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British Isles coastal waters: the concentrations of selected heavy metals in sea water, suspended matter and biological indicators - a pilot survey

by

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ABSTRACT

Data, from British Isles coastal waters, on the concentrations of selected metals in sea water and biological indicators, have been obtained by analytical techniques based on atomic absorption spectrophotometry. The results show that there are some areas where significant contamination exists, and the east Irish Sea appears to have the highest concentrations of most metals. However, data in most regions indicate that the concentrations of the metals examined are not significantly higher than those in the open Atlantic Ocean adjacent to the British Isles. The sampling of seaweeds strongly suggests that concentrations of most metals, including those in polluted areas, have changed little over the ten years up to 1970: the concentrations of cadmium may well, on average, have fallen over this period. In the Irish Sea, where the most detailed examination has been made, there is a rapid decrease in seawater concentrations from the shoreline to offshore, and in general the proportions of a metal associated with suspended matter remain fairly constant with respect to variations of total concentrations in either time or space.

INTRODUCTION

Studies of the distribution of artificial radioactivity in the marine environment have provided a broad outline of the behaviour of the radionuclides of selected heavy metals which exist at trace concentration in sea water (i.e. μg/litre or less). These studies have indicated the conservative nature of some radionuclides with respect to sea water, their degree of accumulation on the surfaces of finely divided suspended matter, bed sediments or living organisms, and their propensity in some cases for true bioaccumulation. On occasion, this behaviour has been in marked contrast to what was known of, or could be inferred from, the behaviour of the stable nuclide.

A programme of trace element analysis was therefore begun in 1967, since a study of the relative behaviour of stable and radio nuclides of the same element presents an opportunity to investigate aspects of "biological availability" which are of basic importance not only to environmental radioactivity problems but also to problems of metal pollution. This programme was devoted initially: (i) to the environment and particularly to the selection and testing of appropriate sampling, sample preparation and analytical techniques (to be published by Dutton and Harvey); (ii) to the establishment of a sampling network primarily in the north Irish Sea, but also elsewhere in British coastal waters for comparative purposes; and (iii) to Atlantic water to provide open ocean water background observations. Recently more extensive coverage has been extended to areas of the North Sea, and this will be a continuing feature of future programmes, as will be some element of open ocean sampling which might also provide data within the GEOSECS/IDOE programme for the North Atlantic. The selected analytical techniques have already been applied within the GEOSECS intercalibration exercise and are now also used in experimental work in aquaria.

The parallel programme of experimental work in aquaria is concerned with an examination of the problems of biological availability in relation to chemical state, with the metabolic behaviour of stable and radionuclides in selected marine organisms, and with the establishment of values for such parameters as biological half-life and concentration factor which are of importance, from a pollution control point of view, in assessing the significance of water concentrations of specific nuclides.

SAMPLING AND ANALYTICAL PROCEDURE

Sampling and sample storage

Surface samples were collected using a polypropylene bucket and rope; subsurface collections were made by drawing the water through a 2.5 cm diameter PVC hose (reinforced with braided terylene) with the aid of an electrically-driven pump, constructed entirely from polypropylene and PTFE except for a small carbon shaft-seal. No significant variation between the methods of sampling has been detected.

It was decided that some form of separation of the sample into 'mainly solid' and 'mainly liquid' phases was essential - the chief reason being the large variation in suspended load due to weather conditions;

Millipore cellulose acetate filter papers (142 mm diameter, 0.2 μm pore size) mounted in a PTFE filter press were used to effect this separation rapidly, in preference to centrifuging because of the difficulty in carrying out the latter operation on board ship. The contamination problem from the Millipore filters is well known (Robertson 1968) and much work has been done at this laboratory on the problems of the leaching of impurities from the paper (Harvey and Woods, unpublished data). The filtrate was collected in a polythene container, rapidly frozen and stored at -20°C until required for analysis - this procedure has been shown to be satisfactory (Harvey and Woods, unpublished data) and does not require the use of concentrated acids at sea. The samples were left frozen until the start of the analysis, when they were thawed and acidified to pH 2 with redistilled hydrochloric acid to ensure that iron was in a form suitable for subsequent analysis. The filter membrane and filter were stored in a 5 inch (approx. 13 cm) polystyrene petri dish until required for analysis.

Limpets were removed from the rocks by rapidly sweeping a group with a suitable flat stone; in this way, since they were only loosely attached, several could be removed at once. The animals were then removed from their shells, using a plastic knife with a serrated blade or a polythene spatula. Fucus seaweed, generally F. vesiculosus, was collected by removing the leafy fronds - old stalky growth was not taken. Good growing Porphyra was sampled by hand-picking. All these materials were well washed by agitation in local sea water (freed of suspended matter by settlement, in a plastic bucket, to remove sediment) and were then rapidly frozen and stored at -20°C.

Analytical methods

Sea water

The selection of the analytical method was made on the basis of sensitivity, multielement capability and the existing facilities of the laboratory, and had to include the following elements: zinc, copper, iron, manganese, nickel, silver, cadmium and lead. The use of the well-favoured technique of neutron activation was excluded for several reasons, especially the distance of the laboratory from the reactors at UKAEA Harwell, which effectively ruled out the determination of elements with short half-lives, and the method finally chosen was solvent extraction followed by atomic absorption spectrophotometry; the use of chelating resin was ruled out because of the inclusion of iron in the analytical requirement. The method chosen involves extraction into chloroform at pH 6 of the ammonium pyrollidine dithiocarbamate (APDC) complexes, followed by atomic absorption spectrophotometry on a small portion of this extract, using the tantalum boat technique (Kahn et al. 1968) for cadmium, lead and silver· the remaining portion of the chloroform extract is converted to methanolic solution and aspirated directly into a Perkin-Elmer 303 instrument, using standard conditions in an air/acetylene flame and Boling multi-slot burner. With an initial seawater volume of 1 litre and 2 x 25 ml chloroform extracts, the listed elements are extracted with yields of > 95 per cent, and the use of methanol as aspirant means that the extracted samples can be directly compared with a mixed element standard of the metal chlorides dissolved in methanol.

Suspended matter

On analysis the filters were leached by boiling in the bottom of a wide beaker with 100 ml of 0.1N hydrochloric acid ("Aristar") plus 1 ml of 100 volume hydrogen peroxide of similar quality; a large clock-glass prevented foreign matter from entering the beaker. When the liquid had evaporated to about 20 ml it was transferred, with the help of a little distilled water, to a 50 ml polythene bottle and made up to a known weight (about 30 ml).

This solution was analysed by direct atomic absorption spectrophotometry for zinc, iron, manganese, copper and nickel against standards in 0.3N HCl. By placing further 1 ml quantities of the solution on a tantalum boat, results may be obtained for lead, silver and cadmium if the levels are sufficiently high or if larger samples (e.g. 5 litres) of sea water are used.

Blank determinations were carried out with each batch, using reagents only.

Biological materials

The analysis of biological samples was accomplished by direct atomic absorption spectrophotometry on a 0.5M HCl solution of the material after wet-oxidation of the oven-dried (105°C) sample, using high-purity nitric and perchloric acids. Analysis of the Bowen kale sample (Bowen 1967) was also carried out as a check on the technique; the results are shown in Table 1.

Table 1 Concentrations of heavy metals in the Bowen kale intercomparison sample

Element	µg/g dry kale (mean of 3 results)	Consensus values (Bowen 1967)
Zn	32.1	31.88 ± 4.82
Fe	120.8	119.5 ± 19.5
Mn	14.9	14.9 ± 1.8
Cu	5.0	4.81 ± 0.735
Ni	0.87	-
Pb	4.1	-
Cd	1.1	-
Ag	0.42	-

Corrections for broadband matrix interferences were made by a method found to give good results with the Bowen kale intercomparison sample. This entailed preparation of blank solutions containing previously determined appropriate amounts of sodium,potassium and calcium as chlorides, dissolved, as for the samples, in 0.5M HCl. These solutions produced considerable noise at all wavelengths and positive interference, which had to be subtracted, in the determinations of cadmium, lead, silver and nickel. Precision figures for the determination of all elements, which were obtained by twelve replicate analyses of a sample of Fucus vesiculosus, are given in Table 2.

Table 2 Precision of analytical method (using Fucus vesiculosus)

Element	Mean µg/g	Coefficient variation %
Zn	489 ± 22.8 (σ)	4.7
Fe	111 ± 12.3	11.1
Mn	96 ± 5.9	6.1
Cu	8.3 ± 0.37	4.6
Ni	3.66 ± 0.88	24.0
Pb	7.2 ± 1.9	26.0
Ag	0.41 ± 0.06	14.2
Cd	1.70 ± 0.24	14.4

SAMPLING NETWORK

For the purpose of comparing different sea areas the waters around the British Isles were divided into the six areas indicated in Fig. 1, which also indicates the individual sampling positions for sea water and biological materials. The Irish Sea sampling positions, which were more numerous than in other areas (because of the predominant radio-ecological interest in the Irish Sea), are shown separately in Fig. 2. In this area seawater samples were taken at surface, mid-water and bottom, but elsewhere surface samples only were taken. In 1970, the second year of the large-scale sampling programme, shoreline water samples were also taken in the Irish Sea (Fig. 2).

RESULTS AND DISCUSSION

The geometric mean values for filtered surface sea water for the major areas in 1969 and 1970 are given in Table 3. There is analytical evidence that the copper data obtained for the filtered sea water in 1969 are high. This evidence has been strengthened by comparing our results with those of other laboratories in the GEOSECS intercomparison exercise (Brewer and Spencer 1970). However, no constant correction factor could reasonably be applied and, since the evidence against inclusion is not overwhelming, the data have been included without alteration.

High levels of zinc were also found, especially in Area 2 (western Irish Sea). This may be evidence of terrestrial contamination, but since the data for individual stations appear to be distributed in a non-random manner this seems unlikely and they have been included.

Reagent contamination for cadmium and lead was significant, but suitable blank corrections have been made. In Area 4A samples (north-east Atlantic), however, significant sample contamination for lead was noted, and these data have therefore not been tabulated.

Sea water and suspended matter

The major points of interest which arise from the data in Table 3 are the noticeably higher zinc concentrations already noted for Area 2 in 1969, and the higher manganese values in Area 3 in 1970. In neither case were these attributable to very high isolated values such as might be associated with sample contamination, nor was the overall pattern of high values at individual stations consistent with systematic contamination of a sequence of sampling positions. Rather do the results suggest an enhanced level in the sea water at that time. Interestingly enough, this high level was reflected in the residue after filtration in the case of zinc, but not in the case of manganese.

Comparison of sea areas shows that the eastern Irish Sea most frequently exhibited the highest mean concentrations, the notable exception being cadmium which had its highest value in the North Sea.

Table 3 Concentrations of selected heavy metals in British Isles coastal sea water (filtrate) (μg/litre). A, geometric mean; B, range; C, number of observations

Element		Area 1	Area 2	Area 3	Area 4	Area 4A	Area 5
1969							
Zn	A	6.4	7.1	6.5			4.6
	B	4.3-9.0	3.0-20.0	1.8-14.8			–
	C	4	16	22			1
Fe	A	0.7	0.1	0.5			2.0
	B	0.2-2.3	0.1-0.6	0.1-1.1			–
	C	4	16	22			1
Mn	A	0.4	0.5	0.6			0.4
	B	0.3-0.5	0.3-0.8	0.2-2.2			–
	C	4	16	22			1
Cu	A	1.3	1.3	1.3			1.4
	B	1.1-1.6	0.7-2.8	0.8-1.9			–
	C	4	16	22			1
Ni	A	0.7	0.5	0.7			0.5
	B	0.5-1.3	0.3-1.2	0.3-1.4			–
	C	4	16	22			1
1970							
Zn	A	2.0	3.0	4.2	2.0	3.0	3.1
	B	1.2-3.8	0.8-9.0	2.3-7.5	1.3-3.4	1.4-7.0	1.5-6.9
	C	4	10	21	8	5	4
Fe	A	0.3	0.09	0.18	–	–	0.06
	B	0.06-1.3	0.03-0.6	0.06-1.9	–	–	0.06-1.5
	C	4	10	21	8	5	4
Mn	A	0.32	0.53	1.95	0.18	0.06	0.34
	B	0.10-0.49	0.15-2.6	0.22-14.6	0.02-0.49	0.03-0.09	0.24-0.54
	C	4	10	21	8	5	4
Cu	A	0.46	0.59	0.66	0.34	0.26	0.48
	B	0.23-1.29	0.18-3.75	0.28-0.98	0.19-0.62	0.05-0.80	0.24-1.70
	C	4	10	21	8	5	4
Ni	A	0.38	0.38	0.71	0.53	0.43	0.31
	B	0.22-0.95	0.22-0.55	0.32-22.9	0.36-0.79	0.29-0.66	0.16-0.51
	C	4	10	21	8	5	4
Pb	A	0.17	0.19	0.11	<0.05	–	0.21
	B	<0.05-1.1	<0.05-0.7	<0.05-1.0	–	–	<0.05-0.8
	C	4	10	21	8	5	4
Cd	A	0.06	0.11	0.04	<0.01	0.04	0.41
	B	<0.01-0.38	<0.01-0.52	<0.01-0.62	<0.01-0.18	<0.01-0.41	0.29-0.60
	C	4	10	21	8	5	4

In general, open Atlantic water is lower than, or as low as, any other area in its trace metal content, and there is little indication of widespread pollution in any offshore water samples from any area. By an analysis of variance, only manganese ($P < 0.001$) and nickel ($P < 0.01$) in Area 3, and cadmium ($P = 0.05$) in Area 5 show average concentrations significantly higher than those of other areas. Clearly the number of samples taken in the North Sea is small, and more attention is being paid to this area before drawing any final comparison with Area 3.

Table 4 Heavy metal concentrations in shoreline sea water (filtrate) from the Irish Sea, 1970 (μg/litre). A, geometric mean; B, range; C, number of observations

Element		Area 2	Area 3
Zn	A	6.6	6.8
	B	4.9-11.1	3.8-49.1
	C	9	11
Fe	A	6.1	11.9
	B	2.5-23.9	5.3-24.7
	C	9	11
Mn	A	2.2	6.1
	B	0.7-10.8	2.5-25.5
	C	9	11
Cu	A	1.4	1.7
	B	0.9-2.7	1.1-3.1
	C	9	11
Ni	A	1.4	2.6
	B	0.9-3.1	1.3-9.8
	C	9	11
Pb	A	1.6	1.3
	B	0.9-2.9	0.6-2.4
	C	7	8
Ag	A	0.08	0.04
	B	0.02-0.24	0.03-0.16
	C	9	11
Cd	A	0.41	0.46
	B	0.03-1.43	0.15-1.14
	C	9	11

Reference to Table 4 shows that shoreline waters in the Irish Sea in 1970 have significantly higher concentrations ($P < 0.05$) than offshore waters in the same area at the same time. It is interesting in this context to take individual station results in the North Wales area, offshore of the Conway estuary, and from the shore at Colwyn Bay, and to compare them with the recently reported results of Elderfield et al. (1971) for Conway local sea water:

	Zn	Pb	Cu	Ni	Cd
Conway, local	8.8	3.6	3.0	3.7	0.76
Colwyn Bay	11.0	1.3	2.0	3.4	0.2
Conway, offshore	5.8	0.1	0.7	0.7	0.2

Agreement between Elderfield's Conway local sea water and the shoreline samples is good, except for the noticeably lower cadmium at Colwyn Bay, and the offshore samples show the expected, sharp decline in concentration.

An examination of the data in Table 5 (filtered residues) shows a very similar average partition of zinc, iron, manganese and copper, as between water and presumed suspended matter, regardless of area and type of sample - shoreline, offshore or open ocean. The shoreline water residue analyses for nickel, lead, cadmium and silver indicate relatively little involvement of cadmium with suspended material.

Biological materials

Selected biological materials can be used as indicator systems by virtue of their ability to reconcentrate metals and to integrate water concentrations over reasonably long intervals of time and thus smooth out any large but short-term fluctuations in water concentration. The materials selected in this survey were the seaweeds Fucus vesiculosus (bladder wrack) and Porphyra umbilicalis (laverweed), and limpets (Patella vulgata). Mytilus edulis (common mussel) was not selected, in spite of its ready availability in all areas, because of the variable burden of silt and other finely divided matter always associated with this organism, which would have led to wide variation in the concentration of individual metals.

Fucus seaweeds were sampled in all areas, but limpets and Porphyra only from the shoreline of the Irish Sea where the sampling positions used for shoreline water were adopted. The concentrations of individual metals in the three materials in various areas are given in Tables 6 and 7, and it is noteworthy that on the whole they also reflect the greater degree of contamination in the eastern Irish Sea already revealed by the water samples, suggesting that the average water concentrations are reasonably representative of the state of this area. In addition, the data for copper in Table 6 suggest a significantly higher level in the

Table 5 Percentage $\frac{\text{"Particulate"}}{\text{Total}}$ values for heavy metals in sea water from shoreline and offshore areas of the British Isles

Area		Zn		Fe		Mn		Cu		Ni	Pb	Cd	Ag
		1969	1970	1969	1970	1969	1970	1969	1970	1970	1970	1970	1970
1		48.4	50.0	81.1	98.3	76.5	66.7	79.7	87.8				
2	Sea	55.1	40.0	99.7	99.7	83.3	68.8	73.5	81.2				
	Shore		47.6		97.8		73.8		69.6	50.0	50.0	20.0	46.7
3	Sea	39.3	31.1	99.2	99.1	83.3	33.3	61.8	75.9				
	Shore		73.4		99.1		83.6		77.0	50.0	81.7	16.7	69.2
4			48.7		99.1		66.1		92.8				
4A			25.0				75.0		92.6				
5			49.2		99.7		76.9		89.1				
Geom. mean		47.2	43.6	92.9	99.0	81.0	66.0	71.3	82.8	50.0	63.9	18.3	56.9

eastern Irish Sea and the North Sea, though isolated high values do occur at sampling points known to be associated with heavy industry in other areas, for example 20.5 $\mu g/g$ at Barry (South Wales) in Area 1. This sampling location also exhibits the highest values in Area 1 for cadmium, nickel and zinc, indicating a significant degree of metal contamination in this area. Similarly, Seaham Harbour in the Tyne-Tees locality produces the highest values in Area 5 for zinc and cadmium, ~~and the second highest values in Area 5 for zinc and cadmium,~~ and the second highest value for lead. The Clyde (Hunterston) records the highest levels in Area 4 for manganese, copper, nickel and zinc, and within Area 3 Hoylake produces the highest zinc and copper values. All these values may be taken as evidence of metal contamination in the vicinity of these sampling points.

The shoreline water values may be used in conjunction with these biological material values to derive estimates of concentration factors, and these are presented in Table 8, where the high reconcentration of cadmium, iron and silver in the flesh of limpets is the outstanding feature. <u>Fucus</u> seaweed would appear to be a good indicator species for zinc, iron, manganese and silver. Since samples of this seaweed were also available from a comprehensive survey conducted in 1961 for weapon-test fallout radionuclides, they were also analysed for trace metals, and the results are shown in Table 9. The results from 25 of these stations are compared in pairs with the 1970 results as the quotient $\frac{\text{metal concentration 1970}}{\text{metal concentration 1961}}$ and the mean quotient for each nuclide is tested for any significant difference from unity, using Student's t test. The results are shown in Table 10, and it can be seen that there are no significant differences in the mean concentrations of the nuclides between 1961 and 1970 except in the case of cadmium, where the data suggest that on average there may have been a significant decrease ($P = 0.02$) in concentration during the last decade, Barry (South Wales) being the notable exception and the place where the highest values of both surveys were recorded.

The data therefore do not support the view that average concentrations of these trace metals have increased in British coastal waters over the past decade. Examination of the data in detail reveals the even more interesting fact that there has been no significant increase in concentration between 1961 and 1970 even in the more heavily contaminated localities: i.e., where there is contamination, the degree of contamination has not significantly changed.

REFERENCES

BOWEN, H. J. M., 1967. Comparative elemental analyses of a standard plant material. Analyst, Vol. 92, pp. 124-131.

BREWER, P. G. and SPENCER, D. W., 1970. Trace element intercalibration study. Woods Hole Oceanographic Institution Technical Report 70-62.

ELDERFIELD, H., THORNTON, L. and WEBB, J. S., 1971. Heavy metals and oyster culture in Wales. Marine Pollution Bulletin, Vol. 2, No. 3, pp. 44-47.

KAHN, H. L., PETERSEN, G. E. and SCHALLIS, J. E., 1968. Atomic absorption microsampling with the "sampling boat". Atomic Absorption Newsletter, Vol. 7, pp. 35-39.

ROBERTSON, D. E., 1968. Role of contamination in trace element analysis of sea water. Analytical Chemistry, Vol. 40, No. 7, pp. 1067-1072.

Table 6 Concentrations of heavy metals in *Fucus* spp from coastal areas of the British Isles, 1970 (μg/g dry material). A, geometric mean· B, range; C, number of observations

Element		Area 1	Area 2	Area 3	Area 4	Area 5
Zn	A	80	94	171	72	110
	B	46-44	42-450	88-962	60-124	64-233
	C	7	7	13	7	6
Fe	A	143	189	249	127	216
	B	69-312	84-293	85-515	56-417	100-1517
	C	7	7	13	7	6
Mn	A	65	67	99	64	70
	B	40-88	34-94	52-141	33-190	39-123
	C	7	7	13	7	6
Cu	A	5.3	4.6	9.0	3.2	10.1
	B	2.9-20.5	2.4-9.3	3.7-16.9	1.7-12.4	2.6-28.4
	C	7	7	13	7	6
Ni	A	5.5	4.3	6.7	4.1	6.0
	B	3.4-18.0	2.9-9.5	5.0-9.8	1.8-8.4	2.9-10.9
	C	7	7	13	7	6
Pb	A	3.2	3.2	3.4	2.1	4.0
	B	2.2-4.2	1.4-7.7	0.6-9.0	0.5-4.3	2.3-5.7
	C	7	7	13	7	3
Ag	A	0.29	0.24	0.30	0.20	0.35
	B	0.13-0.56	0.13-0.47	0.07-0.79	0.11-0.58	0.13-0.66
	C	7	7	13	7	6
Cd	A	1.4	1.1	1.4	1.2	1.2
	B	0.4-20.8	0.5-1.5	0.5-3.0	0.9-2.1	0.6-2.1
	C	7	7	13	7	6

Table 7 Irish Sea, 1970: concentration of heavy metals in <u>Porphyra</u> spp and limpets ($\mu g/g$ dry material). A, geometric mean; B, range; C, number of observations

Element		Area 2			Area 3	
		<u>Porphyra</u>	Limpet (soft parts)		<u>Porphyra</u>	Limpet (soft parts)
Zn	A	63	90	A	66	158
	B	36-174	56-195	B	35-177	109-274
	C	9	9	C	13	8
Fe	A	309	2450	A	387	2060
	B	104-3800	1580-7800	B	137-1820	1380-3270
	C	9	9	C	13	8
Mn	A	29	31	A	29	42
	B	13-72	18-94	B	14-93	23-88
	C	9	9	C	13	8
Cu	A	8.9	9.9	A	11.5	14.4
	B	2.8-23.3	5.5-20.0	B	6.6-19.5	9.5-22.0
	C	9	9	C	13	8
Ni	A	2.2	7.3	A	2.0	7.0
	B	0.2-9.6	3.1-24	B	0.6-9.7	4.5-9.9
	C	9	9	C	13	8
Pb	A	3.1	7.8	A	2.7	7.9
	B	0.8-10.5	3.5-85	B	1.1-10.5	5.4-12.5
	C	9	9	C	13	8
Ag	A	0.13	1.3	A	0.09	2.1
	B	0.01-0.30	0.6-2.7	B	0.01-0.21	1.3-3.6
	C	6	9	C	8	8
Cd	A	0.35	8.4	A	0.25	13.1
	B	0.10-0.97	2.8-35	B	0.05-0.87	3.8-23
	C	9	9	C	12	8

Table 8 Irish Sea, 1970: concentration factors $\frac{(\mu g/g \text{ dry material})}{(\mu g/g \text{ seawater})}$ for selected heavy metals for *Fucus*, *Porphyra* and limpets (soft parts)

Element	*Fucus* (18 observations)	*Porphyra* (20 observations)	Limpets (17 observations)
Zn	2.0×10^4	1.0×10^4	1.9×10^4
Fe	2.4×10^4	3.6×10^4	2.8×10^5
Mn	2.3×10^4	7.0×10^3	1.1×10^4
Cu	4.5×10^3	6.3×10^3	7.6×10^3
Ni	2.8×10^3	1.1×10^3	3.6×10^3
Pb*	2.4×10^3	2.0×10^3	5.5×10^3
Ag	5.0×10^3	1.9×10^3	3.1×10^4
Cd	2.7×10^3	6.6×10^2	2.5×10^4

*The number of observations for Pb was 13, 15 and 12 respectively

Table 9 Concentrations of heavy metals in Fucus spp from coastal areas of the British Isles, 1961 (μg/g dry material). A, geometric mean; B, range; C, number of observations

Element		Area 1	Area 2	Area 3	Area 4	Area 5
Zn	A	73	93	146	116	130
	B	38-386	32-322	53-875	75-223	69-365
	C	5	3	12	10	6
Fe	A	196	155	211	155	209
	B	62-678	128-190	87-527	45-680	64-1035
	C	5	3	12	10	6
Mn	A	70	76	96	76	122
	B	38-106	67-97	51-301	45-134	53-258
	C	5	3	12	10	6
Cu	A	4.1	6.0	8.9	4.0	7.5
	B	1.6-18.7	4.6-8.1	4.2-22.9	2.5-14.5	2.6-36
	C	5	3	12	10	6
Ni	A	4.7	4.9	7.5	4.6	5.9
	B	1.6-15.4	3.5-6.8	4.0-22.2	2.7-7.8	1.2-20
	C	4	3	12	10	6
Pb	A	3.1	3.6	3.8	3.0	3.8
	B	1.3-8.7	2.3-5.4	1.5-11.3	1.6-5.8	1.3-5.8
	C	5	3	12	10	6
Ag	A	0.17	0.50	0.31	0.37	0.50
	B	0.07-0.31	0.44-0.59	0.09-0.68	0.16-0.61	0.26-1.5
	C	5	3	12	10	6
Cd	A	1.9	1.7	2.0	1.5	2.5
	B	0.54-21.0	1.5-1.8	0.83-11.8	0.05-5.7	1.8-5.1
	C	5	3	12	10	6

Table 10 Significance testing of the quotient $\frac{\text{metal concentration 1970}}{\text{metal concentration 1961}}$

Element	Mean quotient	Standard deviation	P
Zn	1.02	0.43	< 0.9
Fe	1.16	0.55	< 0.2
Mn	0.95	0.44	< 0.6
Cu	0.98	0.38	< 0.8
Ni	1.05	0.55	< 0.7
Pb	1.03	0.66	< 0.9
Ag	1.02	0.88	$= 0.9$
Cd	0.76	0.46	$= 0.02$

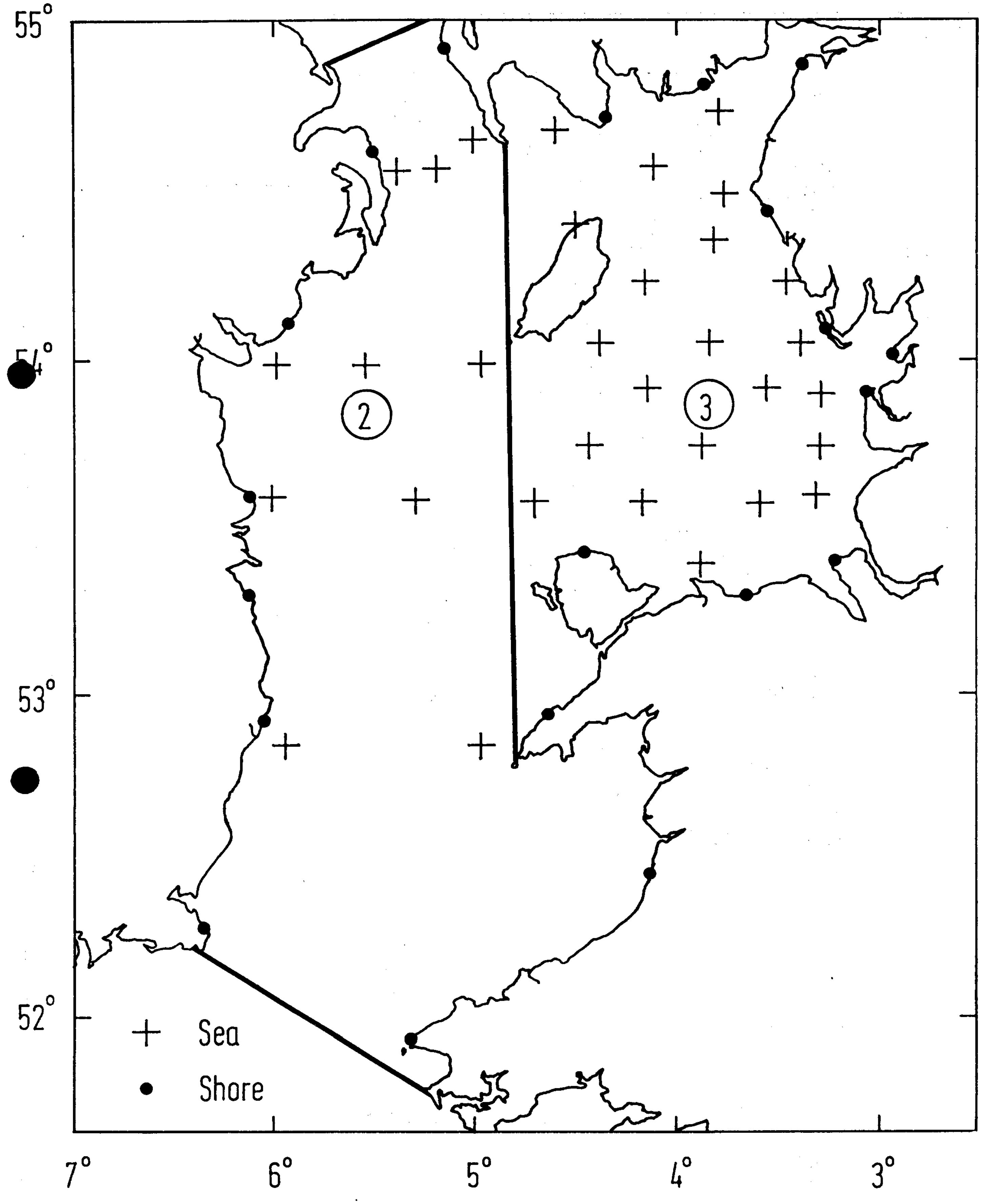

Figure 2 Seawater sampling stations in the Irish Sea, 1970.

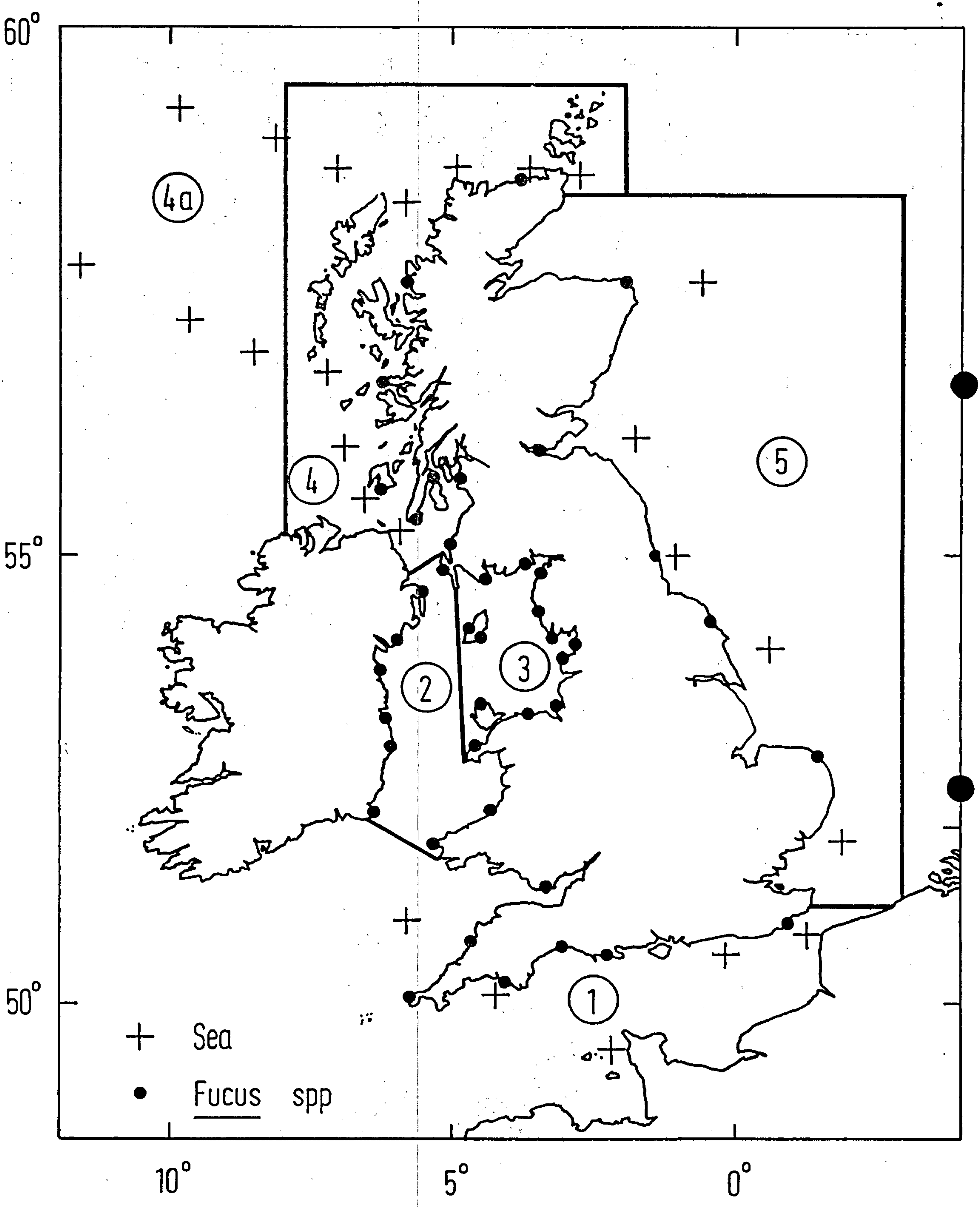

Figure 1 Seawater and Fucus spp. sampling stations in coastal sea areas of the British Isles (1970 only).