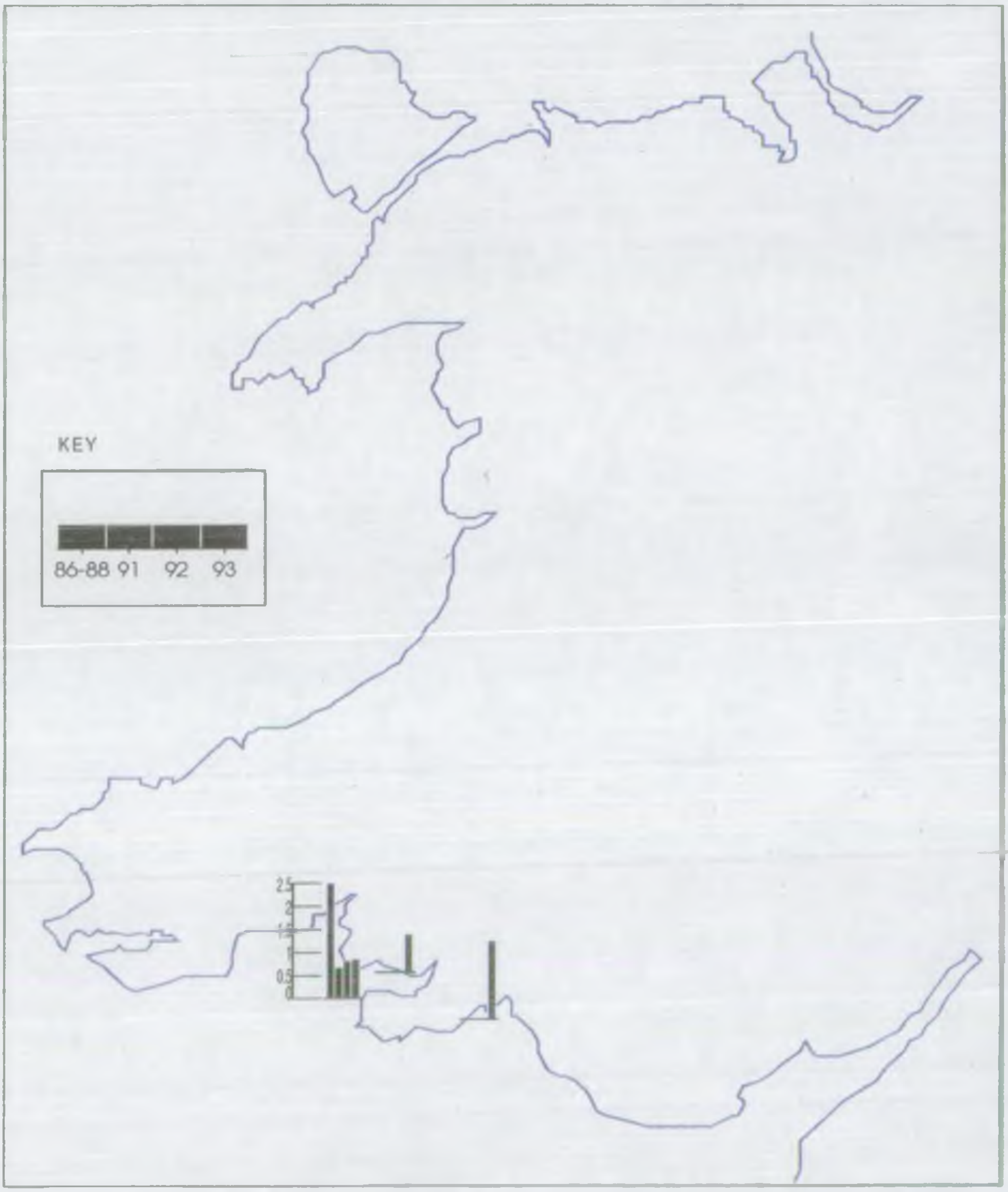


Fig. 23 Cerastoderma edule. ARSENIC (ug/g dry tissue wt)

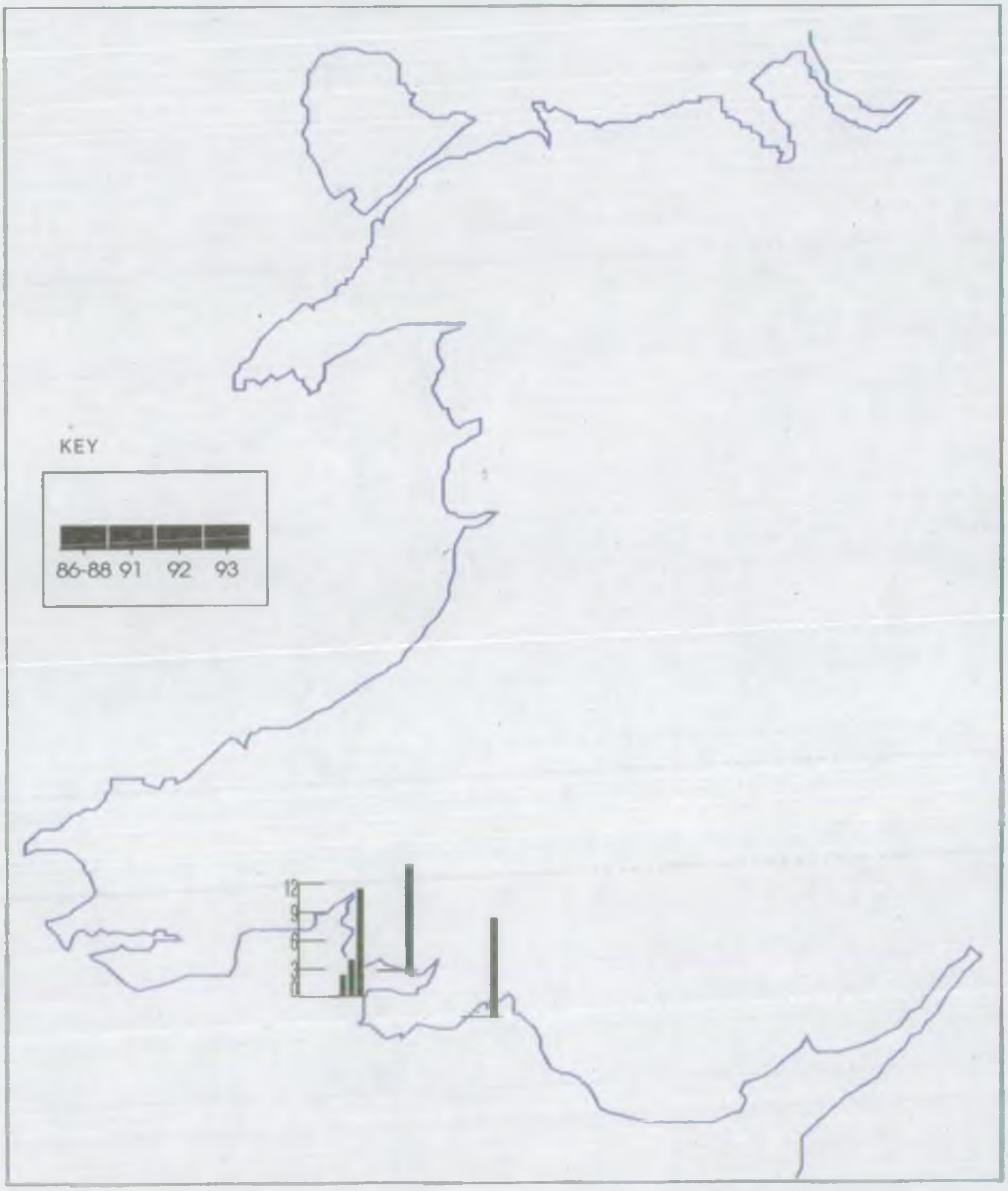


Fig. 24 Cerastoderma edule. CHROMIUM (ug/g dry tissue wt)

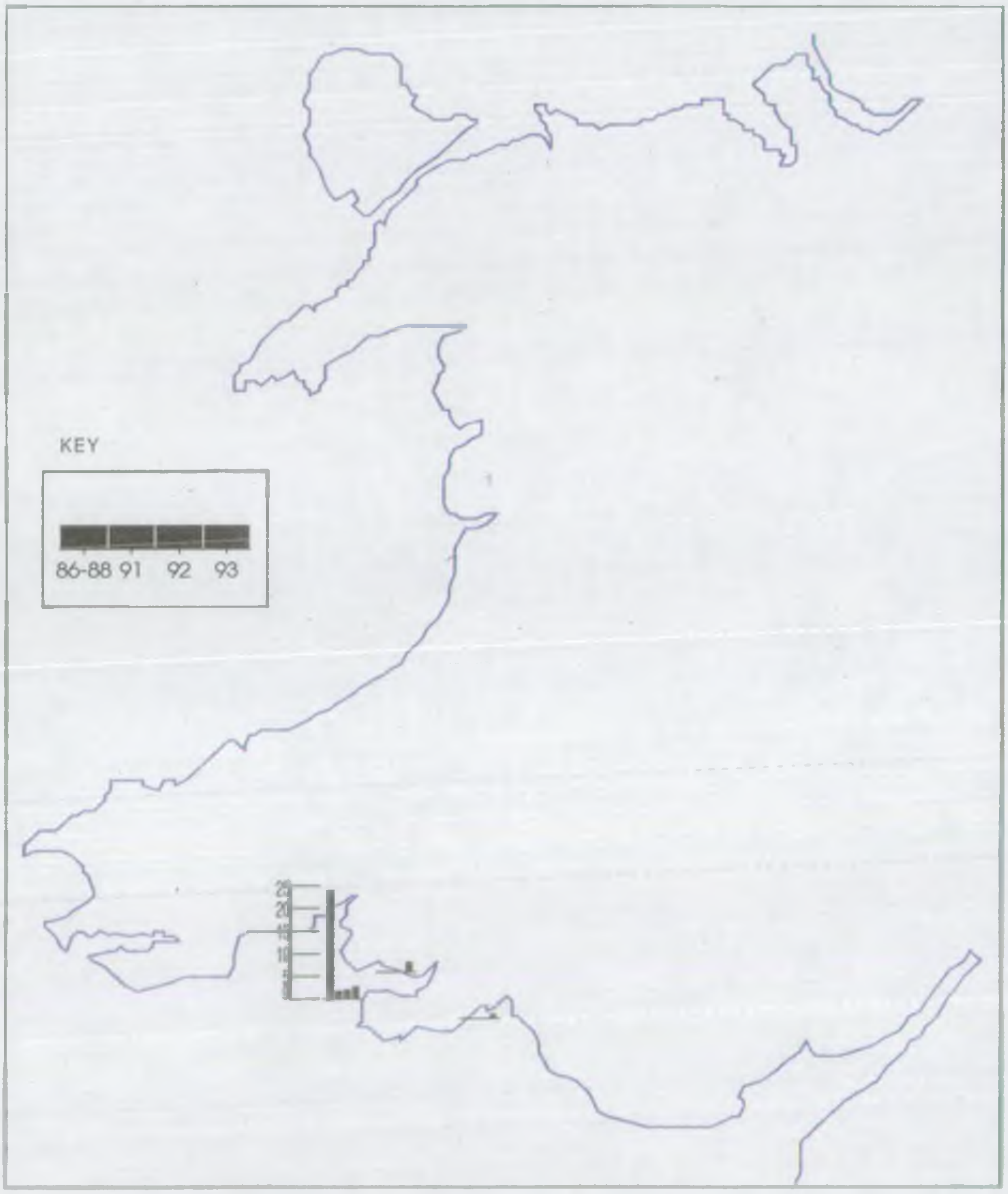


Fig. 25 Cerastoderma edule. NICKEL (ug/g dry tissue wt)

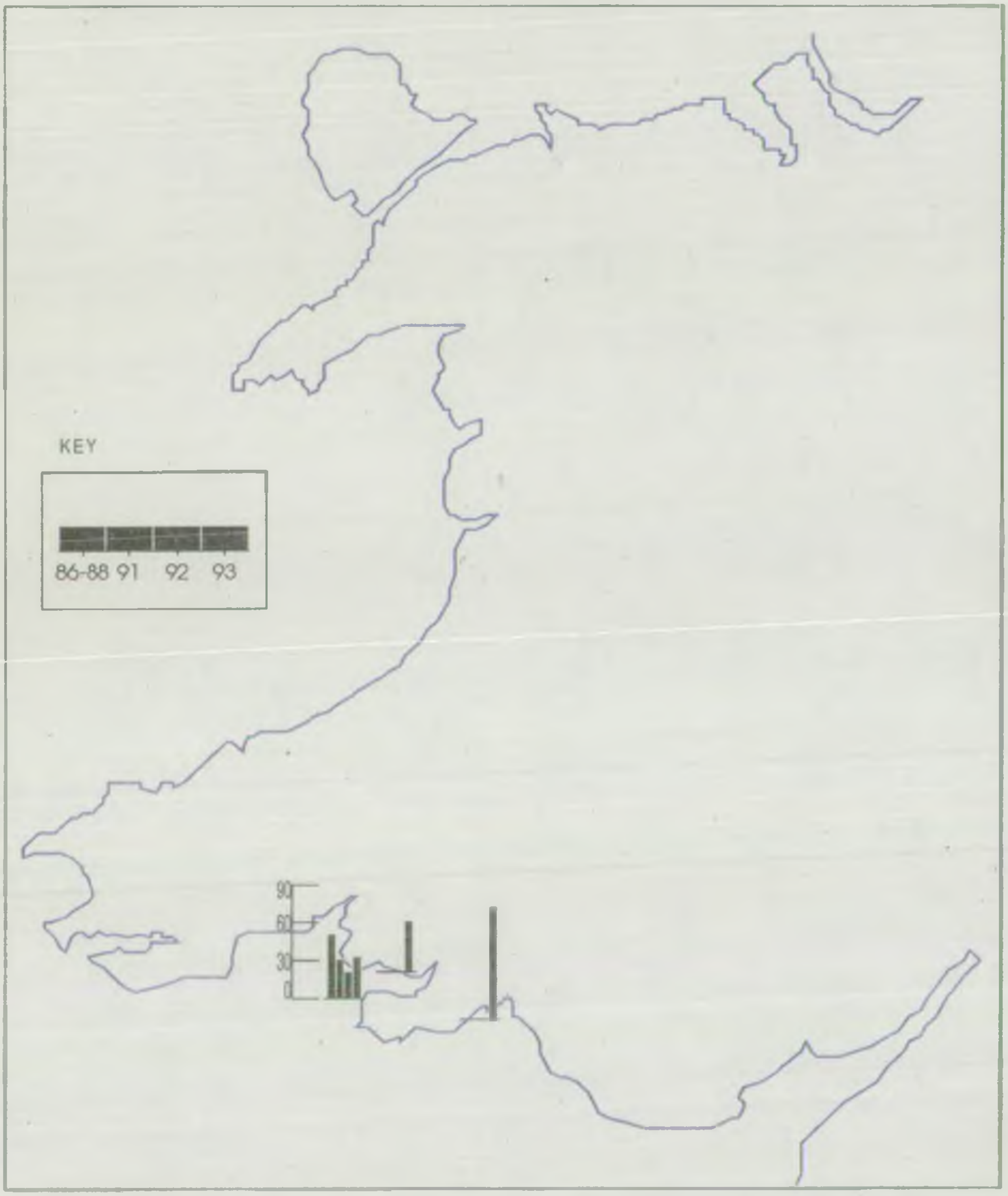


Fig. 26 Distribution of metals in Fucus spp. for each site in 1993 expressed as a percentage of the total.

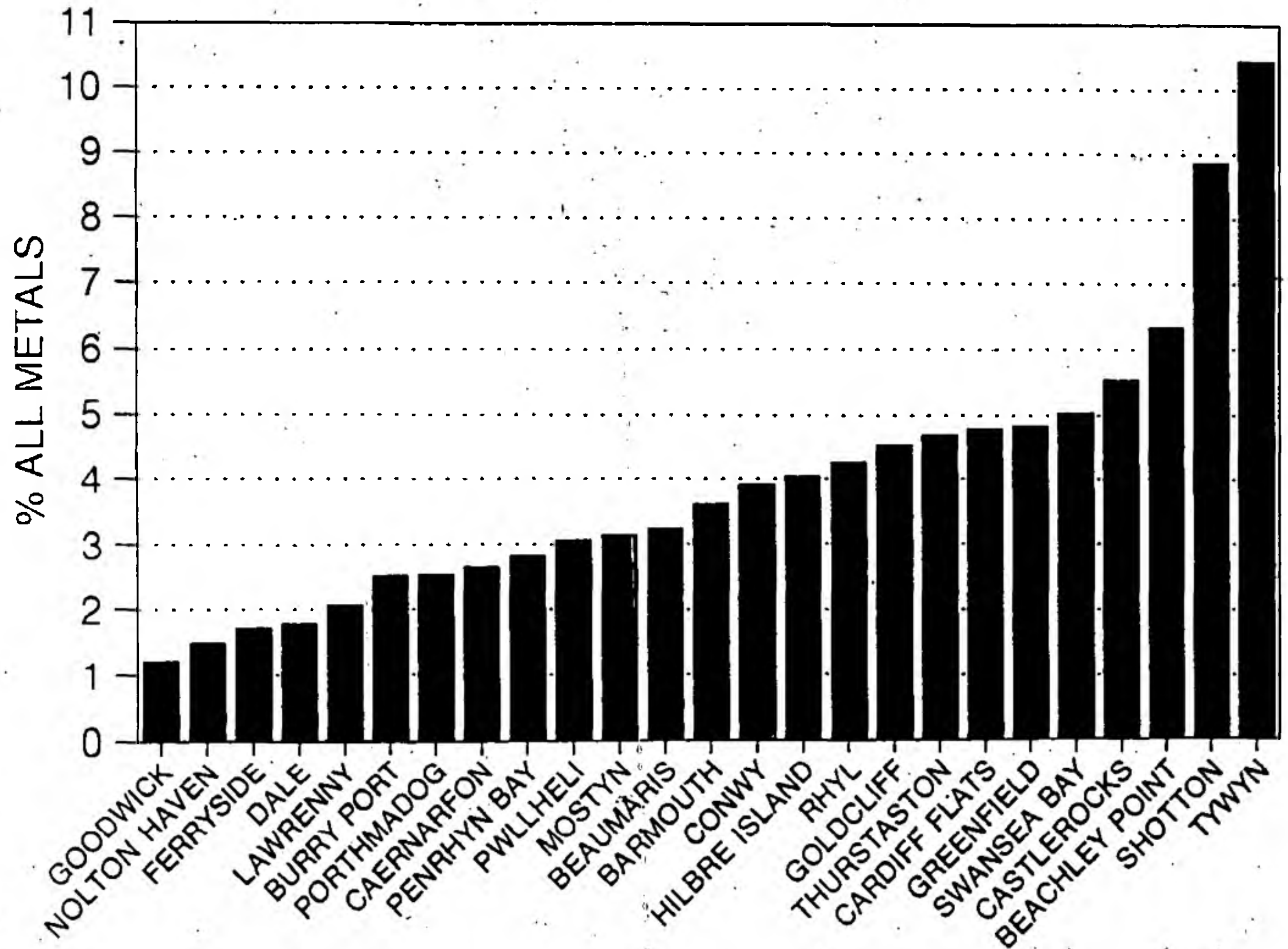


Fig. 27 Distribution of metals in Mytilus edulis for each site in 1993 expressed as a percentage of the total.

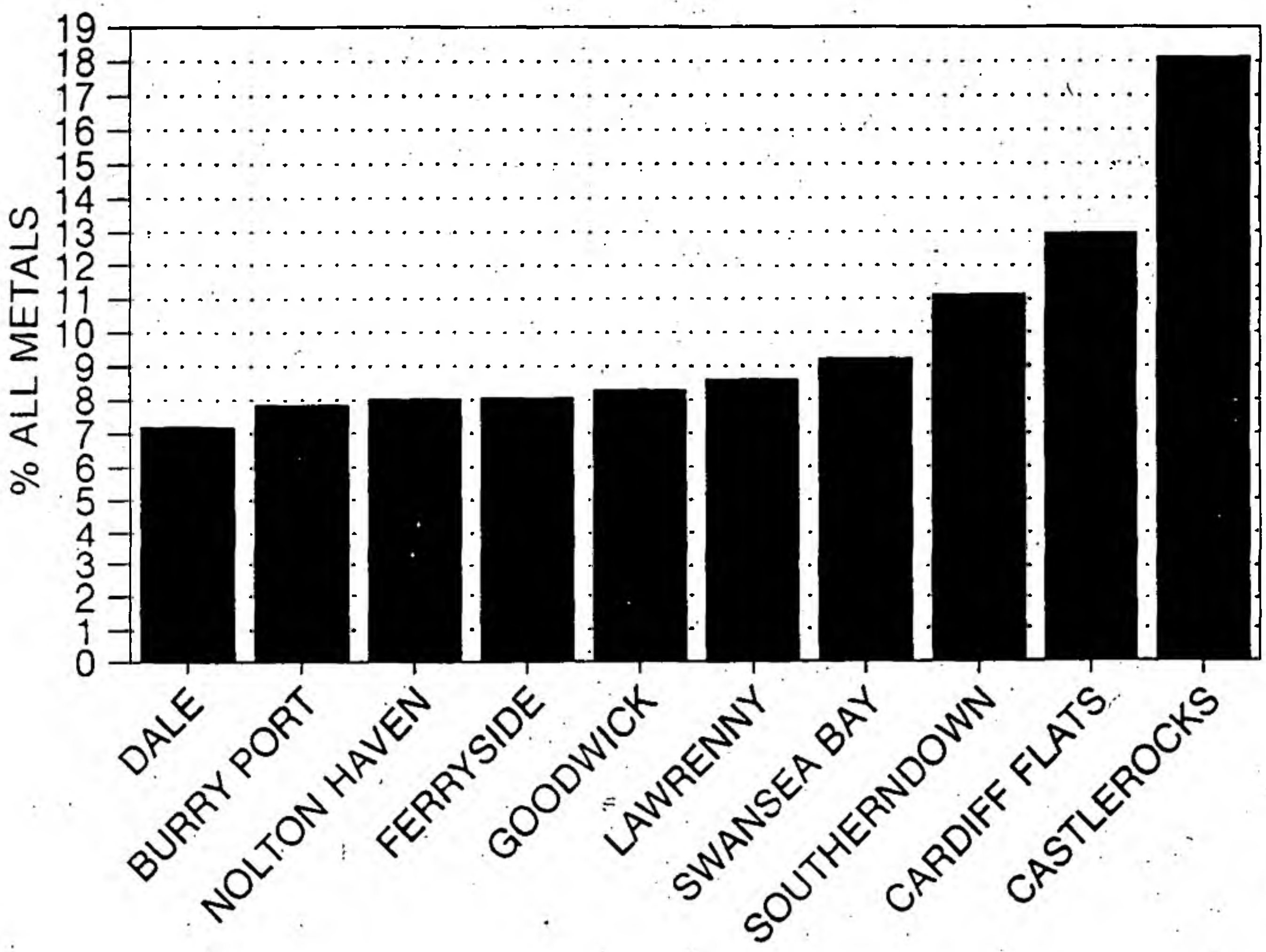
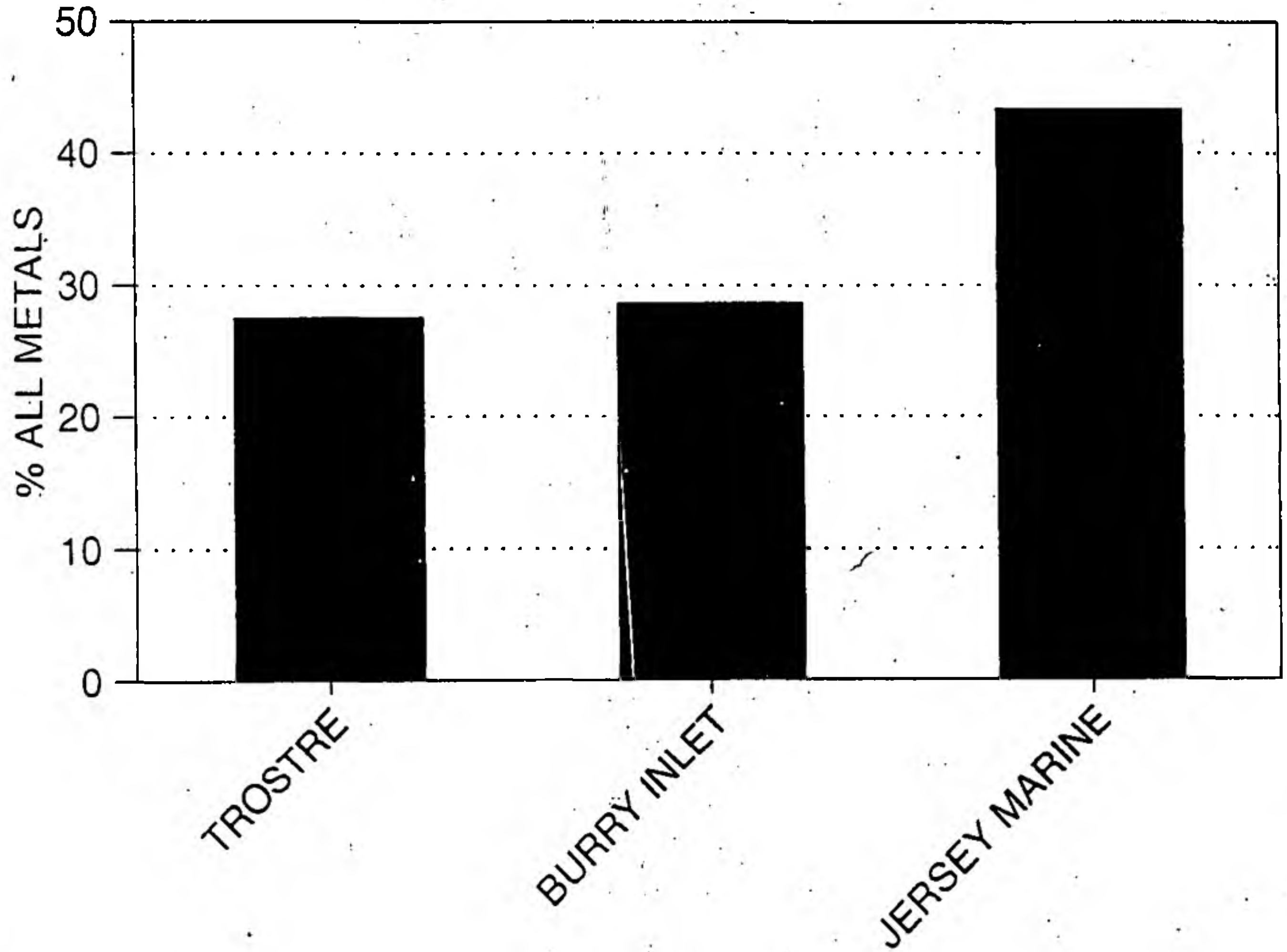


Fig. 28 Distribution of metals in Cerastoderma edule for each site in 1993 expressed as a percentage of the total.



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^{o}C)	Old Thallus only
M. edulis	No	scrape off growth on shells and scrub clean	48 hours	Deep frozen (-18^{o}C)	Remove Shells
C. edule	Kept cool in sediment (up to 24 hrs)	scrubbing/ washing	3-4 days	Deep frozen (-18^{o}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 *Fucus* spp. (ug/g dry weight)

SITE	82-88	1991	1992	1993
Beachley Point	35.8	39.0	18.8	24.1
Goldcliff	31.3	18.0	15.6	17.3
Cardiff Flats	28.1	17.6	20.0	18.2
Swansea Bay	24.1	10.9	10.9	13.9
Burry Port Jetty	9.7	28.0	10.0	10.2
Ferryside	--	--	--	5.1
Lawrenny	--	--	--	6.8
Dale	--	--	--	4.7
Nolton Haven	--	--	--	4.1
Goodwick	--	--	--	2.8
Castlerocks	--	--	--	6.9
Tywyn	--	--	--	5.6*
Barmouth	--	--	--	10.9*
Porthmadog	--	--	--	17.4*
Pwllheli	--	--	--	8.3*
Caernarfon	--	--	--	9.3
Beaumaris	--	--	--	11.9
Conwy	--	--	--	8.5
Penrhyn Bay	--	--	--	7.2*
Rhyl	--	--	--	12.4
Mostyn	--	13.7	9.7	6.4*
Greenfield	--	16.2	12.1	9.5
Shotton	--	16.2*	12.3*	9.7*
Thurstaston	--	16.1	9.6#	13.3*
Hilbre Island	--	14.6	15.5*	9.7

* *Fucus spiralis* # *Fucus serratus*

II.2 ZINC *Fucus* spp. (ug/g dry weight)

SITE	82-88	1991	1992	1993
Beachley Point	430	973	302	372
Goldcliff	365	321	214	262
Cardiff Flats	339	382	408	274
Swansea Bay	458	170	145	277
Burry Port Jetty	103	239	101	127
Ferryside	---	---	---	75
Lawrenny	---	---	---	94
Dale	---	---	---	71
Nolton Haven	---	---	---	46
Goodwick	---	---	---	43
Castlerocks	---	---	---	340
Tywyn	---	---	---	690*
Barmouth	---	---	---	208*
Porthmadog	---	---	---	131*
Pwllheli	---	---	---	171*
Caernarfon	---	---	---	132
Beaumaris	---	---	---	163
Conwy	---	---	---	231
Penrhyn Bay	---	---	---	163*
Rhyl	---	---	---	246
Mostyn	---	305	198	189*
Greenfield	---	675	362	303
Shotton	---	675*	658*	583*
Thurstaston	---	245	343#	288*
Hilbre Island	---	275	296*	244

II.3 CADMIUM *Fucus* spp. (ug/g dry weight)

SITE	82-88	1991	1992	1993
Beachley Point	21.90	26.00	12.89	18.60
Goldcliff	16.10	8.40	7.97	9.20
Cardiff Flats	9.30	8.03	7.39	9.03
Swansea Bay	4.80	2.40	1.99	3.49
Burry Port Jetty	2.70	2.30	1.99	1.51
Ferryside	---	---	---	1.35
Lawrenny	---	---	---	0.65
Dale	---	---	---	0.85
Nolton Haven	---	---	---	1.03
Goodwick	---	---	---	0.50
Castlerocks	---	---	---	1.41
Tywyn	---	---	---	2.20*
Barmouth	---	---	---	0.99*
Porthmadog	---	---	---	0.52*
Pwllheli	---	---	---	0.96*
Caernarfon	---	---	---	1.54
Beaumaris	---	---	---	1.52
Conwy	---	---	---	0.70
Penrhyn Bay	---	---	---	1.01*
Rhyl	---	---	---	1.25
Mostyn	---	0.63	0.53	0.54*
Greenfield	---	0.58	0.67	0.61
Shotton	---	0.58*	0.54*	0.53*
Thurstaston	---	0.70	0.92#	0.95*
Hilbre Island	---	1.04	0.86*	0.74

* *Fucus spiralis* # *Fucus serratus*

II.4 MERCURY *Fucus* spp. (ug/g dry weight)

SITE	82-88	1991	1992	1993
Beachley Point	--	0.086	0.036	0.024
Goldcliff	--	0.076	0.035	0.025
Cardiff Flats	--	0.054	0.051	0.033
Swansea Bay	--	0.079	0.035	0.191
Burry Port Jetty	--	0.093	0.027	0.023
Ferryside	--	---	---	0.026
Lawrenny	--	---	---	0.029
Dale	--	---	---	0.029
Nolton Haven	--	---	---	0.030
Goodwick	--	---	---	0.017
Castlerocks	--	---	---	0.032
Tywyn	--	---	---	0.025*
Barmouth	--	---	---	0.035*
Porthmadog	--	---	---	0.024*
Pwllheli	--	---	---	0.035*
Caernarfon	--	---	---	0.085
Beaumaris	--	---	---	0.090
Conwy	--	---	---	0.068
Penrhyn Bay	--	---	---	0.042*
Rhyl	--	---	---	0.102
Mostyn	--	0.100	0.078	0.032*
Greenfield	--	0.066	0.088	0.082
Shotton	--	0.066*	0.065*	0.057*
Thurstaston	--	0.110	0.036#	0.131*
Hilbre Island	--	0.071	0.086*	0.051

II.5 LEAD *Fucus* spp. (ug/g dry weight)

SITE	82-88	1991	1992	1993
Beachley Point	4.60	2.80	1.34	1.79
Goldcliff	4.50	2.20	1.03	1.59
Cardiff Flats	9.30	8.03	0.82	2.64
Swansea Bay	4.40	4.10	1.50	2.02
Burry Port Jetty	3.40	3.40	0.78	1.59
Ferryside	--	--	--	1.35
Lawrenny	--	--	--	2.08
Dale	--	--	--	1.48
Nolton Haven	--	--	--	0.50
Goodwick	--	--	--	0.86
Castlerocks	--	--	--	4.02
Tywyn	--	--	--	32.40*
Barmouth	--	--	--	3.19*
Porthmadog	--	--	--	11.10*
Pwllheli	--	--	--	1.80*
Caernarfon	--	--	--	2.46
Beaumaris	--	--	--	4.14
Conwy	--	--	--	2.42
Penrhyn Bay	--	--	--	1.36*
Rhyl	--	--	--	4.51
Mostyn	--	2.10	1.22	1.67*
Greenfield	--	2.10	2.20	2.62
Shotton	--	7.70*	4.10*	5.35*
Thurstaston	--	2.20	4.00#	4.65*
Hilbre Island	--	3.20	2.90*	1.53

* *Fucus spiralis* # *Fucus serratus*

II.6 ARSENIC *Fucus* spp. (ug/g dry weight)

SITE	82-88	1991	1992	1993
Beachley Point	--	28.40	15.68	27.80
Goldcliff	--	17.60	12.58	26.10
Cardiff Flats	--	13.00	27.32	31.45
Swansea Bay	--	19.80	15.13	57.90
Burry Port Jetty	--	25.30	22.30	35.80
Ferryside	--	---	---	38.90
Lawrenny	--	---	---	41.40
Dale	--	---	---	48.20
Nolton Haven	--	---	---	55.60
Goodwick	--	---	---	37.10
Castlerocks	--	---	---	51.20
Tywyn	--	---	---	32.40*
Barmouth	--	---	---	33.80*
Porthmadog	--	---	---	21.40*
Pwllheli	--	---	---	33.30*
Caernarfon	--	---	---	42.20
Beaumaris	--	---	---	49.40
Conwy	--	---	---	40.60
Penrhyn Bay	--	---	---	23.00*
Rhyl	--	---	---	37.10
Mostyn	--	52.70	39.20	25.80*
Greenfield	--	52.70	341.00	34.40
Shotton	--	38.00*	32.90*	32.50*
Thurstaston	--	44.00	32.50#	29.00*
Hilbre Island	--	32.50	29.80*	31.10

II.7 CHROMIUM *Fucus* spp. (ug/g dry weight)

SITE	82-88	1991	1992	1993
Beachley Point	--	<1.50	2.94	1.49
Goldcliff	--	<1.50	<1.50	1.64
Cardiff Flats	--	<1.50	<1.50	1.99
Swansea Bay	--	<1.50	<1.50	1.07
Burry Port Jetty	--	<1.50	1.69	1.07
Ferryside	--	--	--	1.39
Lawrenny	--	--	--	1.37
Dale	--	--	--	1.41
Nolton Haven	--	--	--	0.56
Goodwick	--	--	--	1.68
Castlerocks	--	--	--	0.47
Tywyn	--	--	--	--
Barmouth	--	--	--	--
Porthmadog	--	--	--	--
Pwllheli	--	--	--	--
Caernarfon	--	--	--	--
Beaumaris	--	--	--	--
Conwy	--	--	--	--
Penrhyn Bay	--	--	--	--
Rhyl	--	--	--	--
Mostyn	--	--	--	--
Greenfield	--	--	--	--
Shotton	--	--	--	--
Thurstaston	--	--	--	--
Hilbre Island	--	--	--	--

* *Fucus spiralis* # *Fucus serratus*

II.8 NICKEL *Fucus* spp. (ug/g dry weight)

SITE	82-88	1991	1992	1993
Beachley Point	20.60	25.00	12.28	22.70
Goldcliff	22.30	16.40	11.64	17.60
Cardiff Flats	11.50	15.58	12.94	17.08
Swansea Bay	17.60	10.90	9.90	16.50
Burry Port Jetty	9.70	9.40	7.03	9.60
Ferryside	---	---	---	6.00
Lawrenny	---	---	---	7.80
Dale	---	---	---	6.60
Nolton Haven	---	---	---	5.30
Goodwick	---	---	---	5.80
Castlerocks	---	---	---	5.20
Tywyn	---	---	---	8.20*
Barmouth	---	---	---	11.90*
Porthmadog	---	---	---	7.10*
Pwllheli	---	---	---	13.10*
Caernarfon	---	---	---	9.20
Beaumaris	---	---	---	11.00
Conwy	---	---	---	6.40
Penrhyn Bay	---	---	---	13.90*
Rhyl	---	---	---	14.40
Mostyn	---	5.70	5.50	10.70*
Greenfield	---	5.70	6.70	7.40
Shotton	---	16.30*	21.90*	22.40*
Thurstaston	---	8.30	11.70#	10.90*
Hilbre Island	---	11.70	13.70*	12.20

APPENDIX III. *Mytilus edulis* metals concentrations

III.1 COPPER *Mytilus edulis* (ug/g dry weight)

SITE	82-88	1991	1992	1993
Cardiff Flats	10.90	8.03	10.89	7.41
Southerndown	---	9.40	10.47	9.10
Afan Estuary	---	5.00	---	--
Swansea Bay	7.60	6.50	8.45	6.30
Burry Port Jetty	6.50	5.40	7.96	7.50
Ferryside	---	---	---	6.40
Lawrenny	---	---	---	7.04
Dale	---	---	---	6.60
Nolton Haven	---	---	---	6.60
Goodwick	---	---	---	6.00
Castlerocks	---	---	---	6.30
Rhyl	---	10.20	7.80	--
Mostyn	---	9.50	8.30	--
Greenfield	---	9.60	9.60	--
Thurstaston	---	---	10.00	--
Hilbre Island	---	10.60	10.80	--

III.2 ZINC *Mytilus edulis* (ug/g dry weight)

SITE	82-88	1991	1992	1993
Cardiff Flats	313	129	135	126
Southerndown	---	118	112	104
Afan Estuary	---	148	---	---
Swansea Bay	219	165	165	89
Burry Port Jetty	136	110	79	75
Ferryside	---	---	---	77
Lawrenny	---	---	---	79
Dale	---	---	---	68
Nolton Haven	---	---	---	78
Goodwick	---	---	---	73
Castlerocks	---	---	---	176
Rhyl	---	109	87	---
Mostyn	---	169	143	---
Greenfield	---	135	118	---
Thurstaston	---	---	128	---
Hilbre Island	---	120	118	---

III.3 CADMIUM *Mytilus edulis* (ug/g dry weight)

SITE	82-88	1991	1992	1993
Cardiff Flats	22.60	11.85	16.36	6.55
Southerndown	--	3.40	3.31	4.30
Afan Estuary	--	4.40	--	--
Swansea Bay	6.27	3.70	1.99	2.35
Burry Port Jetty	1.30	2.20	1.49	1.31
Ferryside	--	--	--	1.81
Lawrenny	--	--	--	1.55
Dale	--	--	--	0.65
Nolton Haven	--	--	--	0.98
Goodwick	--	--	--	1.10
Castlerocks	--	--	--	2.04
Rhyl	--	1.31	0.99	--
Mostyn	--	1.45	1.14	--
Greenfield	--	1.38	0.87	--
Thurstaston	--	--	1.00	--
Hilbre Island	--	1.36	1.42	--

III.4 MERCURY *Mytilus edulis* (ug/g dry weight)

SITE	82-88	1991	1992	1993
Cardiff Flats	0.39	0.28	0.44	0.82
Southerndown	--	0.29	0.23	0.68
Afan Estuary	--	0.22	--	--
Swansea Bay	--	0.09	0.20	0.45
Burry Port Jetty	--	0.13	0.12	0.35
Ferryside	--	--	--	0.92
Lawrenny	--	--	--	0.45
Dale	--	--	--	0.32
Nolton Haven	--	--	--	0.68
Goodwick	--	--	--	0.58
Castlerocks	--	--	--	0.65
Rhyl	--	0.24	0.17	--
Mostyn	--	0.28	0.20	--
Greenfield	--	0.46	0.13	--
Thurstaston	--	--	0.22	--
Hilbre Island	--	0.37	0.23	--

III.5 LEAD *Mytilus edulis* (ug/g dry weight)

SITE	82-88	1991	1992	1993
Cardiff Flats	10.10	3.71	4.21	7.22
Southerndown	--	5.40	2.94	5.24
Afan Estuary	--	10.20	--	--
Swansea Bay	11.50	1.50	3.88	5.00
Burry Port Jetty	4.10	5.70	1.88	2.48
Ferryside	--	--	--	3.01
Lawrenny	--	--	--	3.13
Dale	--	--	--	3.30
Nolton Haven	--	--	--	2.14
Goodwick	--	--	--	4.47
Castlerocks	--	--	--	32.10
Rhyl	--	5.40	3.90	--
Mostyn	--	8.70	7.00	--
Greenfield	--	5.50	5.70	--
Thurstaston	--	--	5.70	--
Hilbre Island	--	4.80	5.20	--

III.6 ARSENIC *Mytilus edulis* (ug/g dry weight)

SITE	82-88	1991	1992	1993
Cardiff Flats	--	4.83	9.75	16.53
Southerndown	--	4.00	6.73	18.20
Afan Estuary	--	4.50	--	--
Swansea Bay	--	5.70	8.20	15.50
Burry Port Jetty	--	6.00	7.26	14.70
Ferryside	--	--	--	14.40
Lawrenny	--	--	--	19.60
Dale	--	--	--	14.30
Nolton Haven	--	--	--	14.90
Goodwick	--	--	--	21.20
Castlerocks	--	--	--	17.60
Rhyl	--	16.90	12.90	--
Mostyn	--	18.40	16.20	--
Greenfield	--	17.40	14.40	--
Thurstaston	--	--	15.70	--
Hilbre Island	--	17.10	13.90	--

III.7 CHROMIUM *Mytilus edulis* (ug/g dry weight)

SITE	82-88	1991	1992	1993
Cardiff Flats	--	4.13	7.99	3.36
Southerndown	--	3.90	3.11	2.43
Afan Estuary	--	5.50	--	--
Swansea Bay	--	4.40	2.68	1.31
Burry Port Jetty	3.75	3.00	2.19	1.01
Ferryside	--	--	--	1.25
Lawrenny	--	--	--	0.84
Dale	--	--	--	0.66
Nolton Haven	--	--	--	1.03
Goodwick	--	--	--	1.24
Castlerocks	--	--	--	1.25
Rhyl	--	--	--	--
Mostyn	--	--	--	--
Greenfield	--	--	--	--
Thurstaston	--	--	--	--
Hilbre Island	--	--	--	--

III.8 NICKEL *Mytilus edulis* (ug/g dry weight)

SITE	82-88	1991	1992	1993
Cardiff Flats	6.25	6.05	4.58	3.16
Southerndown	--	4.40	1.83	3.31
Afan Estuary	--	3.50	--	--
Swansea Bay	4.15	2.90	2.89	2.02
Burry Port Jetty	1.90	2.00	1.34	1.69
Ferryside	--	--	--	2.02
Lawrenny	--	--	--	2.28
Dale	--	--	--	1.59
Nolton Haven	--	--	--	1.89
Goodwick	--	--	--	1.99
Castlerocks	--	--	--	3.33
Rhyl	--	3.60	1.20	--
Mostyn	--	2.70	1.70	--
Greenfield	--	3.10	1.70	--
Thurstaston	--	--	3.30	--
Hilbre Island	--	1.40	2.10	--

APPENDIX IV. *Cerastoderma edule* metals concentrations (ug/g dry weight)

SITE	METAL	86-88	1991	1992	1993
Jersey Marine	Cu	-	-	-	4.54
Burry Inlet	Cu	4.60	3.00	3.47	3.90
Trostre	Cu	-	-	-	5.60
Jersey Marine	Zn	-	-	-	66.20
Burry Inlet	Zn	201.00	61.00	71.90	60.90
Trostre	Zn	-	-	-	48.70
Jersey Marine	Cd	-	-	-	0.73
Burry Inlet	Cd	1.40	0.40	0.49	0.83
Trostre	Cd	-	-	-	0.44
Jersey Marine	Hg	-	-	-	0.55
Burry Inlet	Hg	-	0.10	0.11	1.07
Trostre	Hg	-	-	-	0.44
Jersey Marine	Pb	-	-	-	1.70
Burry Inlet	Pb	2.50	0.68	0.82	0.86
Trostre	Pb	-	-	-	0.84
Jersey Marine	As	-	-	-	10.50
Burry Inlet	As	-	2.40	4.04	11.50
Trostre	As	-	-	-	11.20
Jersey Marine	Cr	-	-	-	1.29
Burry Inlet	Cr	24.10	2.00	2.24	2.95
Trostre	Cr	-	-	-	2.49
Jersey Marine	Ni	-	-	-	88.60
Burry Inlet	Ni	50.80	31.00	21.47	33.10
Trostre	Ni	-	-	-	41.00

APPENDIX V. Tidal Waters Bioaccumulation Programme

V.1 *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	10.90	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 cont.

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	0.50
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

V.2 *Mytilus edulis*

SITE	Cu	Cd	Ni	Zn	Pb	Cr	Hg
Cardiff Flats	13.80	36.93	9.46	327.0	19.76	15.16	0.39
Swansea Flats	9.03	12.70	5.80	189.0	12.46	6.46	0.44
Nolton Haven	7.43	2.36	1.33	77.3	18.10	1.50	0.18
Aberystwyth	6.40	4.30	0.00	221.0	33.40	1.10	----
Tywyn	7.10	1.60	1.80	96.0	23.90	1.60	----
Barmouth	4.10	2.35	0.70	107.5	19.55	1.10	0.29
Porthmadog	5.50	2.20	0.00	118.0	6.90	0.00	----
Pwllheli	8.40	3.50	0.00	160.0	25.90	2.00	----
Caernarfon	9.75	2.65	0.45	140.0	34.45	1.30	0.57
Beaumaris	7.85	3.45	1.20	144.5	10.70	5.00	0.47
Conwy	7.45	2.05	0.60	119.0	8.25	0.00	0.48
Penrhyn Bay	9.85	3.45	1.30	174.5	38.90	0.40	0.56
Rhyl	6.25	1.45	2.05	167.0	8.95	0.10	0.36
Mostyn	4.25	0.70	1.20	294.5	6.70	0.00	----
Hilbre Island	14.70	0.85	0.30	258.5	5.80	0.15	0.33