4

Chemistry

4.1 Introduction

This chapter summarises the most recent information for Region III on the inputs and environmental concentrations of heavy metals, persistent organic substances, nutrients, radionuclides and oil.

Contaminants introduced into the sea are either natural or synthetic. The presence of synthetic substances in the environment always represents contamination. Many substances such as nutrients and metals are commonly found in soils, plants and animals and it is therefore important to differentiate between the normal geochemical fluxes of these materials (e.g. through rivers) and fluxes augmented by human activities. Such distinctions, although often difficult to make, are essential to environmental protection. Clearly, measures to prevent pollution from excessive inputs of nutrients and metals need to be focused on the component of land-sea fluxes that results from human activities.

A key element of the strategy to prevent marine pollution within the OSPAR area is to reduce as far as practicable the quantities of contaminants entering the sea from all sources. This involves a combination of regulatory and management measures designed to reduce waste and encourage cleaner production. It also requires accurate data on the sources and pathways of the more common pollutants to determine quantities entering the sea and the trends in inputs over time. High variability and low sampling frequencies, combined with very low concentrations in large volumes of carrier medium, dictate that in most cases only rough estimates of contaminant inputs are possible. Accordingly, the rate of change and the period for which records are available will determine whether and when a trend can be determined with reasonable confidence. At present, for most inputs to Region III, either the change is too slow or the record too short for trends to be discernible.

4.2 Inputs of contaminants

Agencies responsible for monitoring inputs to Region III are working to improve their monitoring techniques in order to quantify more accurately the trends in contaminant inputs, focusing in particular on inputs via rivers and industrial and municipal outfalls. Atmospheric inputs are determined largely through modelling. At present, any apparent trends should be viewed with considerable caution. Records on inputs to each of the major sea areas are incomplete and in most cases cover less than a decade. Furthermore, the cumulative errors associated with sampling, analysis and flow estimation dictate that most calculations of contaminant loads provide only very rough estimates. These factors, and the inherent inter-annual variability in inputs, restrict current capabilities for input trend assessment.

4.2.1 Direct and riverine inputs

Where some concentrations are below the analytical detection limits the assumptions made in calculating loads affect input assessments. Two approaches are used: 'low load estimates' treat any result recorded as less than the detection limit as having a true concentration of zero, whereas 'high load estimates' treat such results as having a true concentration equivalent to the detection limit. Where the products of these calculations are widely different (as is the case for many organic contaminants), it is probable that the high loads significantly overestimate the true value. For the purposes of the tables summarising direct and riverine inputs *(Tables 4.1 and 4.2)* metals and nutrients are given as high loads and, unless otherwise indicated, organic contaminants as low loads.

The data records on direct and riverine inputs available for the current assessment cover the period 1990 to 1996. It is quite possible that the input trends identified in the following paragraphs may have changed in more recent years. Nevertheless, it seems reasonable to expect that downward trends in response to improved management measures (e.g. reductions at source) would continue.

Direct inputs

Direct inputs consist mainly of discharges to coastal waters from industrial and municipal outfalls. Overall responsibility for controlling direct inputs in accordance with national legislation and the relevant EC Directives rests with the Environment Agency in England and Wales, the Scottish Environmental Protection Agency, the Department of the Environment in Northern Ireland and, in Ireland, the Environmental Protection Agency and local authorities.

Although an increasing number of coastal sewage discharges receive some form of treatment, an estimated half of the total sewage entering the coastal waters of Region III, in terms of both total volume and population served, is either untreated or receives only primary treatment. Much of the latter is associated with major urban/industrial centres (e.g. Merseyside and Dublin) where very large volumes of sewage are generated and the process of upgrading treatment systems is technically complex and therefore takes some time to complete. In other coastal areas significant progress has been made. For example, along the coasts of Wales and the Bristol Channel (Anglesey to Land's End) about two-thirds of the sewage receives either primary (18%), secondary (38%) or tertiary (10%) treatment. In response to the EC Urban Wastewater Treatment Directive (91/271/EEC) many coastal sewage works are in the process of being upgraded to provide a minimum of primary treatment and there is increasing use of secondary, or even tertiary, treatment in areas vulnerable to the effects of organic enrichment and eutrophication.

A compilation of data on direct inputs of contaminants from 1990 to 1996 is given in *Table 4.1*. Records of contaminant inputs in direct discharges around the coasts of Ireland are limited; this is currently being improved. The most complete coverage is for the eastern Irish Sea and Bristol Channel. There are strong indications that in the mid-1990s direct inputs of some heavy metals (i.e. cadmium, mercury and zinc) to these areas were decreasing. On the other hand it appears that inputs of lead have risen slightly and that copper inputs are more or less stable. There are also signs that the amounts of PCBs (and possibly γ-HCH) in direct inputs to the eastern Irish Sea, Bristol Channel and Malin Shelf have decreased since the early 1990s, but more recent data are needed to determine whether or not these trends are genuine.

With the possible exception of phosphorus inputs to the Bristol Channel, which suggest a slow decrease, direct inputs of nutrients to all parts of Region III for which temporal data exist were relatively stable to the mid-1990s. The amounts of nitrogen were invariably greater than the amounts of phosphorus. As no time series data were available on direct inputs from sources in Ireland (i.e. the mid-western Irish Sea, Celtic Sea and Atlantic seaboard), trends in direct inputs across Region III as a whole cannot yet be evaluated.

Direct inputs of radionuclides are discussed in Section 4.8.

Riverine inputs

Overall, the record on contaminant inputs via rivers *(Table 4.2)* is considerably better than that for direct inputs. Although trends can be determined, data on riverine inputs are inherently prone to errors that tend to mask spatial or temporal differences. With this caveat, to the mid-1990s there were indications of a slight decline in inputs of mercury and γ-HCH, and possibly also

Table 4.1 Direct inputs of contaminants to sea areas in Region III 1990–6.

			Cd (t)	Hg (t)	Pb (t)	Cu (t)	Zn (t)	γ–HCH (kg)	PCBs (kg)	NH$_4$-N (kt)	NO$_3$-N (kt)	PO$_4$-P (kt)	Total N (kt)	Total P (kt)	SPM (kt)
Eastern Irish Sea		1990	22.10	2.78	2.8	23.0	316	0.23	0.73	-	0.24	4.81	3.57	4.81	317
		1991	8.41	1.74	1.4	52.3	156	0.14	-	-	0.17	6.49	3.77	6.49	333
		1992	7.26	1.60	17.3	19.5	160	17.10	-	-	0.19	3.17	3.06	3.17	15
		1993	5.65	0.87	57.8	14.3	138	17.30	-	3.30	1.10	1.90	5.60	2.10	59
		1994	3.39	0.60	34.8	34.3	112	3.40	0.30	5.70	0.50	3.80	5.60	4.30	69
		1995	3.21	0.38	28.5	17.3	84	3.50	0.30	2.70	0.40	2.70	3.00	3.10	57
		1996	3.91	0.33	35.8	15.5	90	4.40	0.10	4.48	0.73	3.14	11.60	3.39	59
Western Irish Sea	ROI only	1990	0.06	-3.3	7.5	63	-	-	-	-	-		6.83	1.58	38
	ROI sewage*	1994–6	0.06	0.02	4.2	7.4	29	-	-	-	-	-	-	-	-
	NI only	1993	0.33	0.12	1.1	3.2	17	1.94	-	-	-	-	5.45	0.52	14
	NI only	1994	0.49	0.07	4.1	11.0	25	2.87	-	-	-	0.72	1.20	0.95	24
	NI only	1995	0.23	0.04	2.2	6.5	15	3.12	-	-	-	0.36	2.17	0.50	18
	NI only	1996	0.64	0.02	2.1	4.6	19	1.46	-	-	-	0.32	6.41	0.57	13
Bristol Channel		1990	3.92	0.06	16.9	26.0	308	18.30	1.37	-	1.03	2.07	9.85	2.04	96
		1991	0.34	0.03	14.9	20.6	460	5.75	140.10	-	0.69	1.51	6.91	1.51	72
		1992	4.10	0.05	19.7	37.5	179	4.52	109.30	-	1.32	2.36	15.10	2.36	331
		1993	2.66	0.05	19.3	26.0	159	6.10	26.70	7.30	1.50	1.20	9.00	1.20	61
		1994	2.21	0.06	27.4	29.8	189	6.40	10.10	8.70	1.90	1.40	6.00	1.40	123
		1995	2.18	0.03	25.5	21.2	176	4.00	5.80	8.10	1.90	1.40	10.10	1.40	65
		1996	1.56	0.00	9.2	6.3	96	2.80	32.90	5.25	1.84	1.01	7.24	1.01	29
Celtic Sea	ROI only	1990	0.02	-	3.20	0.01	21.50	-	-	-	-	-	2.67	0.65	18.6
	ROI sewage*	1994–6	0.00	0.00	1.20	2.10	8.30	-	-	-	-	-	-	-	-
Atlantic seaboard	ROI only	1990	0.00	-	0.40	0.80	7.70	-	-	-	-	-	0.70	0.21	4.3
	ROI sewage*	1994–6	0.00	0.00	0.60	1.00	4.10	-	-	-	-	-	-	-	-
Malin Shelf south (NI)		1993	0.59	0.04	1.29	1.66	1.48	0.04	-	-	0.05	0.06	0.37	0.09	3.9
		1994	0.72	0.01	2.23	3.48	2.20	3.18	-	-	0.02	0.07	0.06	0.10	1.4
		1995	0.07	0.03	2.89	3.45	2.65	3.08	-	-	0.06	0.09	0.39	0.12	2.2
		1996	0.87	0.03	2.87	3.19	1.72	0.14	-	-	0.07	0.06	0.30	0.21	2.0

Figures for metals and nutrients are 'high estimates'; figures for organochlorines are 'low estimates'

* estimated annual input; ROI: Republic of Ireland; NI: Northern Ireland; -: no data reported.

Table 4.2 Riverine inputs of contaminants to Region III 1990–6.

		Cd (t)	Hg (t)	Pb (t)	Cu (t)	Zn (t)	γ-HCH* (kg)	γ-HCH† (kg)	PCBs* (kg)	PCBs† (kg)	NH$_4$-N (kt)	NO$_x$-N (kt)	PO$_4$-P (kt)	Total N (kt)	Total P (kt)	SPM (kt)
Eastern Irish Sea	1990	4.33	1.74	80.5	72.5	324	-	7.7	-	76	-	24.1	2.67	31.2	2.67	300
	1991	6.65	0.90	51.7	51.7	313	-	200.0	-	70	-	22.9	2.19	29.4	2.19	161
	1992	4.91	1.07	66.3	61.4	407	-	113.0	-	84	-	28.5	2.41	35.6	2.41	208
	1993	10.70	2.91	124.0	134.0	491	50.3	134.0	88.1	1040	8.2	30.6	4.50	44.8	4.90	365
	1994	4.04	1.40	71.3	82.1	397	3.4	89.7	0.2	514	7.0	33.0	3.30	43.1	3.50	325
	1995	3.26	1.11	50.8	78.4	309	33.6	85.6	0.1	282	8.1	27.3	3.00	33.5	3.20	257
	1996	1.61	1.02	32.8	50.5	313	13.3	45.9	7.3	188	6.3	35.1	2.80	44.9	3.10	152
Western Irish Sea ROI only	1990	0.69	-	6.0	20.7	165	-	-	-	-	3.7	12.2	0.23	24.0	0.49	-
ROI only	1991	-	-	-	-	-	-	-	-	-	5.9	15.3	0.22	31.9	0.38	-
ROI only	1992	0.46	-	4.3	27.4	132	-	-	-	-	2.5	8.9	0.22	22.5	0.31	39
	1993	0.63	0.04‡	7.4	29.5	222	-	2.6‡	-	-	6.3§	14.8§	0.62	37.1	0.86	13‡
	1994	0.69	0.07‡	8.3	30.6	240	-	2.9‡	-	-	3.9§	14.9§	0.62	30.4	1.16	6‡
	1995	1.10	0.66‡	10.2	43.0	239	-	2.9‡	-	-	1.5§	13.1§	0.43	21.5	0.76	7‡
	1996	0.94	0.07‡	8.1	27.3	219	-	2.5‡	-	-	1.1§	19.7§	0.35	27.4	0.73	58
Bristol Channel	1990	3.39	0.88	121.6	62.4	371	25.8	40.9	40.9	671	-	28.4	2.98	28.8	2.98	325
	1991	9.51	0.72	47.5	88.9	391	-	102.0	-	495	-	36.7	1.84	45.4	1.84	326
	1992	3.26	0.58	44.6	58.3	407	-	66.7	-	402	-	41.9	2.49	45.6	2.49	470
	1993	5.81	1.28	76.1	91.6	450	29.4	129.0	34.8	627	9.2	41.9	3.70	51.6	3.70	700
	1994	4.24	0.31	72.6	79.8	378	24.9	87.8	2.7	439	1.5	49.9	3.10	51.1	3.10	1252
	1995	3.06	0.29	51.9	61.4	293	18.0	67.3	-	445	2.5	43.0	2.80	50.5	2.80	631
	1996	1.05	0.13	40.9	33.4	232	29.0	43.8	1.5	88	1.3	38.4	2.20	39.4	2.20	268
Celtic Sea	1990	0.40	-	6.9	18.9	147	-	-	-	-	0.91	26.3	0.61	35.8	1.13	-
	1991	-	-	-	-	-	-	-	-	-	0.46	29.5	0.49	37.8	0.87	-
	1992	0.59	-	9.5	50.0	197	-	-	-	-	0.76	16.5	0.70	24.1	1.09	-
	1993	0.30	-	13.8	28.7	140	-	-	-	-	1.10	25.3	0.95	38.6	1.73	-
	1994	0.42	-	17.2	38.3	218	-	-	-	-	1.49	31.9	1.03	46.5	2.53	-
	1995	0.40	-	9.1	27.8	186	-	-	-	-	1.23	32.3	0.77	41.6	1.19	-
	1996	1.06	-	34.9	22.4	182	-	-	-	-	1.46	38.6	0.85	50.3	2.22	-
Atlantic seaboard	1990	1.14	-	26.5	33.6	236	-	-	-	-	0.52	22.1	0.54	35.9	1.15	-
	1991	-	-	-	-	-	-	-	-	-	0.44	23.0	0.49	30.6	0.99	-
	1992	0.45	-	23.4	59.7	498	-	-	-	-	0.34	14.9	0.61	27.5	1.06	-
	1993	0.37	-	4.5	36.2	165	-	-	-	-	0.63	14.7	0.64	27.8	1.08	-
	1994	0.54	-	14.5	67.6	183	-	-	-	-	0.67	16.4	0.79	33.0	1.46	-
	1995	0.46	-	16.9	62.5	419	-	-	-	-	0.86	14.8	0.77	27.3	1.30	-
	1996	0.77	-	7.6	19.3	138	-	-	-	-	0.54	24.0	0.50	35.0	1.24	-
Malin Shelf south (NI)	1993	0.72	0.01	2.1	11.1	30	8.5	9.5	0	-	-	5.9	0.41	17.4	0.63	60
	1994	1.13	0.84	12.0	26.7	61	18.7	19.5	0	-	-	5.6	0.48	5.8	0.82	77
	1995	0.58	1.32	3.2	18.8	28	14.4	15.5	0	-	-	6.9	0.43	8.0	0.84	78
	1996	0.61	0.79	2.6	18.9	33	7.5	9.8	0.04	-	-	8.6	0.42	9.4	0.81	85

Figures for metals and nutrients are 'high estimates'
* 'low estimate'; † 'high estimate'; ‡ NI only; § ROI only; ROI: Republic of Ireland; NI: Northern Ireland; -: no available or reliable information.

cadmium, through rivers discharging to the eastern Irish Sea and Bristol Channel. The trends in PCB inputs to these areas are uncertain because of the wide and varying differences between the high and low load estimates. For all other contaminants and areas the inter-annual variations in riverine inputs are too great, and the records too short, for trends to be apparent. Inputs of nutrients were generally stable but inputs of total nitrogen and total phosphorus to the Celtic Sea and eastern Irish Sea were slowly increasing. Inputs of nitrogen from rivers are at least an order of magnitude greater than those from direct discharges.

In summary, between 1990 and 1996 there were apparent decreases in the inputs from land-based sources of cadmium, mercury, zinc and PCBs. Most of these decreases were associated with direct discharges (i.e. sewage and industrial effluents); principally in those areas that received relatively high loads of these substances at the start of the 1990s (i.e. the eastern Irish Sea and Bristol Channel). Slight decreases in the inputs of γ-HCH and total phosphorus to the Bristol Channel were also apparent. The loads of other substances monitored in inputs from land were relatively stable.

4.2.2 Inputs from the dumping of wastes at sea

A summary of the quantities of waste and dredged material dumped in various sea areas of Region III over the past decade is given in Section 3.10. As calculations of the quantities of individual contaminants contained in these materials provide only very rough estimates, no data on the input loads from dumping are presented in this report. In accordance with decisions taken by the OSPAR Commission, the disposal at sea of industrial waste is no longer practised in Region III and the sea disposal of sewage sludge has also recently been discontinued. The disposal of dredged material is subject to stringent controls, including a requirement for land disposal of sediments containing persistent substances at potentially harmful concentrations.

Following recent publicity with regard to the stranding of phosphorus flares on coasts of the Irish Sea, attention has been drawn to the past practice of munitions disposal at deep water sites. In the period between 1945 and 1963 approximately 1 million t of munitions were dumped by the UK in the Beaufort's Dyke, a 200 m deep trench in the North Channel to the north of the Irish Sea. Following the signing of the Oslo and London Conventions in 1972, the UK ceased dumping of munitions at Beaufort's Dyke in 1973, with the exception of an emergency dump of a small number of 40 mm munitions in 1976. A further 1160 t were also dumped in the Beaufort's Dyke area by Ireland between 1970 and 1985, including small arms munitions, bombs, depth charges, fuses, primers, shells and grenades. It is not possible to produce a full inventory of munitions dumped by British military authorities as many of the records were routinely destroyed after the disposals. However, the bulk of the munitions dumped were similar in type to those disposed of by Ireland, but with the addition of 14 600 t of five-inch rockets charged with phosgene and an unspecified number of phosphorus flares.

4.2.3 Atmospheric inputs

The atmosphere is an important and sometimes dominant pathway for the transfer of contaminants from anthropogenic sources to distant marine and terrestrial areas. As the prevailing winds over Region III are predominantly westerly, atmospheric contamination is generally low on a European scale. However, even westerly air flows contain measurable concentrations of contaminants. On the other hand, easterly air flows are generally associated with dry weather and wash-out of contaminants from the east tends to be limited.

Measurements of atmospheric deposition are expressed in terms of dry deposition (the fall-out of dust and particles during dry weather) and wet deposition (wash-out during periods of precipitation including mist, rain and snow) or as total or bulk deposition; the sum of both wet and dry measurements. As there are no sampling stations within Region III specifically dedicated to, or optimally located for, the measurement of contami-

Figure 4.1 **Modelled deposition of oxidised nitrogen for 1990. Source: Sandes and Styve (1992).**

gN/m^2/yr
0.40 – 0.70   0.07 – 0.10
0.25 – 0.40   0.04 – 0.07
0.10 – 0.25
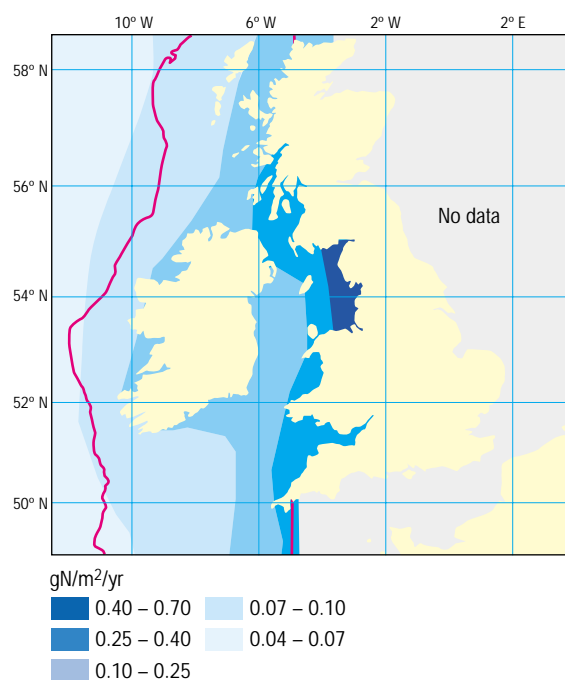
nant inputs to the sea, the best estimates come from large-scale models. These use data from an extended network of stations throughout north-western Europe, including a few sites around the coasts of Ireland and one in Brittany.
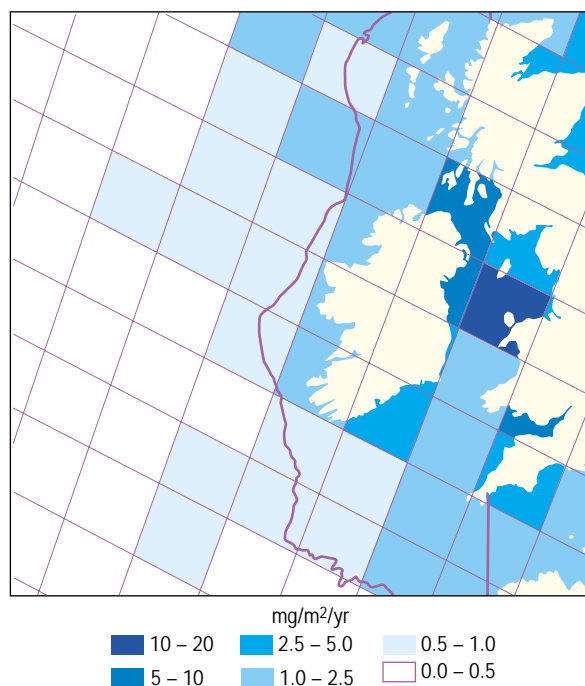
Model estimates of the oxidised nitrogen (NO_x) deposition across Region III during the early 1990s *(Figure 4.1)* indicate a clear decreasing east to west gradient. In general, measured values at coastal stations are in good agreement with these predictions.

In contrast, there are wide discrepancies between measured and predicted depositions of certain heavy metals. For example, model estimates for the deposition of mercury (< 10 µg/m2/yr) tend to be systematically ten times higher than measurements obtained at coastal sites, whereas with cadmium the position is reversed. There is some evidence of an increase in mercury deposition in Region III prior to and during the 1980s, possibly linked to increased industrial activity, especially coal burning. Predicted cadmium deposition from modelling is 10 – 50 µg/m^2/yr with the highest values occurring to the south and north of Ireland and in the Bristol Channel. Although depositional loadings measured in Brittany and on the south-west coast of Ireland are in general agreement with these values, measurements at other Irish coastal stations have been more than ten times higher, possibly due to local sources of contaminants. The latest estimate of the amount of cadmium deposited annually in the waters of Region III is 1.4 t (van Pul *et al.*, 1998); this can be traced to multiple sources in Europe, including metal industries and automotive sources. In comparison, the predicted deposition patterns for lead are in good agreement with measured values, showing that the highest loads are in the central Irish Sea, North Channel and south Malin Shelf *(Figure 4.2)*. An estimated 152 t of lead is deposited annually into the waters of Region III, the lowest deposition rate per unit area within the OSPAR

Figure 4.2 **Modelled deposition of total lead for 1985. Source: Bartnicki (1994).**

mg/m^2/yr

■ 10 – 20	■ 2.5 – 5.0	☐ 0.5 – 1.0
■ 5 – 10	■ 1.0 – 2.5	☐ 0.0 – 0.5

area. Whereas lead deposition is estimated to be between two and five times higher than in pre-industrial times, some decrease may be expected due to recent reductions in the use of leaded fuels. A substantial reduction in the deposition of organo-lead was recorded at a site on the south-west coast of Ireland between 1986 and 1988.

The levels of organic contaminants measured at atmospheric monitoring stations within Region III have generally been below the detection limits, i.e. < 1.0 ng/l for most pesticides and < 2 ng/l for PCBs. Nevertheless, studies of atmospheric contamination in north-west Europe have concluded that appreciable quantities of organic substances may be deposited over the sea and models have been developed to predict depositional patterns in areas such as the North Sea and Irish Sea. The estimated deposition fluxes of pesticides into the Irish Sea are shown in *Table 4.3*.

At UK coastal stations to the east of Region III, concentrations of 3 – 5 ng total PCBs/l were recorded in 1994, corresponding to a total deposition flux of 2.2 – 4.2 µg total PCBs/m^2/yr. These figures are in good agreement with model predictions for adjacent sea areas. On this basis, modelled deposition fluxes of 1.0 – 2.5 µg total PCBs/m^2/yr obtained for the Irish Sea in 1990 seem reasonable. Although estimates for other sea areas of Region III are unavailable at present, a deposition flux of 1.8 µg/m^2/yr estimated for the greater North Atlantic area fits well with the previous predictions. The introduction of

Table 4.3 **Modelled bulk deposition fluxes for pesticides (µg/m^2/yr) in the Irish Sea. Source of data: Baart *et al.* (1995).**

Pesticide	Deposition flux
Lindane	25 – 50
Endosulfan	2.5 – 7.5
Pentachlorophenol	< 25 – 50
Atrazine	< 25
Parathion-ethyl	< 25
2,4 D	25 – 50
Trifluralin	50 – 100
Mecoprop	100 – 250
Fentin-hydroxide	5 – 15
Diuron	< 10 – 25
Azinphos-methyl	< 1
Dichlorvos	1.5 – 7.5
Mevinphos	< 1

strict controls over the use of PCBs in many countries has led to significant reductions in atmospheric emissions since the early 1970s. However there are many uncertainties regarding the rate at which residual levels of PCBs in the atmosphere will fall. Continuing losses from old electrical equipment, evaporation from contaminated soils and cycling between environmental compartments maintain a significant flux which is likely to persist for decades to come. PCB concentrations in dated peat cores from a site in rural north-west England reached a peak in 1964. This was followed by a 65% decrease until 1980 when concentrations increased again. If this pattern is representative of Region III, the decline in PCB deposition since controls were put in place has been relatively modest. At present it is estimated that 10 – 100 t of PCBs are lost to the atmosphere from OSPAR countries each year. As the majority of air masses entering Region III originate over the North American continent, the contribution of North American sources to atmospheric inputs of PCBs to Region III merits closer inspection (see Section 4.5).

The inputs of PAHs from the atmosphere have been estimated for the Irish Sea *(Table 4.4)*. The modelled deposition ranges are reasonably close to those measured in the upper layer (0 – 10 cm) of peat cores from a rural site in north-west England. Evidence from the peat cores indicates that deposition fluxes of fifteen PAHs reached a peak of 3 mg/m^2/yr in the 1930s and that the contemporary flux is approximately 0.74 mg/m^2/yr. The reduction is attributed to emission controls in Europe.

Other organic contaminants for which deposition fluxes to the Irish Sea have been estimated are trichloroethane (0.1 – 1.0 mg/m^2/yr) and total dioxins (< 0.5 – 5 ng/m^2/yr). These estimates require validation through improved ground measurements.

4.2.4 Inputs from mariculture

The principal areas for mariculture in Region III are located to the west of Scotland and Ireland. The main contaminating materials from mariculture operations are faeces, excess feed and chemotherapeutic agents

Table 4.4 Total deposition fluxes for PAHs (µg/m^2/yr) in the Irish Sea region. Source of data: modelled fluxes (Baart *et al*. 1995); measured fluxes (Sanders *et al*. 1995).

	Modelled deposition flux Irish Sea	Measured deposition flux North-west England
Fluoranthene	30 – 100	83 – 204
Benzo[*b*]fluoranthene	50 – 500	30 – 51
Benzo[*k*]fluoranthene	5 – 30	6 – 10
Benzo[*a*]pyrene	25 – 100	20 – 68
Benzo[*ghi*]perylene	5 – 30	47 – 146
Indeno[1,2,3-*cd*]pyrene	15 – 50	-

-: no information.

(mainly antimicrobial compounds and parasiticides). As shellfish production does not require commercial feeds or chemical treatments, the main 'input' tends to be through the deposition of organic material (digested plankton) to the sediments beneath the culture facilities. In contrast, large-scale intensive finfish farming can contribute significantly to the nutrient budgets of sheltered bays if other waste sources, and freshwater inputs, are small. In Ireland, the combined load of organic waste from salmonid mariculture is estimated to be equivalent to that from a human population of between one quarter and half a million (i.e. 12 – 24% of the coastal population; see Section 3.2).

Estimates of nutrient release from salmon farms to surrounding waters depend on the production : waste ratios applied which, in turn, are a function of feeding practices and food conversion efficiencies. For example, in Scottish waters of the Malin Shelf, including the Western Isles, where an estimated 86 000 t of feed were used during 1997 (production *c*. 71 000 t), an estimated 3400 t of nitrogen (particulate and dissolved) and 760 t of phosphorus were discharged annually to the area. In the same year the Irish salmon farming industry produced 16 000 t and released an estimated 1600 t of nitrogen (largely as ammonia) and 250 t of phosphorus, a comparatively higher nutrient loss. In general, food conversion efficiencies in salmon farming are improving and waste production rates (per tonne of fish produced) are decreasing.

There are no accurate statistics on the usage of chemicals by the mariculture industry within Region III. However, it is estimated that about 60% of the 1 – 2 million kg of hydrogen peroxide, 2000 – 3000 kg of oxytetracycline and potentiated sulphonamides, and 1000 – 3000 kg of oxolinic acid and dichlorvos used by the Scottish industry in 1995, were applied in the Malin Sea area. These chemicals have also been used extensively by Ireland's mariculture industry. Reported uses of dichlorvos vary from as little as 1.6 litres at a farm in Bantry Bay (on the Atlantic seaboard) in 1994 to 820 litres at a farm in Lough Swilly (on the Malin Shelf) in 1990. At the latter site, the use of dichlorvos had declined to just 4 litres in 1994 and this is indicative of a trend towards alternative treatments for sea lice (e.g. azamethiphos, cypermethrin, ivermectin and the use of 'cleaner fish') in recent years. The use of antimicrobial agents is likely to be decreasing as a result of improved husbandry and more extensive use of vaccines.

The use of antifoulants on mariculture cages is common for the maintenance of good water circulation. Prior to 1987, the biocide TBT was commonly used and this undoubtedly resulted in localised effects on populations of wild molluscs (see Section 5.14.4). More recently, copper has replaced TBT as the active ingredient in some marine antifouling agents but data on use are available only for a

few individual sites. For example, up to 33 000 litres of copper-based antifoulant (5% copper) have been applied annually to nets at a 1000 t farm in Lough Swilly. An estimated average leaching rate of 20% of the applied material suggests that cage aquaculture represents a significant copper source. However, as the loss rate from various formulations is likely to vary significantly, the actual quantities of copper released are difficult to estimate.

4.2.5 Inputs of oil

Although on a global scale the inputs of oil-based hydrocarbons from human activities on land and at sea are small compared with those from natural sources (e.g. biosynthesis, atmospheric fallout and seepage from the seabed), they can cause significant local damage to marine life and amenities. The principal anthropogenic sources of oil to the marine environment are shipping (both accidental and operational losses), gas and oil installations (both onshore and offshore) and discharges from rivers, industries and municipal wastewater facilities. Few of these inputs are recorded in Region III but some records do exist regarding accidental losses from shipping. Significant releases of oil are recorded in relation to thirteen incidents in Irish coastal waters between 1974 and 1996. There have been no incidents in the Malin Sea area or off the west coast of Ireland during the last twenty years. The most significant releases in Region III in recent decades were: Torrey Canyon (117 000 t) in 1967 off the coast of Cornwall; Universe Leader (2597 t) in 1974, Afran Zodiac (up to 500 t) in 1975 and Betelgeuse (up to 40 000 t) in 1979 in Bantry Bay; Christos Bitas (2420 t) in 1978 in the southern Irish Sea and the Sea Empress (72 000 t crude and 480 t heavy fuel oil) in 1996 on the south coast of Wales (see also Sections 4.7 and 5.13).

4.2.6 Summary

Although information about the inputs of contaminants to Region III is steadily improving, particularly with regard to the relative importance of different pathways, gaps and deficiencies in the database preclude the reliable analysis of patterns and trends.

In general, the loads of heavy metals from rivers and outfalls have been fairly stable during the 1990s. However, in the eastern Irish Sea and Bristol Channel, where inputs of various contaminants have been elevated in the past, there are indications that gross inputs of cadmium, mercury, zinc and PCBs are slowly decreasing.

Inputs of nitrogen and phosphorus are subject to wide inter-annual variability but, on a regional scale, appear to have been relatively stable during the 1990s. There are indications of slight upward trends in nitrogen and phosphorus inputs from the south-east and south coasts of Ireland. Inputs of nitrogen from rivers are significantly greater than from direct discharges. Evidence from models suggests that the atmosphere may also be a significant source of nitrogen, particularly in the Irish Sea. Finfish mariculture is a significant source of nitrogen in some sheltered coastal localities.

The amounts of PCBs entering Region III through the atmosphere, rivers and effluents are now extremely small and there are indications that the trends are steadily downward. Model estimates for the atmospheric deposition of PCBs into the Irish Sea in 1990 (1.0 – 2.5 µg total PCBs/m^2/yr) suggest that the atmosphere may now be the primary source of PCBs to the region.

Oil tankers at Milford Haven

4.3 Background/reference values

In the following sections of this chapter attention is drawn to those locations where concentrations of contaminants in water, sediment or biota are elevated relative to other parts of Region III. The elevated levels are associated with local geochemistry and/or known inputs, either historic or ongoing (e.g. acid mine waters, and municipal and industrial effluents). Account has also been taken of the results for the four other OSPAR regions and of the ecotoxicological profiles of the substances concerned *(see Box 4.1)*.

Instances where contaminant concentrations exceed either background/reference concentrations or ecotoxicological assessment criteria (EACs) are reviewed under the relevant sub-headings.

4.4 Metallic contaminants

Sources of metallic contaminants are covered in Section 4.2.

4.4.1 Fluxes and transport pathways

Transition metals in sea water are generally present at trace levels (ng/l) and these concentrations are influenced by a combination of geochemical, biological and anthropogenic processes. In shelf areas the concentrations of cadmium and copper can be traced primarily to riverine and other land-based sources, whereas lead and mercury may also have a significant atmospheric component. Most of the available data for metals in sea water in the Irish Sea, Celtic Sea and Malin Shelf sectors of Region III

Box 4.1 Reference values

For naturally occurring substances (e.g. metals and nutrients), background concentrations are related to the normal chemistry or geochemistry of the areas concerned. In the case of synthetic substances (e.g. PCBs) there is no natural concentration but some more widely used and persistent substances are now ubiquitous in marine media, albeit at very low concentrations. Where these ubiquitous concentrations are more or less uniform throughout a defined area, they are also termed 'background' concentrations. For guidance purposes, the OSPAR Commission has adopted Background/Reference Concentrations typical of the maritime area or parts thereof (OSPAR 1997a).

Ecotoxicological Assessment Criteria are concentrations that, according to existing scientific knowledge, approximate to concentrations below which the potential for adverse effects is minimal. For guidance purposes the OSPAR Commission has adopted EACs for the common contaminants in sea water, sediments and biota (OSPAR 1997b).

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have been collected as part of the UK National Monitoring Programme. There are however, useful data sets for a number of Irish estuaries and, for the Celtic Sea and to the west of Ireland, data from a number of cruises by German research scientists. These all show lead and mercury to be strongly associated with particulate material and therefore, except very close inshore and near to sources such as rivers, dissolved concentrations are low. Copper, zinc and cadmium tend to stay in the dissolved phase, thus their concentrations tend to reflect much more closely mixing with oceanic sea water. This fits well with modelling data as illustrated by *Figure 4.3* which shows the increasing concentrations northwards through the Irish Sea due to the influence of inputs from the Irish and UK coasts.

4.4.2 Distribution in sea water

Cadmium

Concentrations of dissolved cadmium in sea water from the Celtic and Irish Seas are summarised in *Figure 4.4*. This shows a negative correlation with salinities above about 34.5 but considerable scatter at lower salinities (< 32.5). In the offshore waters of the Celtic Shelf concentrations are generally of the order of 0.01 – 0.03 µg/l, which is similar to the concentration range reported for waters off the west coast of Scotland (0.01 – 0.04 µg/l). There is little difference in the concentrations of estuarine waters around Ireland, with concentrations typically in the range 0.03 – 0.1 µg/l. Concentrations in Belfast Lough are consistently reported to be < 0.04 µg/l and those for the Clyde Estuary do not exceed 0.09 µg/l. The highest concentrations of cadmium in estuarine waters were

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Figure 4.3 **Predicted salinity-related distribution of dissolved copper (µg/l) in the surface waters of the Irish and Celtic Seas. Source: NERC (1992).**
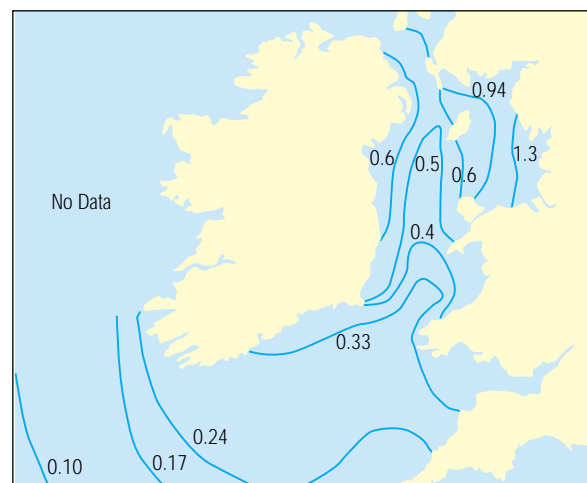
found in the Severn Estuary (median 0.34 µg/l at a salinity of 19.3). These concentrations were strongly negatively correlated with salinity and are believed to reflect historic metal smelting activities at Avonmouth (near Bristol) and on the south coast of Wales. Whilst the concentrations found in estuaries exceed those regarded by OSPAR as background, only those in the Severn Estuary were clearly above the EAC range adopted by OSPAR (10 – 100 ng/l).

Mercury

Concentrations of dissolved mercury in the Celtic Sea and north of Scotland lie in the range 0.2 – 0.5 ng/l, similar to concentrations regarded by OSPAR as background for the North Atlantic (0.1 – 0.4 ng/l). In the Irish Sea concentrations of 0.62 – 0.85 ng/l reflect historic sources of mercury which still affect sediment concentrations in and around the Mersey Estuary and southern Morecambe Bay. A similar, but less marked, situation exists in Cork Harbour. Even these higher concentrations are below the lowest value of the EAC range adopted by OSPAR (5 – 50 ng/l).

Lead

Due to its high particulate reactivity, estuarine suspended solids and near shore sediments act as efficient traps for lead. Accordingly, dissolved concentrations in offshore waters tend to be low. Pooled data from a number of surveys show a distinct gradient with salinity although there is increased scatter at the lower salinities of the Irish Sea *(Figure 4.5)*. The variability of the concentrations of lead in sea water is probably due to the uneven distribution of land-based and atmospheric inputs allied to the

transience of lead in the water phase. In Bantry Bay, periodic cruises have shown relatively high concentrations of lead (0.12 µg/l at a salinity of 35). This represents a significant deviation from the distribution in the adjacent Celtic Sea and it is possibly an analytical artefact. Whilst some of the higher concentrations recorded exceed those regarded by OSPAR as background, all are below the EAC range adopted by OSPAR (0.5 – 5 µg/l).

Copper

There is a strong negative correlation with salinity confirming the land-based origin of copper to Region III. This is further confirmed by data for some estuaries, for example, 0.3 – 2.9 µg/l in the Clyde Estuary and > 50 µg/l in the Avoca Estuary on the east coast of Ireland (both examples relate to the upper estuary). Elsewhere, concentrations above those regarded by OSPAR as background were found in Belfast Lough (*c.* 0.7 µg/l) and in Bantry Bay (0.31 µg/l). These concentrations compare to the EAC range of 0.005 – 0.05 mg Cu^{2+}/l, which is within the background range for total copper in sea water.

Zinc

As for most other metals, the highest concentrations of zinc are associated with the lowest salinity waters. There is however some temporal scatter in the data suggesting that inputs may change with time. Typical concentrations in oceanic waters and off the west coast of Ireland are around 0.5 µg/l, i.e. close to those regarded by OSPAR as background. However, in estuaries considerably higher concentrations have been recorded, particularly in the

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Figure 4.4 **Dissolved cadmium concentrations vs. salinity in the Celtic and Irish Seas. Source of data: (a) NMP; (b) Kremling (1985), Kremling and Hydes (1988), Kremling and Pohl (1989); (c) Muller *et al.* (1994); (d) NMP; (e) Kremling and Hydes (1988).**
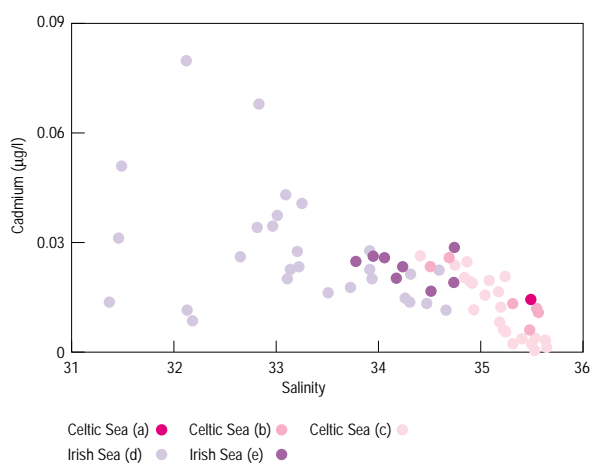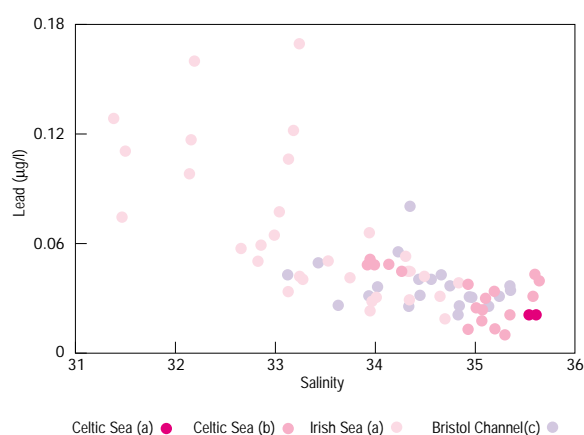

Figure 4.5 **Dissolved lead concentrations vs. salinity in the Celtic Sea, Irish Sea and Bristol Channel. Source of data: (a) NMP; (b) Muller *et al.* (1994); (c) Harper (1991).**

upper reaches, for example > 500 µg/l in the Avoca Estuary and > 40 µg/l in the Shannon Estuary. Concentrations of > 40 µg/l have also been noted in the Severn, Dee and Mersey estuaries on the eastern side of the Irish Sea. These are extreme values and concentrations in estuarine waters are more typically in the order of 10 – 30 µg/l, which exceed the upper value of the EAC range adopted by OSPAR (5 µg/l).

4.4.3 Distribution in sediments

Comparison of data on the concentrations of metals in sediments is only possible if the data are produced by comparable methods and have been treated to eliminate differences due to sediment type, origin and grain size. For reasons related to the original purpose of collecting the data, this is not the case for the different sets of data produced within Region III. The Irish data relate only to estuarine sediments and it was found that normalisation relative to an organic carbon content of 5% gave a good measure of the relative extent of contamination. Data for cadmium, mercury, lead and copper in sediments from around the Irish coast are presented in *Figure 4.6*. The elevated concentrations in the Avoca Estuary are due to acid mine drainage and in Dublin Port to losses of metalliferous ore during loading onto ships. Apart from the concentrations in Bantry Bay, for which no explanation has yet been found, the higher concentrations of mercury are believed to be due to general industrial and urban sources.

Off the Scottish west coast, sediments are typically made up of quartz, clays, feldspars and organic matter. The gravels are mainly quartz with some feldspar, whereas the muds contain more clay minerals. The two groups can be characterised by a potassium/aluminium (K/Al) ratio of greater or less than 0.5. Thus Group 1 are mainly sediments in which sand and gravel predominate and which have a K/Al ratio of > 0.5 (mean 0.66), whereas Group 2 are mainly fine sediments consisting of more clay and with a K/Al ratio of < 0.5 (mean 0.36). In order to overcome differences due to particle size normalisation to scandium can be more effective than normalisation to aluminium. This showed that in almost all cases metal levels were closely related to the types of rock found in the landmasses nearby. In a number of cases it was necessary to normalise the data to iron in order to be sure of the sediment type. This procedure showed elevated concentrations attributable to anthropogenic inputs in a few areas, most notably in the Clyde Sea area.

The most comprehensive dataset for metals in sediments in Region III was collected for the Irish and Celtic Seas between 1990 and 1995. The methods used followed the internationally agreed guidelines on sieving, pre-analysis and digestion using hydrofluoric acid. Normalisation to aluminium was adopted to minimise differences due to mineralogical composition and grain size. *Figure 4.7* shows a general tendency for higher concentrations (after normalisation) of cadmium, mercury, lead and copper in sediments close to coastal sources. Elevated concentrations occur off the coast of the industrialised north-west of England around the Mersey Estuary and in the Severn Estuary. Cadmium is also elevated off the Cumbrian coast due to past discharges from a phosphate rock processing plant.

4.4.4 Distribution in fish and shellfish

There is a considerable body of information on metallic contaminants in a variety of species of fish and shellfish, both from samles collected within Region III and, for
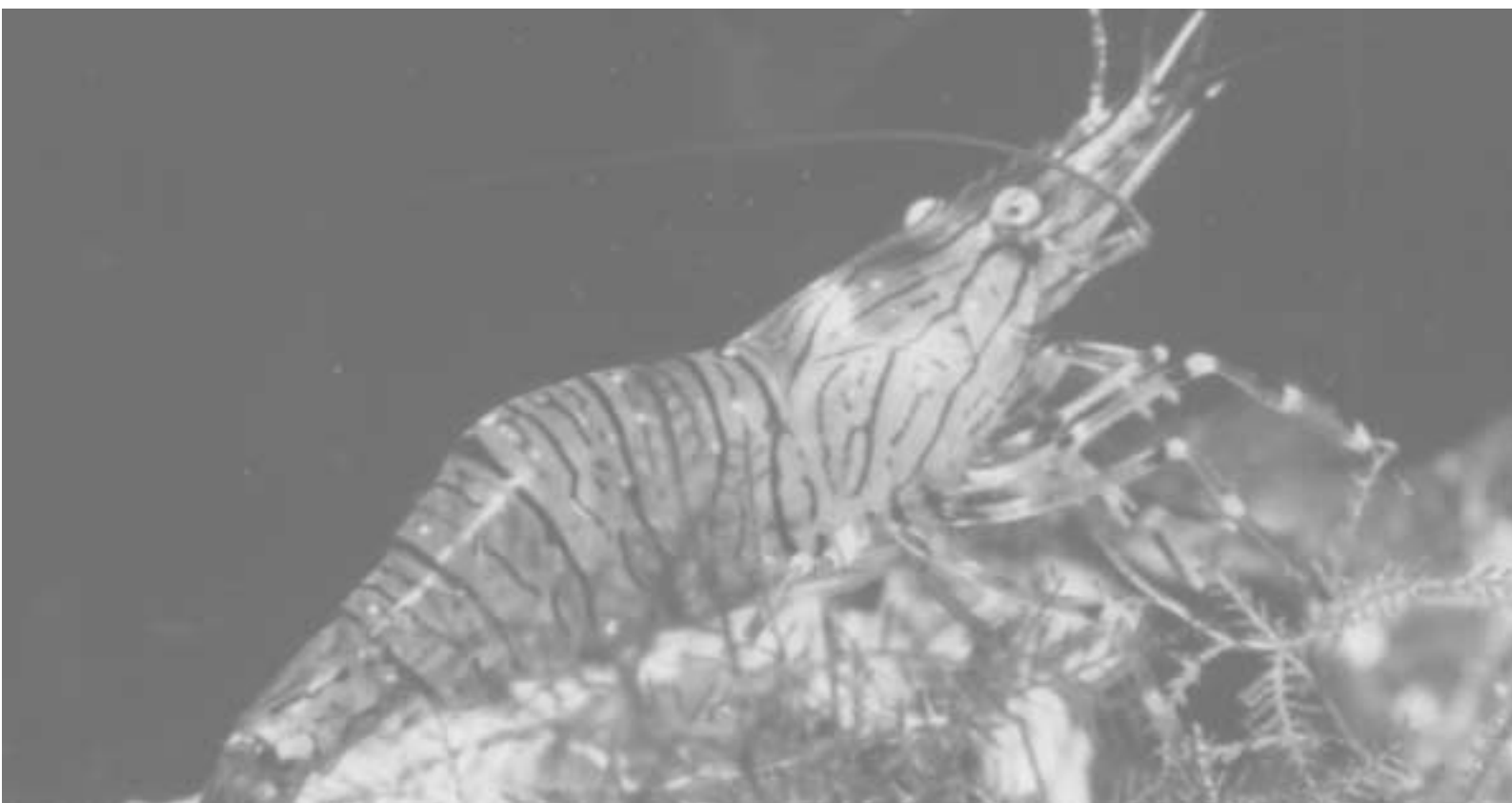
Figure 4.6 **Mean concentrations of metals in whole sediments (mg/kg dw) from Irish coastal and estuarine sites normalised to an organic content of 5%. Source of data: FRC.**
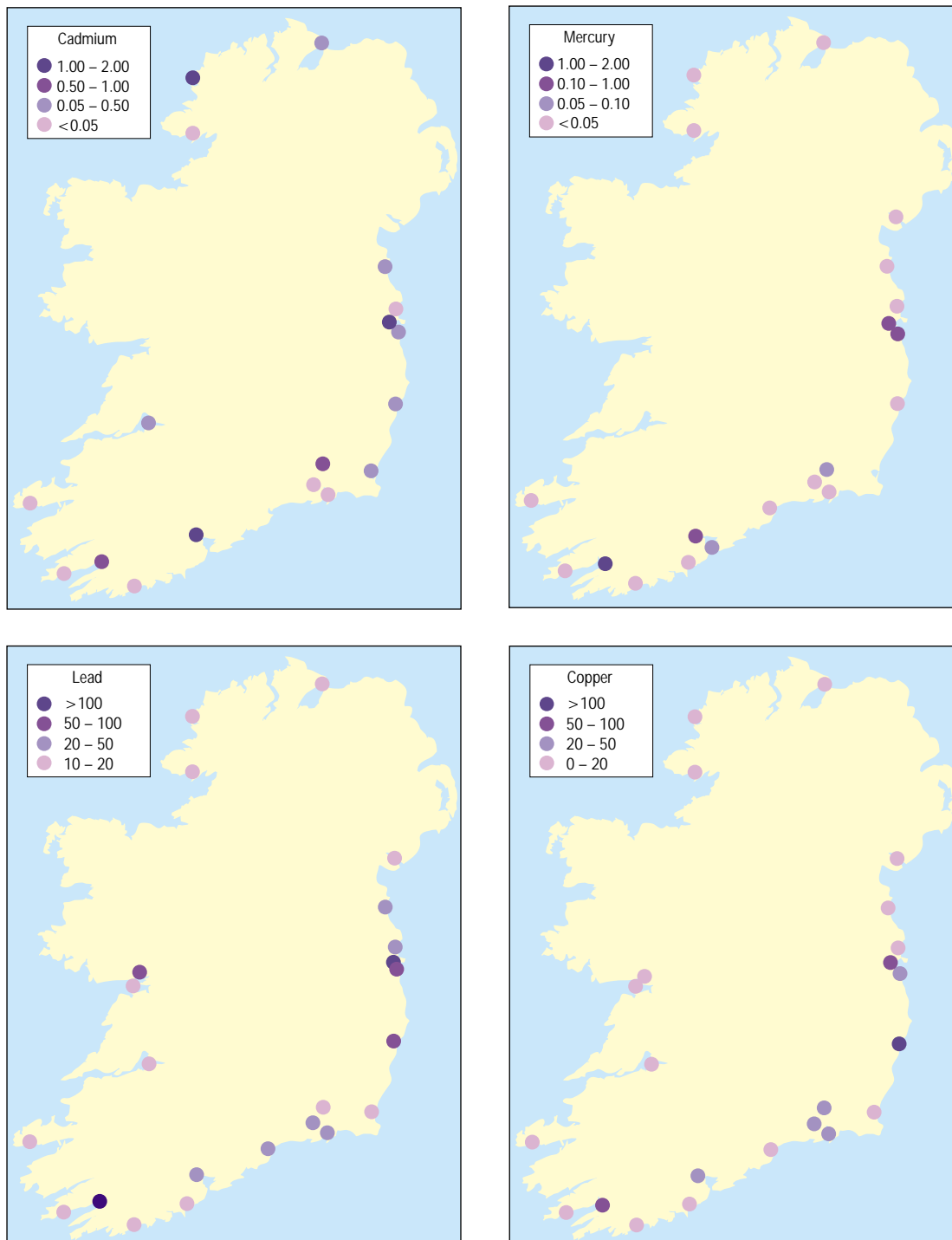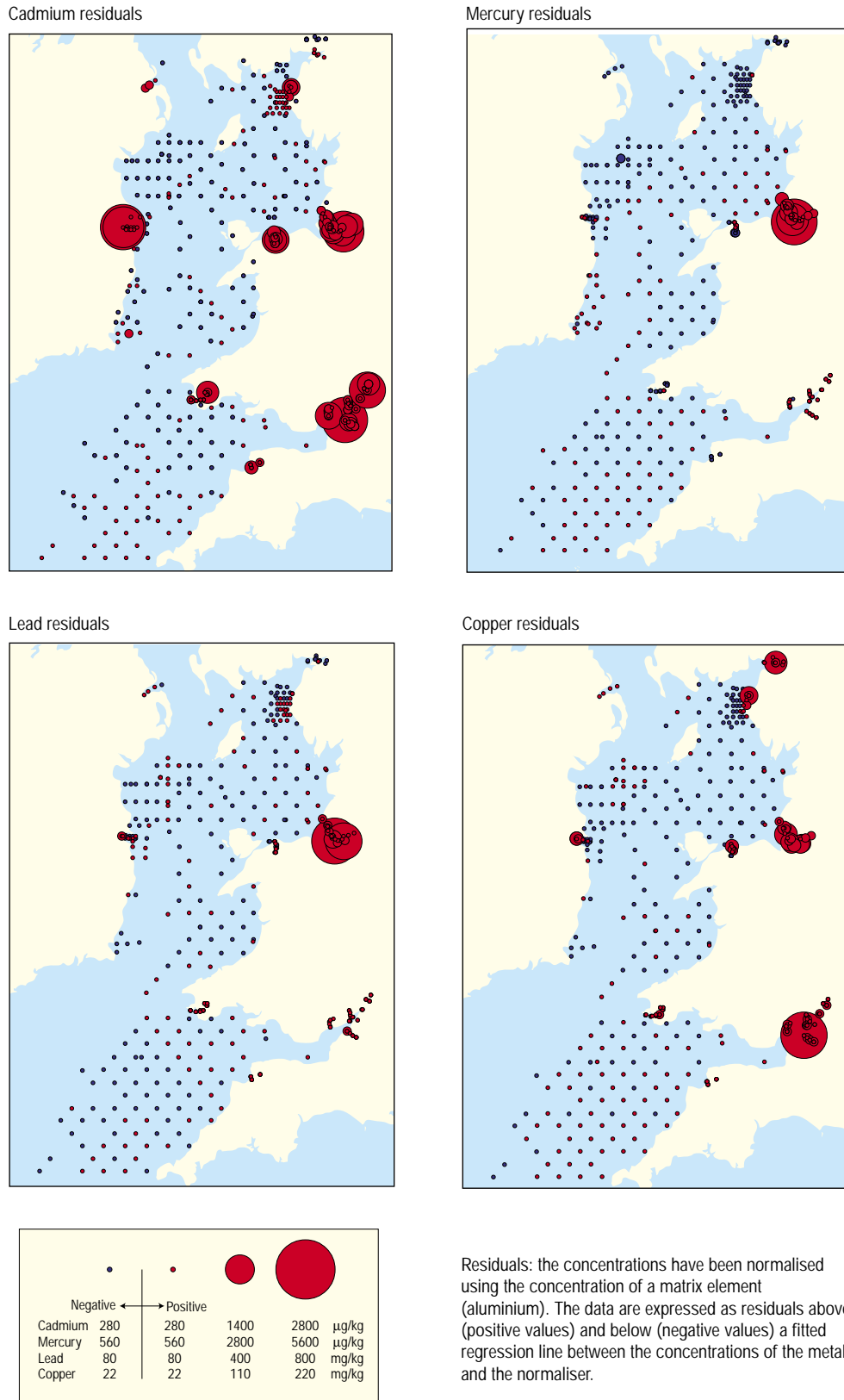
Figure 4.7 **Concentrations of metals in sediments of the Irish Sea and Bristol Channel after normalisation 1990–5. Source of data: CEFAS.**

Cadmium residuals

Mercury residuals

Lead residuals

Copper residuals

	Negative ←	→ Positive			
Cadmium	280	280	1400	2800	µg/kg
Mercury	560	560	2800	5600	µg/kg
Lead	80	80	400	800	mg/kg
Copper	22	22	110	220	mg/kg

Residuals: the concentrations have been normalised using the concentration of a matrix element (aluminium). The data are expressed as residuals above (positive values) and below (negative values) a fitted regression line between the concentrations of the metal and the normaliser.

comparative purposes, from elsewhere. It is known that copper is naturally present in biological tissues and plays a role in structure and metabolism. Cadmium, mercury and lead have no known biological function but are also found in biological material. Fish accumulate mercury in their muscle tissue in proportion to environmental concentrations. Similarly, concentrations of cadmium and lead in shellfish tend to reflect their degree of exposure to these elements.

The mean concentrations of cadmium, mercury, lead and copper in mussels and cod taken from Irish waters *(Table 4.5)* are either below or marginally above those regarded by OSPAR as representative of background

conditions. Cod taken from Scottish waters show little difference between inshore and offshore samples, for example 0.06 mg Hg/kg offshore and 0.05 mg Hg/kg inshore, with cadmium and lead in all cases below the detection limits of 0.001 and 0.02 mg/kg respectively. Concentrations of cadmium and lead (which are below routine detection limits) and copper in samples of fish muscle taken off the English and Welsh coasts, are all low and of no toxicological significance. Data on cadmium, mercury, lead and zinc in mussels from various sites around the Irish Sea in 1996/97 are summarised in *Figure 4.8*. Although some concentrations exceeded

Figure 4.8 **Concentrations of metals in the tissue of mussels (mg/kg ww) at sites around the Irish Sea in 1996/97. Source of data: CEFAS.**
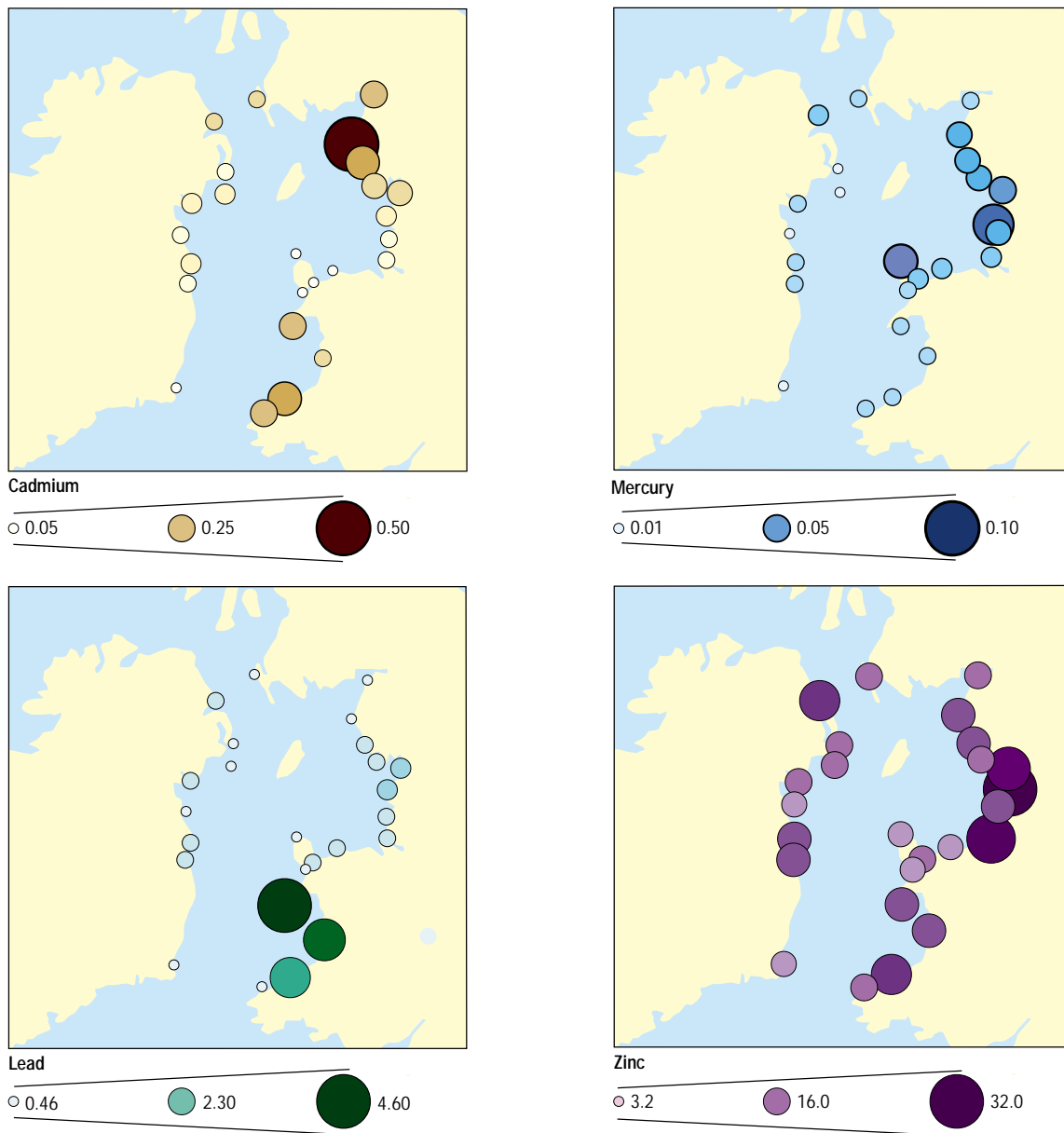
Table 4.5 Mean metal concentrations (± 1 standard deviation) (mg/kg ww) in whole tissues of mussels from shellfish growing areas and cod muscle from the Irish commercial catch. Source of data: FRC.

	Mussel	Cod
Cadmium	0.15 ± 0.04	0.06 ± 0.04
Mercury	0.02 ± 0.01	0.11 ± 0.07
Lead	0.15 ± 0.12	0.03 ± 0.02
Copper	1.45 ± 0.16	0.18 ± 0.05

those regarded by OSPAR as background, none exceeded UK national food safety standards and most of the higher concentrations were found in unexploited wild populations.

The history of mercury discharges from chlor-alkali plants close to the Mersey and Wyre estuaries in north-west England is well known. However, concentrations in fish flesh in the two sea areas adjacent to these two estuaries (Liverpool Bay and Morecambe Bay respectively) have been monitored consistently for many years and the Environmental Quality Standard of 0.3 mg/kg has been met since controls on the inputs were imposed. *Table 4.6* shows the data for 1982 to 1996 which indicate a fall in both areas over this period. Although these trends have low statistical confidence, data analysed specifically for trend determination purposes also suggest declining concentrations (OSPAR, 2000).

4.4.5 Distribution in marine mammals

Samples of various tissues taken from stranded and by-caught marine mammals have been analysed over a number of years. Most of the animals were from around the Irish Sea and off the Scottish coast. With the exception of cadmium, where the highest concentrations are found in the kidney, the highest concentrations of metals are

Table 4.6 Mean mercury concentrations in fish flesh (mg/kg ww) from Liverpool Bay and Morecambe Bay 1982–96. Source of data: CEFAS.

	Liverpool Bay	Morecambe Bay
1982/83	0.27	0.29
1984	0.31	0.27
1985	0.24	0.20
1986	0.24	0.24
1987	0.23	0.23
1988	0.22	0.23
1989	0.20	0.19
1990	0.19	0.20
1992	0.20	0.14
1994	0.17	0.18
1996	0.17	0.17

generally found in the liver. High concentrations of lead and mercury were found in animals from the Liverpool Bay area, probably due to past industrial discharges; the highest concentrations, 7.0 and 430 mg/kg respectively, were found in grey seals. Marine mammals appear to have a mechanism for detoxifying the mercury as mercury selenide. The highest concentrations of cadmium (up to 11 mg/kg) were found in the livers of striped dolphin (*Stenella coeruleoalba*); this is attributed to the dominance of squid (which accumulate cadmium naturally) in their diet rather than to anthropogenic sources. Copper concentrations ranged between 2.2 and 79 mg/kg; this element is believed to be homeostatically controlled within the animals and therefore not of concern. There are few data for the Irish coast but mercury concentrations in samples from Strangford Lough in Northern Ireland were among the higher values encountered in Region III. Off the Scottish coast, samples taken from a variety of stranded marine mammal species have been analysed over a period of almost twenty-five years. In all cases the concentrations found were at the lower end of the ranges for the species concerned.

4.4.6 Summary

Mercury is the only element for which the observed concentrations in Region III give rise to concern. In the past, the mercury concentrations found in fish from Liverpool and Morecambe Bays were close to the agreed Environmental Quality Standard. This is not the case now and although concentrations in marine mammals remain high, they are not in the more toxic organic form. A number of industrialised estuaries and port areas are clearly contaminated and some metals in some estuaries exceed the EACs adopted by OSPAR. However, provided measures to control the input of mercury, and also the inputs of cadmium, lead, zinc and copper, continue to be applied it is unlikely that concentrations of these metals in Region III will present a threat to populations of marine organisms or human consumers of seafood.

4.5 Persistent organic contaminants

Sources of persistent organic contaminants are covered in Section 4.2.

Substances classed as persistent organic contaminants comprise a diverse group of compounds, many of them synthetic, that degrade very slowly in the environment, exhibit relatively high acute and/or chronic toxicities to marine life and are liable to accumulate in biological tissues. They include various pesticides, industrial chemicals and by-products of combustion. This section summarises recent information on the distribution of those persistent organic contaminants commonly

included in national monitoring programmes. Most of the data relate to the major industrialised estuaries, the eastern Malin Shelf, the Irish Sea and Bristol Channel; areas that are most likely to be influenced by land-based inputs of these substances.

Tributyltin

Tributyltin is a widespread contaminant of coastal waters and sediments as a result of its use as an antifouling agent on marine structures, nets and vessel hulls. It can be very persistent in the environment and demonstrates high toxicity to marine organisms, notably endocrine disruption in gastropod molluscs. Although the use of TBT is now restricted to vessels in excess of 25 m in length, residues persist in many coastal locations. Recent surveys have shown that TBT is common in the vicinity of ports, shipping channels and smaller harbours and marinas where there are facilities for small boat mainte-nance.

The presence of TBT can be determined by analysis of water and sediments or inferred from the occurrence of a phenomenon known as imposex – whereby the females of certain gastropod species take on male characteristics. Investigations to establish the prevalence of imposex are increasingly used in monitoring programmes as the detectable concentrations of TBT in water (generally 1 – 2 ng/l but as high as 5 ng/l depending on the perfor-mance of the analytical measurement) and sediments (0.01 µg/g) are only marginally below the estimated thresholds for the induction of imposex. Concentrations sufficiently high to completely inhibit reproduction are estimated to be in excess of *c.* 5 ng/l. The UK has set an Environmental Quality Standard for TBT in sea water of 2 ng/l.

For Region III as a whole, there are very few data on the levels of TBT in sea water. Whereas concentrations in some busy waterways such as Milford Haven and the Mersey Estuary have exceeded the UK Environmental Quality Standard by as much as a factor of ten, concen-trations in coastal and offshore waters are generally below the detection limit. Typical concentrations of TBT in sedi-ments of estuaries on the eastern Irish Sea are in the range < 0.01 – 1.0 µg/g but higher concentrations were found in Swansea Bay (< 0.01 – 2.7 µg/g) and the Mersey Estuary (0.6 – 12.9 µg/g) in 1995. Concentrations in offshore sediments are generally < 0.01 µg/g.

Concentrations in the tissues of dogwhelks (*Nucella lapillus*) have been measured on only a few occasions but are generally very low; the highest concentration found to date (50 ng/g) was in dogwhelks from Milford Haven. Low but detectable concentrations of TBT (≤ 46 ng/g) and its metabolites were measured in the livers of by-caught or stranded harbour porpoises (*Phocoena phocoena*) collected from sites along the Welsh Coast and the north-

west and south-west coast of England. Concentrations in grey seals were lower; only one value above the detection limit of 6 ng/g was recorded from the analysis of four indi-viduals. The toxicological significance of these findings is yet to be established.

Polychlorinated biphenyls

Polychlorinated biphenyls were widely used as plasticizers and heat-transfer fluids. Because of their high toxicity release to the environment is prohibited but residues persist and significant amounts continue to enter Region III through rivers, ocean currents and the atmosphere. As commercial PCB formulations comprise a series of closely related substances (congeners), and analytical techniques applied vary with respect to the number of congeners measured, datasets from different laboratories are often not directly comparable.

The main repositories of PCBs in the marine environ-ment are probably fine-textured sediments but the highest concentrations are found in the fatty tissues of seabirds and marine mammals. The concentrations of PCBs in sediments tend to be closely correlated with organic carbon. Offshore, un-normalised concentrations at sandy sites are generally below the detection limits (0.2 – 0.5 µg/kg) whereas in some muddy areas, such as the north-western Irish Sea, concen-trations are typically 1.0 – 10.0 µg/g dw (for the sum of ten individual chlorobiphenyl (CB) congeners). Although concentrations within this range appear to represent back-ground, they are provisionally classed by OSPAR as concentrations indicating a potential area of concern.

In 1995/96 an extensive survey of PCBs in the sedi-ments of sea lochs and coastal areas to the west of Scotland found that the highest concentrations for the sum of twenty CB congeners (30 – 100 µg/kg dw, un-normalised) occurred in the Clyde Estuary and its sea lochs, whereas offshore sediments generally had concen-trations < 3 µg/kg dw. In sediments of the eastern Irish Sea sampled between 1990 and 1995, concentrations for the sum of eleven CB congeners were all < 2.5 µg/kg dw, whereas higher concentrations (up to 25 µg/kg for CB153 alone) occurred in the Severn Estuary and Bristol Channel. The highest values are known to be the result of a past PCB manufacturing operation at Newport. A survey of estuarine and offshore areas of Cardigan Bay in 1994, where high levels of PCBs have been found in the blubber of small cetaceans, showed that sediment concentrations were in the range < 0.2 – 12 µg/kg dw (for the sum of twenty-five CBs), with the exception of a single sample from Aberystwyth which had a concentration of 400 µg/kg dw. A subsequent and more detailed survey of the Aberystwyth area showed that elevated levels were confined to an accumulating basin off the main harbour and that most sediments in the area had concentrations in the range < 0.2 – 20 µg/kg dw.

Surveys of PCB concentrations in sediments of the western Irish Sea and Cork Harbour, conducted between 1992 and 1995, showed that elevated concentrations (i.e. not correlated with organic carbon) of a total of ten CBs occurred only in the soft sediments of Dublin port and Cork Harbour. Offshore concentrations were always < 10 µg/kg ww [2].

Information on the spatial distribution of PCBs is obtained through analyses of mussels (*Mytilus edulis*) from selected sites around the coasts. Samples collected on coasts of the Irish Sea and North Channel in 1996/97 had concentrations, expressed as the sum of seven

congeners (CBs 28, 52, 101, 118, 138, 153 and 180), ranging from below the detection limit (< 0.001 mg/kg ww) to a maximum of 0.019 mg/kg ww at the mouth of the River Mersey (Liverpool Bay). The highest concentration (0.012 mg/kg ww) recorded from the Irish coast was in a sample of mussels from Cork Harbour collected in 1990. Concentrations in mussels from Irish shellfish-growing areas have been consistently low. At all sites monitored the concentrations (as the sum of seven CBs) were below the concentrations regarded by OSPAR as background (0.35 – 1.7 mg/kg ww).

Figure 4.9 **Mean concentrations (±1 standard deviation) of organochlorines in the blubber of male harbour porpoises (mg/kg lipid). Source: western Irish seaboard (Smyth, 1996); Irish Sea, Shetland, the UK North Sea coast (Kuiken *et al.* 1994); Cardigan Bay (Morris *et al.*, 1989); Danish coast (Granby and Kinze, 1991).**
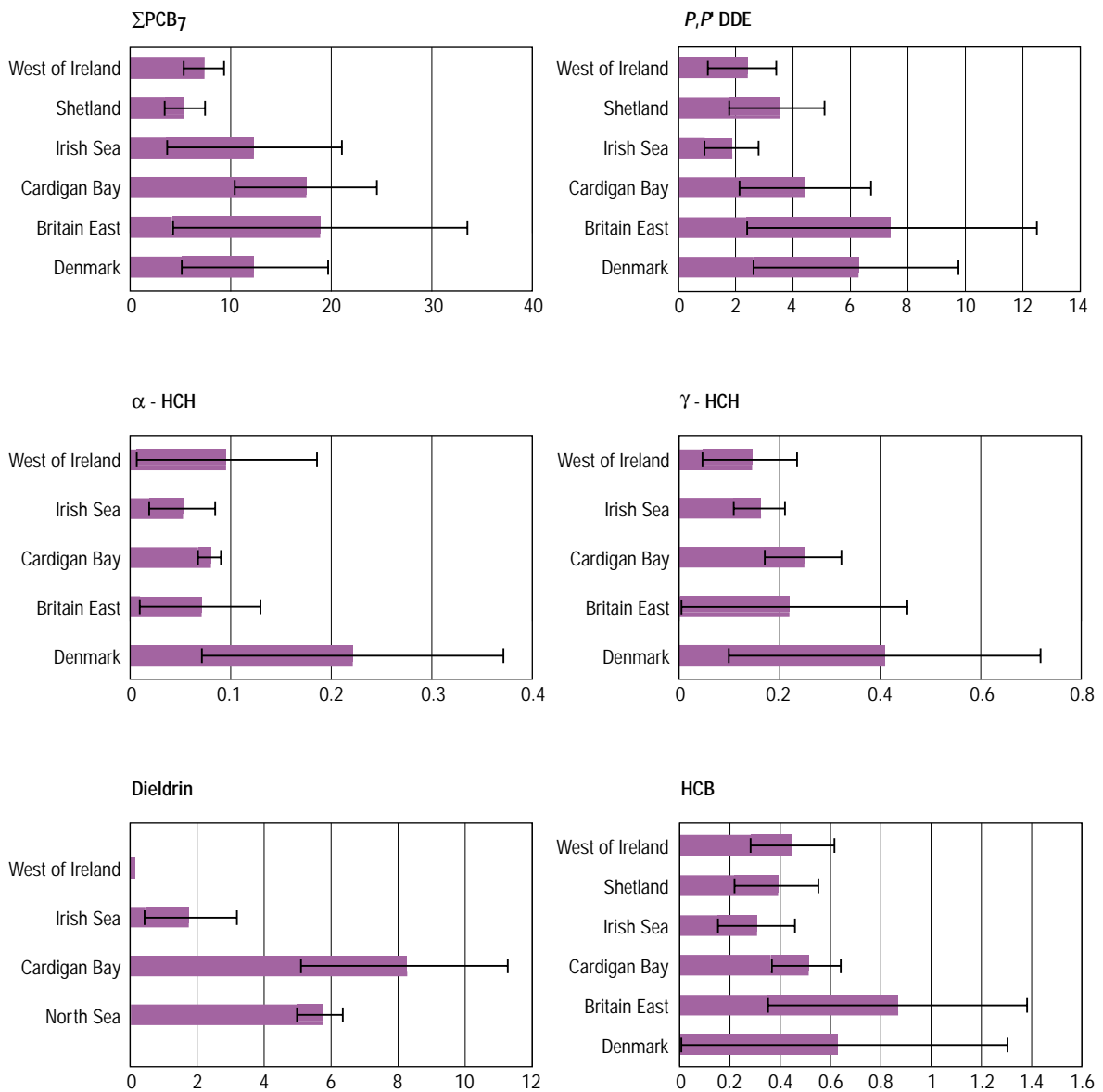
[2] On average, tissue concentrations in wet weight are approximately 30% lower than in dry weight (Fisheries Research Centre, Dublin).

Figure 4.10 **Polycyclic aromatic hydrocarbons in sediments (µg/kg) from the Irish Sea and Bristol Channel 1992–5. Source of data: CEFAS.**

ΣPAH

720   3600   7200

Phenanthrene

100   500   1000

Pyrene

100   500   1000

Benz[a]anthracene

100   500   1000

The highest concentrations of PCBs in the tissues of fish occur in the livers of whiting from Liverpool Bay and Morecambe Bay, where the levels recorded in 1996 were 1.9 mg/kg ww and 1.7 mg/kg ww respectively for the standard set of seven CB congeners (3.0 and 2.6 mg/kg respectively when twenty-five CBs were measured; 6.3 and 5.7 mg/kg respectively when expressed as Aroclor 1254). PCB contamination in the area has been well documented and current levels of CBs in roundfish livers are within the 'upper' contamination category as specified in the old OSPAR Joint Monitoring Programme (JMP) guidelines for cod liver (applied here for roundfish generally). Concentrations of the seven CBs in the livers of Irish Sea flatfish between 1994 and 1996, including samples from Liverpool and Morecambe Bays, were in the range 0.06 – 0.6 mg/kg ww (i.e. within and below the old JMP 'medium' contamination category for flatfish: 0.50 – 1.0 mg/kg ww).

PCBs tend to occur at high concentrations in fish-eating birds and mammals. The extent of PCB contamination in these organisms is difficult to assess because of the limited availability of samples, the different congeners measured, variability between species and the dependency of concentrations on factors such as age, sex and reproductive stage.

There has been a significant decline in the PCB concentrations in seabird eggs for those colonies where concentrations were high in the early 1970s. For example, the total PCB concentrations in gannet (*Sula bassanus*) eggs from Ailsa Craig and Scar Rocks (Malin Shelf) that were > 10 mg/kg ww in the 1970s had fallen to just over 1 mg/kg by the mid-1980s. Similarly, concentrations in eggs of gannets and other species at various other localities were frequently > 5 mg/kg ww throughout the 1980s, whereas data obtained since 1994 from sites on the Isle of Man and the south coast of Ireland (Dunmore East and the Saltee Islands) suggest that concentrations are now generally well below this level. Evidence that the area surrounding the Saltee Islands had been subject to unusually high PCB contamination was obtained in the late 1970s/early 1980s when very high concentrations (i.e. > 200 mg/kg ww) were reportedly found in the adipose tissues of razorbills, shags (*Phalacrocorax aristotelis*), cormorants and guillemots; the concentrations were comparable to those known to have toxic effects. However, analysis of eggs from the same colonies in 1998 shows that the levels are now similar to those at other sites in the Irish and Celtic Seas.

The levels of PCBs (the sum of CBs 28, 52, 101, 118, 138, 153 and 180) in marine mammals are illustrated by data pertaining to the blubber of male harbour porpoises stranded on coasts of the Irish Sea, the west of Ireland and the Shetland Islands. The concentration ranges for these localities are shown in *Figure 4.9* in comparison with values for the North Sea. The concentrations of PCBs

in harbour porpoises (approximately 10 – 20 mg/kg lipid) are similar to those in common porpoises (*Delphinus delphis*) but somewhat higher concentrations have been found in white-sided dolphins (*Lagenorhynchus acutus*). Anomalously high concentrations (15 – 455 mg/kg lipid) have occurred in the livers of otters from south-west Ireland. There is insufficient information to assess trends in PCB residues in marine mammals of Region III.

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons can be formed naturally (e.g. in forest fires) although the most common source is anthropogenic emissions and the highest concentrations are generally found near urban centres. Their widespread occurrence results largely from formation and release during the incomplete combustion of coal, oil, petrol and wood, but they are also components of petroleum and its products. PAHs reach the marine environment via sewage discharges, surface run-off, industrial discharges, oil spillages and deposition from the atmosphere (see Section 4.2).

Although the lower molecular weight PAHs can be acutely toxic to aquatic organisms the major concern is that some PAHs form carcinogenically active metabolites (benzo[*a*]pyrene is the prime example). PAHs accumulate in sediments and high concentrations have been linked with liver neoplasms and other abnormalities in bottom-dwelling fish. Elevated PAH concentrations may therefore present a risk to aquatic organisms and potentially also to human consumers of fish and shellfish.

Concentrations of fifteen parent (un-alkylated) PAHs were determined in sea water from the Celtic and Irish Seas in 1993/94. In offshore waters concentrations were low or undetectable (the maximum total PAH concentration was 15 ng/l). In the Bristol Channel, concentrations of total PAHs in unfiltered water were 104 and 164 ng/l at a mid-channel site and 1150 ng/l adjacent to a steelworks. Several samples from the Mersey Estuary had total PAH concentrations of > 500 ng/l, the highest concentration being 1370 ng/l (almost an order of magnitude lower than the maximum value recorded in that particular study, i.e. 10 700 ng/l in the River Tees on the east coast of England (Region II) adjacent to a steelworks).

Very high concentrations of total PAHs in sediments were recorded during a 1995 survey of Dublin port and Cork Harbour (on the east and south coasts of Ireland respectively). The mean concentration in Dublin port sediments was 1600 µg/kg, close to the average for the twenty-two sites surveyed. The PAHs detected were mostly parent (un-alkylated) PAHs, indicating that combustion, rather than petroleum inputs, was the most likely source. Further studies to determine the origin and extent of PAH contamination in the sediments of Cork Harbour and Dublin port are warranted.

Figure 4.10a shows the distribution of total PAHs in sediment samples collected from sites in the Irish Sea and

Bristol Channel between 1992 and 1995 and *Figures 4.10b-d* illustrate the distribution of phenanthrene, pyrene and benz[*a*]anthracene respectively in these areas. Total PAH concentrations of 1 – 5 mg/kg were found at sites in the Severn Estuary. These sites also showed relatively high concentrations of individual PAH compounds (e.g. phenanthrene, pyrene and benzo[*a*]pyrene). Concentrations of total PAHs of 1 – 10 mg/kg have been measured in the sediments of Swansea Bay. Following the Sea Empress oil spill in February 1996, sediment at one site in Milford Haven yielded total PAH concentration of 93 mg/kg. Sediments from the Celtic Deep (in the north-east Celtic Sea) showed total PAH concentrations of 366 – 786 µg/kg dw.

Toxaphene

Toxaphene has been used extensively as a pesticide in North and South America, Russia and Asia but only to a minor extent in western Europe. It is not routinely included in OSPAR monitoring programmes. However, samples of fish collected between 1990 and 1992 from areas within and adjacent to Region III were found to contain toxaphene residues *(Figure 4.11)*. The highest concentrations were found west of Ireland and the UK, with lower concentrations in the North Sea. Because commercial formulations and environmental residues of toxaphene differ in composition, a subsequent study (Alder *et al.*, 1995) focused on three specific toxaphene congeners (chlorobornanes). Data for herring are presented in *Table 4.7*. The data are not normalised for age and length of fish and therefore may not give a true indication of toxaphene distribution. Nevertheless, it is clear that toxaphene is a widespread contaminant in the North-east Atlantic.

Although the origin of this contamination is unknown, in view of the apparent decrease from west to east it is probable that toxaphene, along with other volatile contaminants such as mercury and PCBs, are transported from the American continents by a combination of atmospheric and oceanic processes. The use of toxaphene has been banned in the United States since 1982 but continued usage in Central and South America may contribute to residues of this pesticide in the western Atlantic. A European programme is currently underway to assess further the status of toxaphene in the waters of the North-east Atlantic.

Other pesticides

Whereas the pesticides DDT, lindane and dieldrin are still occasionally detectable in inputs from land and the atmosphere, both inputs and environmental concentrations are low, generally stable and, in view of the restrictions placed on their use, likely to be slowly decreasing. Thus, in Region III, these substances are of

Table 4.7 Concentrations of three chlorobornanes in herring (µg/kg lipid) from the North-east Atlantic. Source of data: Alder *et al.* (1995).

	n	Concentration
West of Ireland	3	87 – 181
Rockall Trough	1	102
West of Norway	2	102 – 170
Central North Sea	11	16 – 613
Skagerrak	3	7 – 19
Baltic	5	132 – 258

n: number of samples taken.

lesser priority than those discussed in the preceding paragraphs and in recent years have received less attention in regional monitoring programmes.

DDT and its isomers

Sediments from coastal and offshore areas of the Malin Shelf, sampled in 1995/96, had absolute (un-normalised) total DDT concentrations ranging from < 1.0 µg/kg in offshore areas to 10 – 30 µg/kg in the Clyde Estuary. However, when normalised to organic carbon, the highest concentrations (300 – 1200 µg/kg) occurred in two sea lochs: Loch Fyne and Loch Goil.

Similarly, in the Irish Sea, offshore sediments had lower concentrations of DDT than estuaries. A comparative study of sediments in the western Irish Sea, Dublin port and Cork Harbour, carried out between 1992 and 1995, showed that only three sites (Dublin port, Cork Harbour and a site just north of Dublin Bay) had un-normalised concentrations of total DDT (2.5 – 5.0 µg/kg ww) that were elevated. All other sites had concentrations < 2.5 µg/kg ww.

In the period 1985 to 1996, concentrations of total DDT in the tissues of mussels from the Irish Sea, Bristol Channel and coastal areas to the south and west of Ireland were 2 – 14 µg/kg ww, whereas concentrations in the livers of flatfish were somewhat higher at 7 – 140 µg/kg ww. Levels of DDE in Irish Sea mussels were recorded as 1 – 3 µg/kg ww. The highest levels of DDT in biota were recorded in the north-eastern Irish Sea (Liverpool and Morecambe Bays). All concentrations of DDT in the commercial species tested were below the EACs adopted by OSPAR (5 – 50 µg DDE/kg ww for fish and 5 – 50 µg DDE/kg dw for shellfish) and the Codex Alimentarius Commission's Maximum Recommended Level for food safety (5 mg/kg in meat fat).

Up to the mid-1980s the eggs of seabirds from colonies in the Malin Sea and Celtic Sea, as well as the Atlantic coast of Ireland, had concentrations of *p,p'*-DDE in excess of 1.0 mg/kg ww. However records from the 1990s indicate that there has been a marked decrease at most of these sites and concentrations of *p,p'*-DDE

Figure 4.11 **Total toxaphene levels in fish (µg/kg lipid) sampled around Ireland and Britain between 1990 and 1992. Source: adapted from de Boer and Wester (1993).**

white fish liver   mackerel flesh
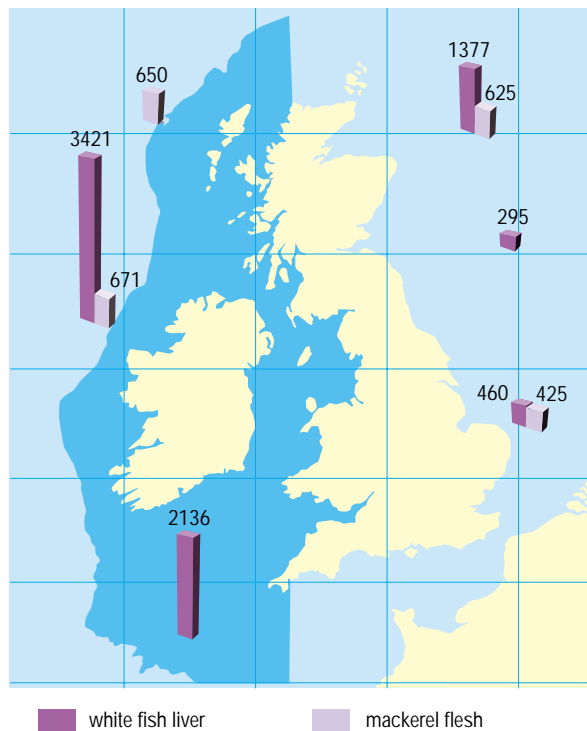
in the eggs of seabirds in Region III are now generally < 0.4 mg/kg ww. Levels of *p,p'*-DDE in the blubber of male harbour porpoises stranded in the Irish Sea and to the west of Scotland and Ireland during the 1990s have been in the range 2 – 6 mg/kg lipid *(Figure 4.9)*.

Hexachlorocyclohexane

Concentrations of α- and γ-HCH (lindane) in sea water were determined at sites in Cardigan Bay and the Irish Sea during the period 1990 to 1993. In Cardigan Bay concentrations were low or undetectable, with maxima of about 0.3 and 0.7 ng/l for α- and γ-HCH respectively. Concentrations of α-HCH ($\leq$ 0.2 ng/l) and γ-HCH ($\leq$ 0.6 ng/l) were also low in unfiltered water from five locations in the Bristol Channel during 1990 to 1996. No clear gradients in concentration were observed. Higher concentrations (up to about 3 and 8 ng/l respectively) were found in sea water from the Mersey Estuary. Intermediate values were observed in Morecambe Bay, the Solway Firth and at offshore sites in the Irish Sea. The findings suggest that residues at near shore sites are introduced via rivers. Limited sampling in the north Celtic Sea indicates little difference in HCH concentrations between offshore sites in the Irish and Celtic Seas.

Concentrations of γ-HCH in sediments from coastal

and offshore sites to the west of Scotland, sampled in 1995/96, were invariably < 0.3 µg/kg dw. Slightly higher (and marginally 'elevated') concentrations (0.1 – 0.5 µg/kg ww) were found occasionally in sediments of the north-western Irish Sea, Cork Harbour, Dublin Bay and Dublin port sampled between 1992 and 1995; most samples had levels < 0.05 µg/kg ww.

Concentrations of γ-HCH in the tissues of mussels around the Irish Sea, Bristol Channel, Celtic Sea and Atlantic coasts are in the range 0.2 – 2.0 µg/kg ww and, in the livers of flatfish from the Irish Sea, approximately 1 – 30 µg/kg ww. The highest levels of lindane in fish liver (up to 64 µg/kg total-HCH) occur in Liverpool Bay. These concentrations are within or above the EAC range adopted by OSPAR (0.5 – 5 µg/kg for lindane in fish), which actually relate to whole fish, and they are well below the Codex Alimentarius Commission's Maximum Recommended Level for food safety (2 mg/kg for γ-HCH in meat fat). Concentrations of α- and γ-HCH in the blubber of stranded male harbour porpoises from the Irish Sea *(Figure 4.9)* and west of Scotland during the past ten years have been approximately 0.2 to 0.4 mg/kg lipid.

Dieldrin

There are no recent data on levels of dieldrin in sea water within Region III. All sediments sampled to the west of Scotland in 1995/96 had absolute (un-normalised) dieldrin concentrations of < 6 µg/kg dw. Apart from the Clyde sea lochs, most areas had concentrations in the range 0.1 – 0.3 µg/kg dw. Similarly, in the early 1990s un-normalised concentrations of dieldrin in sediments from the north-western Irish Sea, Dublin Bay and Cork Harbour were in the range 0.1 – 0.5 µg/kg ww. Concentrations in the south-western Irish Sea (between Dublin Bay and Carnsore Point) were invariably < 0.05 µg/kg ww.

Concentrations of dieldrin in mussels from sites around the coast of Ireland decreased by an order of magnitude between 1970 and 1990. In the decade to 1994, concentrations in mussels from coasts of the Irish Sea and Bristol Channel, as well as the Celtic Sea and Atlantic coasts of Ireland, were in the range 1 – 3 µg/kg ww. Concentrations in the livers of flatfish from the Irish Sea were in the range 4 – 32 µg/kg ww. These concentrations are within the EAC range adopted by OSPAR (5 – 50 µg/kg ww for whole fish and 5 – 50 µg/kg dw for shellfish) but below the Codex Alimentarius Commission's Maximum Recommended Level for food safety (0.2 µg/kg in meat fat).

Recent data on dieldrin concentrations in seabird eggs indicate a marked decline over the 1990s and the levels are now predominantly < 0.2 mg/kg (previously 0.05 – 0.5 mg/kg) and, locally, as much as an order of magnitude less. The concentrations of dieldrin in the

Table 4.8 Concentration ranges of five phthalate esters in sea water (ng/l) from the Mersey Estuary.

DMP	DEP	DiBP	DnBP	DEHP	Source of data
n.d. – 973	n.d. – 67	65 – 709	114 – 2120	83 – 335	Preston and Al-Omran (1986)
84 – 695	68 – 243	338 – 1100	541 – 1010	125 – 693	Preston and Al-Omran (1989)
< 1	< 1 – 51	81 – 110	140 – 4800	390 – 1500	Law *et al.* (1991)

DMP dimethyl phthalate; DEP diethyl phthalate; DiBP di-*iso*-butyl phthalate; DnBP di-*n*-butyl phthalate; DEHP di-(2-ethylhexyl) phthalate; n.d.: not detectable.

blubber of harbour porpoises stranded in the Irish Sea and Scottish sectors of the Malin Shelf during the 1990s have been in the range 2 – 10 mg/kg *(Figure 4.9)*. In other species of cetacean stranded to the west of Scotland in the early 1990s concentrations were predominantly < 2 mg/kg.

Hexachlorobenzene

Hexachlorobenzene is present in sediments of the Irish Sea at very low levels (i.e. < 0.2 µg/kg). Concentrations in the livers of dab (*Limanda limanda*), sampled at sites in the Irish Sea between 1992 and 1994 were also low, generally in the range 0.001 – 0.003 mg/kg ww. Slightly higher levels (0.006 – 0.007 mg/kg ww) occurred in the livers of dab from Liverpool Bay. Concentrations in mussels were invariably < 0.001 mg/kg ww. Concentrations of HCB in the blubber of harbour porpoises stranded on the coasts of the Irish Sea and to the west of Ireland have been in the range 0.3 – 0.6 mg/kg lipid *(Figure 4.9)*.

Triazines

In a 1992 survey of the eastern Irish Sea, concentrations of atrazine and simazine in sea water were highest in samples from the Mersey Estuary where the maxima were 42 and 37 ng/l respectively. In Cardigan Bay concentrations of both herbicides were < 2 ng/l. Concentrations in samples from the Solway Firth, Morecambe Bay and offshore in the Irish Sea generally fell between these two extremes. In the Bristol Channel there was an apparent gradient decreasing seawards from maxima of about 5 and 3 ng/l for atrazine and simazine respectively, to values of < 1 ng/l offshore (in comparison, sea water from the German Bight sampled in the early 1990s had maximum concentrations of atrazine and simazine of 100 and 180 ng/l respectively).

Total hydrocarbons

Between 1984 and 1997, samples of sea water from offshore waters were collected in the Celtic Sea and Irish Sea for total hydrocarbon (THC) analysis. The Celtic Sea and Western Approaches were surveyed in 1984, and again in 1990 and 1991, and showed THC concentrations of 0.3 – 6.4 µg/l, with most samples < 2.0 µg/l. Similar concentrations were found in the Irish Sea in 1986. In the Irish Sea, THCs were highest in turbid waters (the samples were unfiltered), inshore and in areas with a high incidence of shipping activity. The lowest values were found in the central part of the eastern Irish Sea away from coastal influences. In coastal environments the highest THC concentrations were found close to harbours and coastal towns.

In the early 1990s, a pilot survey of total extractable hydrocarbons in sediments from Irish harbours indicated concentrations (normalised to 5% organic content) in the range < 5 – 40 mg/kg ww. Comparatively elevated concentrations were evident in the sediments of upper Cork Harbour (200 – 1000 mg/kg), in Dublin port (200 – 300 mg/kg), Dun Laoghaire Harbour (80 – 200 mg/kg) and Killybegs Harbour (80 – 200 mg/kg). These levels probably represent aliphatic hydrocarbon contamination from cargo and fishing vessels.

Phthalate esters

Concentrations of phthalate esters (esters of 1,2-benzene dicarboxylic acid) were determined in samples from the Mersey Estuary on three occasions in the late 1980s

Table 4.9 Oil pollution incidents in the Irish Sea. Source of data: ACOPS (1998).

	1980	1981	1982	1983	1984	1985	1986	1987
Open sea	2	3	3	2	4	3	7	6
Tidal river/estuary	0	2	3	0	0	0	0	0
Bay/nearshore water	0	3	0	4	1	5	1	2
Beach/shore	10	3	5	7	4	3	3	2
Port	2	22	20	3	10	19	19	13
Total	14	33	31	16	19	30	30	23
Oil spilled (t/yr)	< 250	< 150	50 – 100	< 50	100 – 150	4	263	51
Clean up costs (£000)	9	8	-	5	10	1	74	49

Guillemot killed by spilled tanker oil

(Table 4.8). Comparable, quality-controlled data are sparse, partly because of the contamination problems encountered when determining trace concentrations of phthalate esters (these concentrations are however broadly similar to those reported for the Rhine, Meuse and Ijssel in the Netherlands).

4.6 **Multiple chemical inputs**

All available data on inputs of chemicals to Region III are summarised in Section 4.2.

4.7 **Oil**

Estimates of the amounts of petroleum hydrocarbons entering Region III, from a variety of sources, are given in Section 4.2. Shipping sources are not included but ships are permitted to discharge low concentrations of oil (known as 'operational discharges') from bilges and engine room spaces whilst on passage. If carried out at the MARPOL 73/78 approved rates such discharges should not give rise to visible oil on the sea surface. Slicks do occur when ships fail to observe the rules concerning discharge rates and areas in which discharges are

permitted. In practice however, most oil pollution in Region III arises as a result of accidents.

Statistics on oil pollution incidents in the Irish Sea were collected by the Advisory Committee on the Protection of the Sea, between 1980 and 1987 and the data are presented in *Table 4.9*. In most cases the amounts of oil involved were relatively small but the clean-up costs were not inconsiderable (see also Sections 4.2.5 and 5.13).

Other single source large inputs of oil may arise in oil-based drilling muds, but these can no longer be discharged. Such mud was only used in one well in Irish waters – in 1984. The remaining inputs, whilst substantial in terms of the total tonnes involved, occur as low concentrations in rivers and municipal and industrial discharges etc.

For the purposes of judging return to normality following the Sea Empress oil spill on the south coast of Wales in 1996, background (i.e. ubiquitous – *see Box 4.1*) concentrations of total petroleum hydrocarbons for the region were judged to be 0.2 – 0.9 µg/l in sea water, ≤ 10 mg/kg in dry sediments and 2 – 10 µg/kg in biota. Oil is a naturally occurring substance in the marine environment and concentrations in water below a few mg/l are considered unlikely to give rise to harmful effects (including sub-lethal effects) in most marine species. Such concentrations are not normally encountered in Region III and only surface slicks caused by spills or illegal discharges give rise to biological impacts.

4.8 **Radionuclides**

4.8.1 **Sources**

For the last forty years, inputs of artificial radionuclides to Region III have been dominated by discharges from the nuclear reprocessing facilities at Sellafield (formerly Windscale) on the Cumbrian coast. The magnitude of these releases, authorised by the UK Government, has tended to mask contributions of radionuclides from other sources such as the 1986 Chernobyl accident, the effects of which are largely terrestrial, and residues from atmospheric weapons testing. The proportion attributable to the latter is more evident in regions remote from Sellafield, such as the west coast of Ireland.

In addition to Sellafield, a number of establishments on the west coast of Great Britain are also authorised to release small amounts of radioactivity. The activities concerned include power generation, nuclear fuel production, manufacturing of medical supplies and military/naval operations. Their discharges and the adjacent environments are subject to regular monitoring. In all cases the resulting public radiation exposures are very low and difficult to distinguish from radiation due to Sellafield and nuclear fallout.

4.8.2 Trends in discharges from Sellafield

The authorised discharge limits from Sellafield are reviewed periodically and annual discharge figures are published both by the operator and the UK Department of Environment, Transport and the Regions. Discharges peaked in the 1970s, since when a number of counter-measures have been introduced and the quantities of radionuclides discharged have changed markedly as a result of changes in throughput, chemical processes, storage and waste treatment. The Site Ion Exchange Effluent Plant (SIXEP), introduced in 1986, controlled

caesium-137 discharges and since 1994 the Enhanced Actinide Removal Plant (EARP) has allowed the treatment of medium-active, stored liquors. Releases of the α-emitters have declined significantly since the introduction of the EARP. For many radionuclides current discharges are at least 100 times lower than at the time of peak discharges in the 1970s. However the EARP does not remove technetium-99 and discharges of this radionuclide rose rapidly *(Figure 4.12)*, although they have subsequently declined from the peak in 1995. Discharges of iodine-129, strontium-90, carbon-14, cobalt-60 and tritium have also increased as a result of operational changes at the site, including the starting-up of the Thermal Oxide Reprocessing Plant (THORP).

Figure 4.12 **Discharges of technetium-99 from Sellafield. Source: CEFAS.**
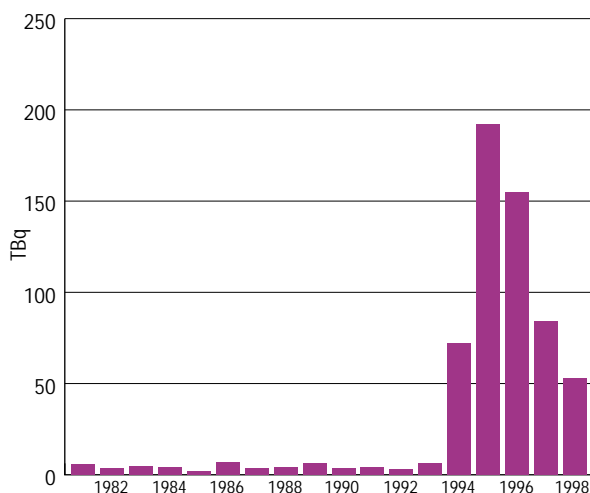
4.8.3 Inputs of naturally-occurring radionuclides

Prior to 1992 when the operation was discontinued, the Irish Sea received about 35 t/yr of naturally-occurring uranium (and unquantified amounts of daughter products) from phosphate rock processing at Whitehaven. This resulted in elevated concentrations of radium-226 in sea water, polonium-210 in biota, and thorium-230 and lead-210 in sediments. These concentrations have now fallen substantially. About 4 t of uranium have been released annually from Sellafield, but without an equivalent loading of daughter products, and the impact has been negligible. The sediments of the Ribble Estuary can contain relatively high concentrations of thorium-234 and protactinium-234m discharged from the fuel fabrication plant at Springfields. The influence of

Figure 4.13 **Concentrations of caesium-137 in filtered sea water at Balbriggan, County Dublin, 1988–95. Source of data: Pollard *et al.* (1996).**
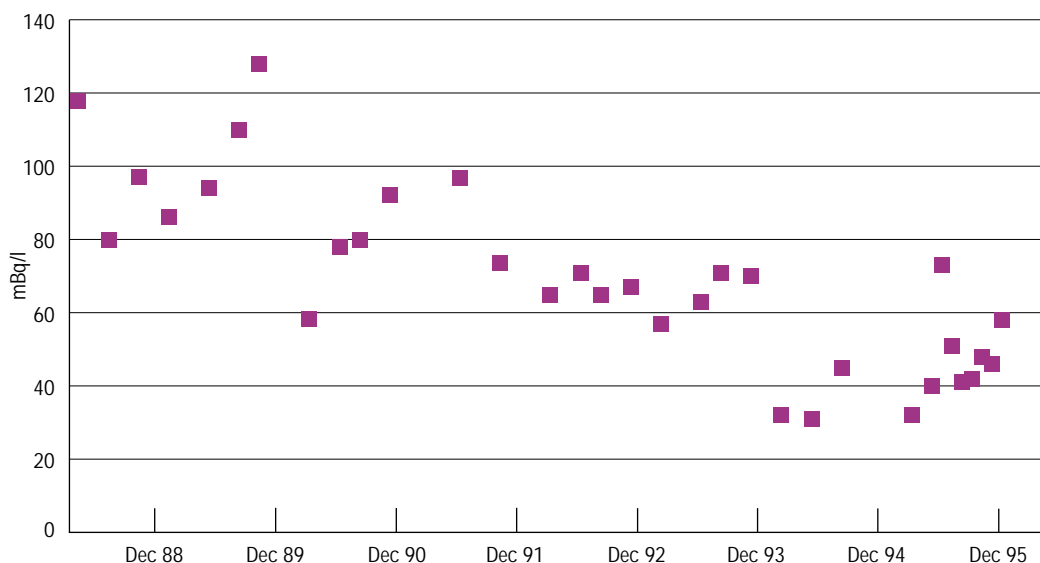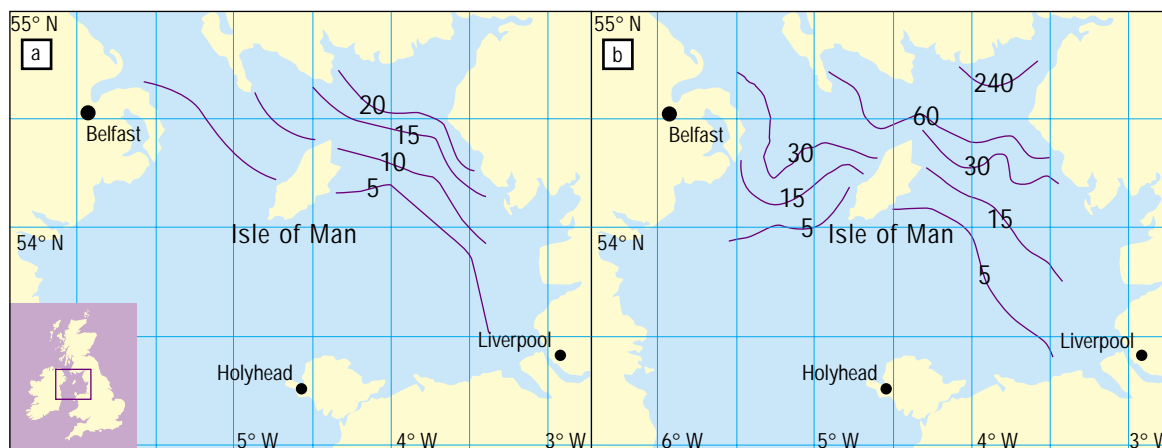
Figure 4.14 **Technetium-99 in surface waters (Bq/m^3): (a) pre-EARP release, (b) post-EARP release. Source: Leonard *et al.* (1997).**

these residues is unlikely to extend significantly beyond the estuary due to the short half-life of thorium-234 (24 days).

4.8.4 Environmental distributions

Environmental monitoring and radiological assessments are carried out both in Ireland and the UK. The results are published in annual or biennial reports. Research has established the distribution of radionuclides in sea water and subtidal and intertidal sediments, and the key processes responsible for their distribution have been investigated. Most of the input of 'soluble' radionuclides such as caesium-134, caesium-137, technetium-99, strontium-90 and iodine-129 has been transported out of the Irish Sea, whereas most of the plutonium and americium-241 resides in subtidal, muddy sediments in the eastern Irish Sea. Tides, storms, trawling and burrowing organisms mix this activity up to 1.5 m into the seabed, dilute the degree of contamination and transport sediment away from the point source, especially towards the southern Scottish coast and, to a lesser extent, to muddy sediments west of the Isle of Man. The seabed is now a source of caesium-137, remobilised as a result of the much lower sea water concentrations following the substantial decrease in the discharge. Thus, although superficially the overall distribution patterns have seemed constant with time, the redistribution of sediment-bound radionuclides is continuing.

As a result of the northerly outflow of sea water through the North Channel, Sellafield-derived radionuclides are readily detectable in the Scottish Coastal Current. The highest concentrations of caesium-137 occurred in the North Channel/Clyde Sea area in the mid- to late-1970s, but these had decreased by about two orders of magnitude by the mid-1990s. The remobilisation of caesium-137 from sediments will result in concentra-

tions entering the Malin Sea higher than otherwise expected due to the decrease in discharges alone. Several studies have shown a tongue of water, rich in caesium-137, extending to the west of the Outer Hebrides. Increased discharges of technetium-99, due to the commissioning of the EARP in 1994, led to a five-fold increase in technetium-99 in the surface waters of the Scottish Coastal Current within about eight months. It is expected that concentrations of plutonium in the Scottish Coastal Current, which have been consistently higher than fallout levels, will continue to decrease.

### 4.8.5 Levels in sea water

The general trend of decreasing concentrations of caesium-137 in sea water is illustrated by conditions off the east coast of Ireland where a slow but steady decline has been recorded since 1988 *(Figure 4.13)*. In contrast, the significant increase in the discharge of technetium-99 in 1994, combined with the relatively rapid dispersion of this radionuclide (the transit time to the Irish coast is less than 5 months), led to a marked increase in concentrations of technetium-99 in sea water at the North Channel and in the western Irish Sea *(Figure 4.14)*. Plutonium and americium-241 also occur in the water column but the quantities are much smaller than those in sediments. The dispersion route for plutonium is similar to caesium but concentrations are lower by several orders of magnitude.

4.8.6 Levels in sediments

The subtidal sediments of the Irish Sea contain substantial amounts (tens to hundreds of kilogrammes) of artificial radionuclides, particularly caesium, plutonium and americium. The highest concentrations in surface sediments are close to the Sellafield outfall and in a zone of muddy

Figure 4.15 **(a) caesium-137 concentrations (Bq/kg dw) and (b) silt distribution (% < 63 μm) in the surface sediments (0 – 5 cm) of the Irish Sea in 1988. Source: McCartney *et al.* (1994).**
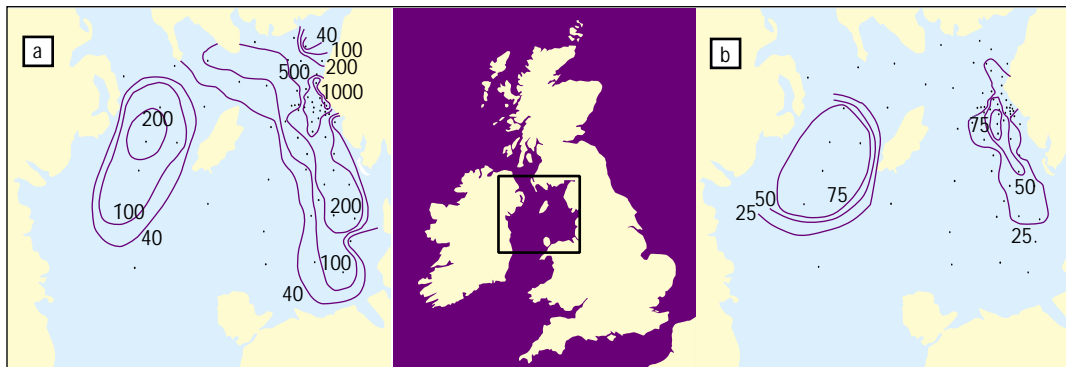
sediments running parallel to the English coast. The area of fine-grained sediments to the west of the Isle of Man also has elevated concentrations *(Figure 4.15)*. The eastern Irish Sea sediments are now the principal source of particle-bound plutonium. The estimated total quantity of plutonium in sediments is about 200 kg. Although the subtidal sediments contain a much greater total amount of plutonium than the intertidal sediments the latter are more critical in terms of human contact.

Radionuclide concentrations in intertidal sediments have responded to the variation in discharges, the greatest changes occurring close to the source. Levels of caesium-137 in sediment have fallen steadily throughout the Irish Sea since the early 1980s, largely as a result of remobilisation and release into the water column; in some areas (e.g. the western Irish Sea) this has probably resulted in a relative enhancement of sediment concentrations. Changes in sediment-bound plutonium also reflect the slow redistribution of sediments away from the English coast to other parts of the Irish Sea, such as the large area of muddy sediments to the west of the Isle of Man. As these muddy sediments are slowly accumulating, they act as a long-term sink for plutonium and other long-lived and particle-reactive radionuclides. Accordingly, their response to decreased plutonium discharges will be considerably slower than in the case of caesium.

4.8.7 Levels in biota

Seaweeds such as the bladder wrack (*Fucus vesiculosus*) are good indicators of soluble radionuclides such as caesium and technetium in the surrounding environment. Concentrations of caesium-137 in bladder wrack diminish with increasing distance from Sellafield and have fallen in response to reductions in the discharge. On the east coast of Ireland they decreased by approximately 20% per year during the period 1983 to 1986, and although the downward trend continues it is now less pronounced. Similar changes have been

measured in fish and shellfish *(Figure 4.16)*.

Concentrations of technetium-99 in seaweeds and the edible tissues of lobsters (*Homarus gammarus*) rose rapidly in response to the increased discharges after 1994. As with caesium, the concentrations decrease with increasing distance from Sellafield. Monitoring of seaweeds around Ireland during 1997 showed concentrations of technetium-99 at sites on the east coast to be almost 30 times higher than the pre-1994 level. The trends at Balbriggan and Greenore suggested that concentrations had not reached equilibrium *(Figure 4.17)* although, more recently, monitoring on the UK coast close to the discharge shows levels declining in response to lower inputs.

In general the concentrations of plutonium and americium are higher in shellfish than in fish. The most recent monitoring shows that their concentrations in fish and shellfish from routinely monitored sites in the Irish Sea are relatively stable.

Figure 4.16 **Caesium-137 concentrations in fish and prawns landed at western Irish Sea ports 1982–97. Source: Long *et al.* (1998).**
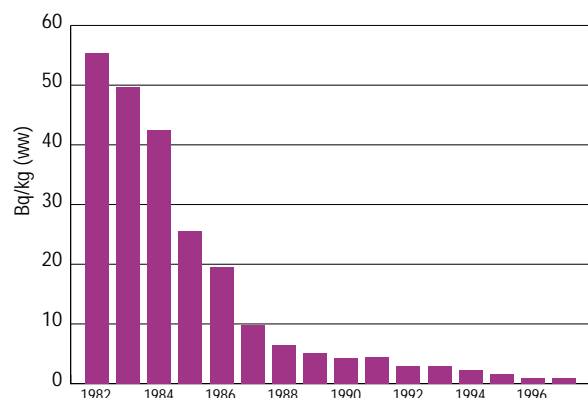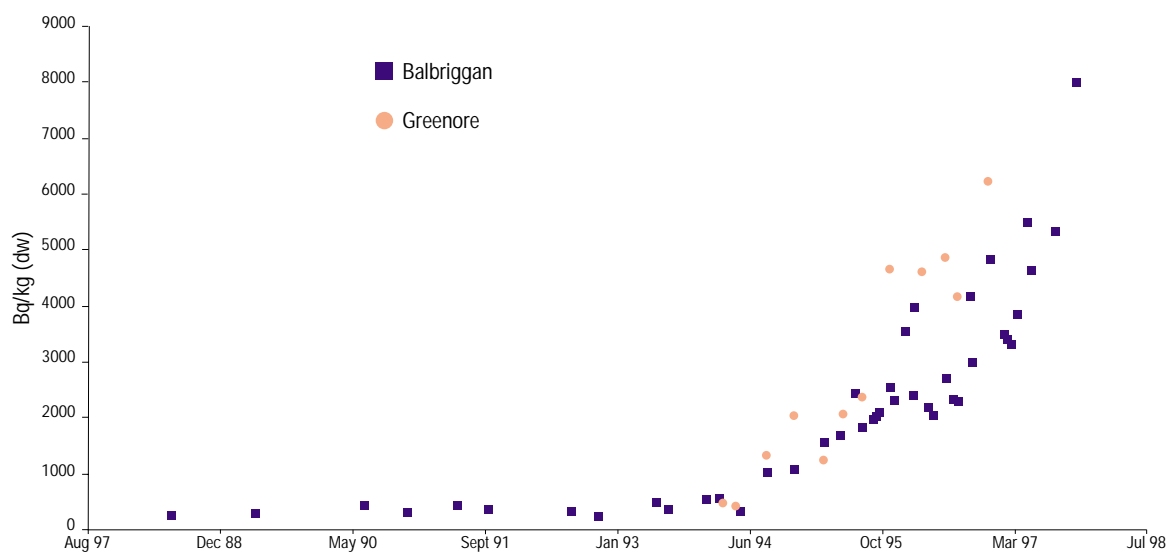
Figure 4.17 **Technetium-99 concentrations in bladder wrack from Balbriggan and Greenore 1988–97. Source: Long *et al.* (1998).**

4.8.8 Radiation exposures

Studies of the uptake of radionuclides by marine organisms have been undertaken since the early 1960s. These have included the levels of iodine-129, rubidium-106, technetium-99, plutonium and polonium-210 in a variety of fish, shellfish and seaweed. Calculation of doses to consumers of fish and shellfish has formed part of a comprehensive programme to assess the radiological impact of the Sellafield operations. Doses have varied according to the discharges and the critical groups involved. It is estimated that the highest individual doses occurred in the mid-1970s (approximately 1.9 mSv/yr) due to radiocaesium and other nuclides in fish and shellfish. This contrasts with estimated doses, due to polonium-210 and lead-210 in shellfish near the discharge point, of approximately 5 mSv/yr in the early 1980s as a result of phosphate waste discharged near Whitehaven. Collective doses *(see Box 4.2)* from all artificial sources peaked at 130 man-Sv for the UK, and 110 man-Sv for other European countries, in the 1970s. These had fallen to 3 and 20 man-Sv respectively by 1995.

The increased discharges of technetium-99 from Sellafield since 1994 have resulted in corresponding increases in the contribution of this radionuclide to the doses to seafood consumers. However, because of the low radiotoxicity of technetium-99 it contributes only about 15% of the total dose (man-made) due to radioactivity in Irish Sea fish and shellfish, still significantly less than the 65% attributable to caesium-137. In Ireland the radiation dose in 1997 to a heavy consumer of seafood (73 kg of fish; 7.3 kg of shellfish) from the north-eastern Irish Sea was estimated to be 1.4 µSv whereas the corresponding figure for the early 1980s was 70 µSv (Long *et al.*, 1998). The highest dose to consumers on the Cumbrian coast in 1981 was reported to be 3450 µSv or 69% of the then recommended dose limit of 5000 µSv (using an enhanced gut transfer factor for plutonium). On the west coast of Scotland (Hunterston, Firth of Clyde), the exposure to the most exposed group of fish and shellfish consumers in 1996, including external radiation, was 23 µSv. These figures may be contrasted with average doses from all sources of radiation received by members of the public. For example, the average annual dose to a person in Ireland currently stands at about 3000 µSv (Long *et al.*, 1998).

Reviews of available data on the effects of chronic radiation exposure on aquatic organisms indicate that the estimated dose rates to organisms in the north-eastern Irish Sea, and elsewhere in Region III, are unlikely to produce adverse effects at the population level. This applies even to historical dose rates that are likely to have been more than an order of magnitude greater than at present.

4.9 Nutrients and oxygen

4.9.1 Introduction

The growth of plants in the sea depends upon the availability of nutrients and light. Although a number of

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Box 4.2 Collective dose

The effects of radiation from all sources on a large group of people is measured in terms of that group's **collective dose** and is expressed in man-sieverts (man-Sv), that is **the number of people within the group being considered multiplied by the average dose received by each person within that group** (this assumes uniform irradiation of the whole group).

Figure 4.18 **Winter nitrate/salinity relationships for three major eastern Irish Sea estuaries. Source of data: EA.**
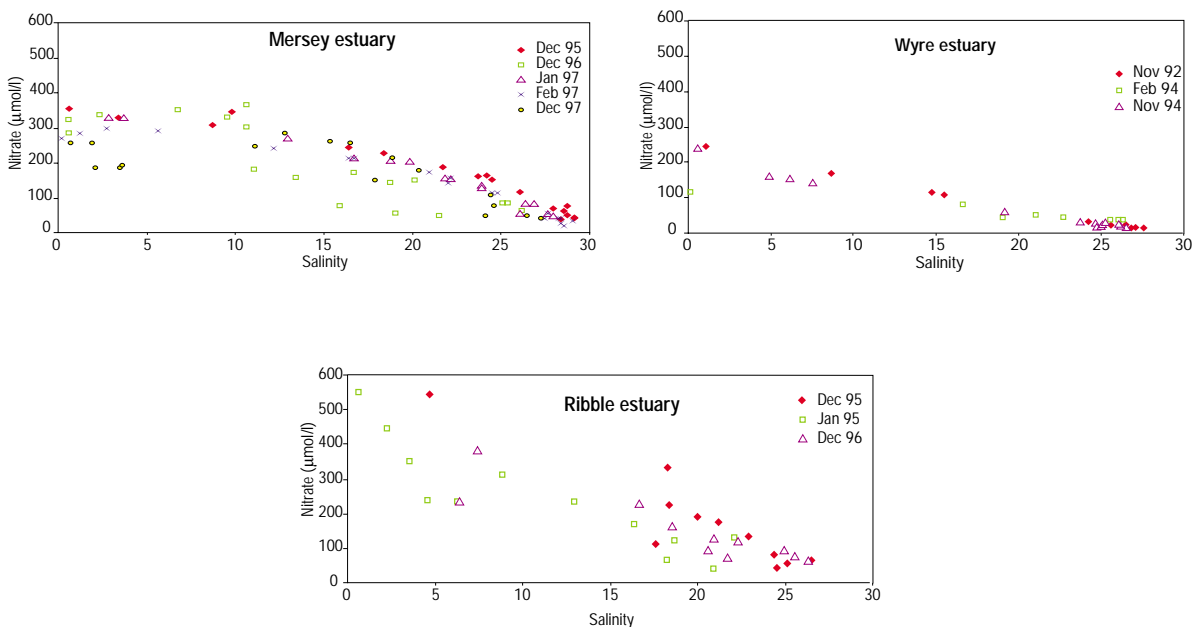
substances are recognised as being required in trace concentrations, it is normally the availability of dissolved forms of nitrogen (ammonium and nitrate), phosphorus (phosphate) and silicon (silicate) that limits plant (phytoplankton and macroalgae) growth. Although there are circumstances where the availability of silicon may limit the growth of diatoms (species that have a siliceous cell wall), nitrogen is the nutrient most likely to control growth of phytoplankton in marine waters.

In Region III, concentrations of dissolved nutrients exhibit a pronounced seasonal cycle, typical of northern temperate shelf seas. During late autumn and winter, when light is limiting, biological uptake of nutrients is low and concentrations in water increase, primarily due to the *in situ* breakdown of organic matter. In spring and summer, nutrient concentrations in the euphotic zone become depleted as phytoplankton growth resumes. This is particularly evident in areas where the water column becomes thermally stratified because this inhibits replenishment from below.

4.9.2 Sources, inputs and distributions of nutrients

In addition to the input of nutrients via oceanic water and the seasonal cycling of nutrients in the sea, nutrients are supplied to coastal waters via run-off (e.g. from agriculture and vehicle emissions), from sewage treatment plants, from certain types of industry and, over the whole area, from the atmosphere. These additional inputs can

enhance the growth of phytoplankton and in extreme cases, most often in semi-enclosed coastal embayments, where there is restricted water circulation and exchange with the open sea, high levels of nutrients can produce a large phytoplankton biomass and give rise to nuisance blooms of algae. Some algal species can give rise to toxins that can be transferred to man via shellfish (see Section 5.3). As the blooms die their decomposition may lead to reduced oxygen concentrations in the water and at the seabed, thus causing mortality of indigenous animals.
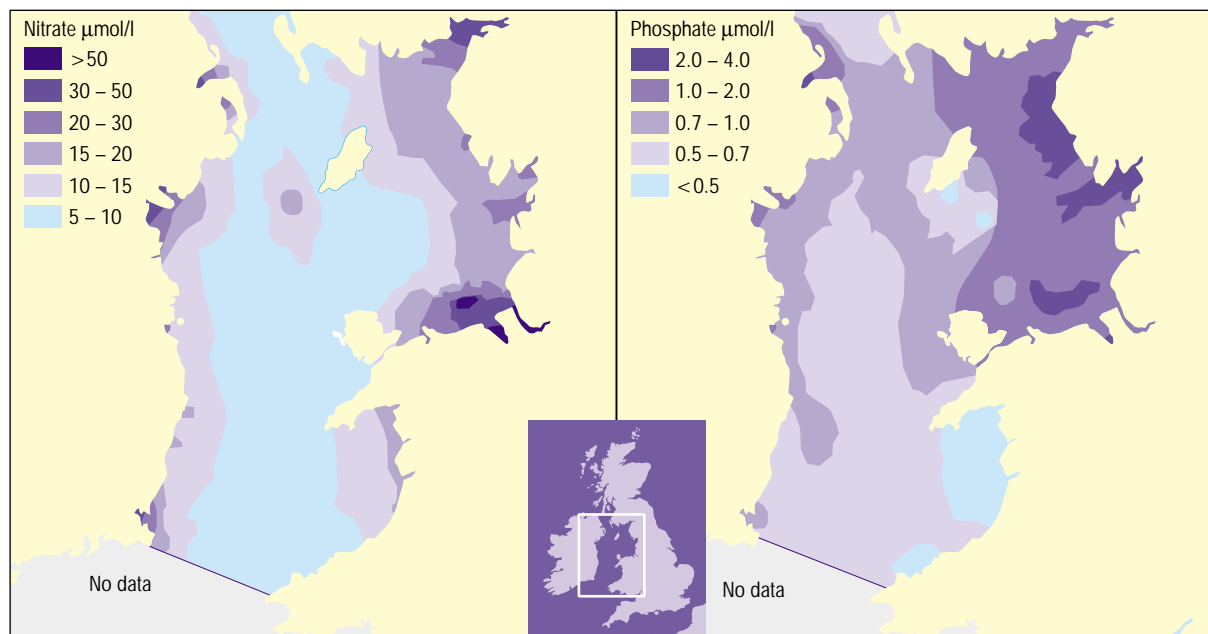
Irish Sea

Section 4.2 provides details of the various nutrient inputs to the Irish Sea area and *Table 4.10* summarises the estimates made by an Irish Sea Study Group in 1990. Since then the input of phosphate to the north-eastern Irish Sea has been substantially reduced through process changes at a phosphate rock processing plant on the Cumbrian coast and because sewage sludge disposal ceased

Table 4.10 **Nutrient inputs (t/yr) to the Irish Sea. Source of data: ISSG (1990b).**

	Nitrogen	Phosphorus
Atmospheric	43 000	2 000
Riverine	76 400	6 120
Domestic	10 700	1 900
Industrial	2 640	16 260
Sludge	3 840	720

Figure 4.19 **Nitrate and ortho-phosphate concentrations (µmol/l) in the Irish Sea January/February 1991. Source: NORSAP (1992).**

completely in 1999. The inputs from land-based sources are superimposed on natural inputs introduced by oceanic water entering the Irish Sea via the Bristol Channel, which are estimated at more than 100 million t of nitrogen and 28 million t of phosphate annually.

Although relatively small in terms of load, concentrations of nutrients in inputs from land, particularly rivers, are much higher than concentrations in Atlantic water. Nitrate : salinity plots for some major Irish Sea estuaries in winter are shown in *Figure 4.18*. Nitrate concentrations in these freshwater sources range from 200 – 350 µmol/l and for most estuaries the plots show a linear relationship, indicating the dominant process is dilution. The Mersey is an exception and shows the importance of denitrification within that estuary in substantially reducing the quantity of nitrogen exported to sea. Phosphate concentrations in freshwater range from as low as 0.2 µmol/l (i.e. lower than winter concentrations in coastal sea water) to > 20 µmol/l. The phosphate : salinity plot for most Irish Sea estuaries is not linear due to the interaction of phosphate with particulate matter. Riverine inputs exhibit marked seasonality, being higher during winter when run-off is greatest. This variability in load is most pronounced for nitrate, which originates largely from agricultural sources and flushes rapidly from land during heavy rainfall. In contrast phosphate leaches at a relatively constant rate; furthermore a large part of the phosphate load comes from sewage treatment works. As a generalisation, phosphate concentrations tend to decrease with increasing river flow, whereas nitrate concentrations increase.

Figure 4.19 shows winter concentrations of nutrients in the Irish Sea as observed in 1991, i.e. before the changes in inputs referred to in the first paragraph of this section. The influence of land-based sources is very clear for both nitrate and phosphate. The extent of coastal influence is more marked in the north-eastern Irish Sea than along the Irish coast. This is primarily due to the comparatively longer retention time of sea water in the shallow sector of the Irish Sea to the east of the Isle of Man. The nitrate distribution, in particular, closely follows the salinity contours throughout the Irish Sea and shows clearly the influence of riverine inputs such as those from the Dee and Mersey, as well as those from the River Slaney on the south-east coast of Ireland and the rivers discharging into Dundalk Bay on the north-east coast of Ireland.

Much of the Irish Sea is well mixed throughout the year and nutrients do not become seriously depleted except in the stratified north-western Irish Sea. For example, in that area, concentrations of oxidised nitrogen (nitrate plus nitrite) were reduced from 6–7 µmol/l in March 1992 to 0.5 µmol/l in July. Similarly, orthophosphate concentrations decreased from 0.9 – 0.1 µmol/l and silicate from 6.0 – < 1.0 µmol/l over the same period. The concentrations of all three nutrients recovered rapidly during autumn and winter with concentrations approaching the March concentrations by November, largely due to *in situ* remineralisation of nutrients from suspended organic matter. The seasonality noted in the Irish Sea is much less marked in the Bristol Channel where high turbidity in the middle and upper reaches severely restricts phytoplankton growth. Temporal data

Table 4.11 Mean nutrient concentrations to the west of Scotland (µmol/l) 1960–90. Source of data: FRS.

	Nitrate		Phosphate		Silicate	
	winter	summer	winter	summer	winter	summer
Clyde Sea	12.5	0.8	1.2	0.3	9.3	1.0
Inner Malin Shelf	7.3	0.6	0.6	0.1	5.2	0.9
Outer Malin Shelf	8.6	0.5	0.6	0.2	4.3	0.6
Shelf west of Hebrides	9.3	1.4	0.6	0.2	4.1	0.4
North Minch	7.0	0.1	0.6	0.3	5.1	1.2
North Channel*	8 – 13.0	-	0.5 – 1.1	-	4.6 – 10.3	-
North coast*	7.5 – 8.5	-	0.5 – 0.9	-	3.2 – 8.9	-

* data are for a sea area off Northern Ireland in 1991; -: no information.

from the 1990s on winter nutrient concentrations west of 5° 36' W, show no evidence of trends in oxidised nitrogen but there are indications that phosphate increased prior to 1994/95 and decreased thereafter.

The Celtic Sea and Atlantic Shelf west of Ireland
There are very few data on the concentrations of nutrients in near shore waters of the Atlantic Shelf west of Ireland and in the Celtic Sea but it is likely that winter nitrate and phosphate concentrations are correlated with salinity.

During the spring, major changes in nutrient concentrations occur in all shelf waters as primary production resumes. Off the west coast of Ireland the timing of the onset of spring production dictates the pattern of nutrient depletion. For example in 1990 the spring bloom was well established by mid-April with clear reductions in surface nitrate and phosphate concentrations. However, in 1992 the spring bloom was poorly developed by mid-April and the respective concentrations of nitrate and phosphate were up to 5.0 and 0.4 µmol higher than in 1990. In summer both the Celtic Sea and shelf waters to the west of Ireland become extensively nutrient depleted. Exceptions occur in the vicinity of tidal fronts such as the Ushant Front and the Celtic Sea Front. Within these localised transition zones, both nutrient levels and light are sufficient to enhance algal growth throughout the summer months. At a number of locations on the west coast of Ireland occasional upwelling events occur during the summer months. These events are associated with inshore tidal mixing and result in increased nutrient availability in stratified waters that would normally be nutrient depleted. Such events may stimulate occasional toxic algal blooms (see Section 5.7).

Malin Shelf west of Scotland
The area to the west of Scotland comprises a number of zones with distinct hydrographic features. The mean nutrient concentrations found in these five zones in winter and summer between 1960 and 1990 are summarised in

Table 4.11. The waters in these areas are generally well mixed but nutrient depletion following the onset of the spring bloom is clear in all areas. Off the coasts of Northern Ireland and in the North Channel, winter nutrient concentrations are similar to those found off the Scottish coast (i.e. excluding the Clyde Sea area) in winter.

The west coast of Scotland is a heavily glaciated landscape with deep fjordic inlets. By far the largest estuary in terms of development is that of the Clyde. In the Clyde, nitrate tends to behave conservatively but nitrite and ammonium behave non-conservatively, probably reflecting both nutrient input and internal denitrification. Dissolved phosphate also behaves non-conservatively, responding to changes in suspended load, waste inputs and biological activity. Outside the Clyde most freshwater run-off enters the fjordic sea lochs where nitrate and phosphate concentrations (typically 6 and 0.5 µmol/l respectively) reflect the generally lower input from terrestrial sources. However, many of these sea lochs contain fish farms and these can give rise to enhanced ammonium and phosphate concentrations close to the farm sites. The significance of such inputs is discussed in Section 5.6.

4.9.3 Trends
Given the marked seasonal variations and the differences observed from year to year in the onset of phytoplankton growth it is difficult to resolve any anthropogenic influence from natural processes. Although the recently established National Marine Monitoring Programme should eventually lead to a consistent set of time series data for the area west of the UK, there is a lack of such data at present. Even in the Irish Sea there is a lack of consistent time series of data on concentrations of nutrients. However, one time series (1967 – 1994) for a site in the central Irish Sea near the Isle of Man, does suggest that both winter nitrate and phosphate concentrations have increased since sampling started at the site in 1954. This trend may be partially climate related but it is consistent with increased nutrient inputs to the Irish Sea as a result of human activities.

Table 4.12 UK guideline criteria for determining whether estuaries and coastal waters are eutrophic, or at risk of eutrophication, in the context of the EC Urban Wastewater Treatment Directive.

	Estuaries	Coastal waters	
		acceptable	requires investigation
Dissolved oxygen	≥ 7 mg/l median and not less than 6 mg/l	≥ 7 mg/l median and not less than 6.5 mg/l	< 7 mg/l median and/or values less than 6.5 mg/l
DAIN	-	< 12 µmol/l*	> 12 µmol/l*
		+	
DAIP	-	< 0.2 µmol/l	-
Chlorophyll a	-	< 10 µg/l	> 10 µg/l

DAIN dissolved available inorganic nitrogen; DAIP dissolved available inorganic phosphorus; * summer value; -: no guideline.

Support for the concept of increased nutrient concentrations over time can be discerned in the measurements of chlorophyll *a* at the Isle of Man site where, between 1967 and 1994, there was a 100% increase. Further south in the well-mixed zone, data from the Continuous Plankton Recorder programme suggest the colour index fell between 1970 and 1980 but increased thereafter. However, as this increase in the colour index was also observed throughout the Malin Shelf and Western Shelf, it is likely that the cause is macro-scale changes in the North-east Atlantic rather than land-based inputs.

4.9.4 Deoxygenation

Elevated concentrations of nitrogen and phosphorus, in the absence of similar scale increases in silicate, are generally considered to favour the growth of microflagellate and dinoflagellate species rather than diatoms. In some estuarine and coastal areas blooms of certain dinoflagellate species occasionally cause deoxygenation when the blooms collapse and decompose in summer. There is, however, no consistent pattern which might be regarded as symptomatic of eutrophication, though blooms of *Phaeocystis* spp. do occur regularly in the north-eastern Irish Sea; in Liverpool and Morecambe Bays.

Generally the offshore waters of Region III are well mixed and seriously depressed oxygen levels are unusual. The only areas where oxygen depletion is occasionally detected are the outer Clyde Estuary and Liverpool Bay at times of stratification. In both cases this is attributable to sewage sludge disposal, rather than algal blooms, and is expected to cease now that sludge disposal has stopped. Although parts of the north-western Irish Sea also stratify in summer and the bottom waters become isolated for several months, the attendant drop in oxygen concentration is small. The position rapidly reverses once stratification breaks down.

4.9.5 Eutrophication criteria

As an integral part of the OSPAR Strategy to Combat Eutrophication adopted in 1998, a classification of the eutrophication status of the maritime area is being undertaken. Within UK waters a first stage screening procedure has identified three broad areas for more detailed consideration: the Firth of Clyde, Anglesey to the Solway Firth and the Severn Estuary upstream from Bideford Bay to Carmarthan Bay. In response to the consideration of adverse eutrophication effects under the EC Directives on Urban Wastewater Treatment (91/271/EEC) and Nitrates (91/676/EEC), a special study group derived a number of guideline concentrations. These guidelines, which are not standards, are summarised in *Table 4.12*. Preliminary findings suggest that, at least for the purposes of the

Figure 4.20 **Irish estuaries and embayments for which nutrient data are available.**

Urban Wastewater Treatment Directive, the Mersey Estuary/southern Liverpool Bay area and Belfast Lough are considered to require some protection in the form of improved sewage treatment.

Similar guidelines were drawn up by Irish scientists for assessment purposes. Their conclusions are summarised in *Table 4.13* and, as with the UK figures, the numbers are guidelines rather than water quality standards. They have been used to assess the status of twenty-three major estuaries and embayments around Ireland *(Figure 4.20)*. The overall conclusions drawn are that, with the exception of locations in places such as the Malahide Estuary, Dublin Bay and Cork Harbour, eutrophication is not a problem in Irish waters.

Table 4.13 Water quality indices applied to Irish estuaries and coastal areas for assessment purposes.

	units	Category low	Category moderate	Category high
BOD	mg/l	< 3.0	3.0 – 5.0	> 5.0
Oxidised nitrogen (0 – 20 psu)	mg N/l	< 1.0	1.0 – 3.0	> 3.0
Oxidised nitrogen (> 20 psu)	mg N/l	< 0.2	0.2 – 1.0	> 1.0
Orthophosphate	mg P/l	< 0.05	0.05 – 0.15	> 0.15
Total ammonia	mg N/l	< 0.2	0.2 – 1.0	> 1.0
Un-ionised ammonia	mg NH_3/l	< 0.02	0.02 – 0.05	> 0.05
Chlorophyll a	mg/m^3	< 10	10 – 25	> 25
Dissolved oxygen	% saturation	< 70	70 – 110*	> 110

* the 'moderate'category denotes the normal concentration range for dissolved oxygen.

Sea Stacks