The Centre for Environment, Fisheries & Aquaculture Science

Monitoring and surveillance of non-radioactive contaminants in the aquatic environment and activities regulating the disposal of wastes at sea, 1995 and 1996

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Number 51

Monitoring and surveillance of non-radioactive contaminants in the aquatic environment and activities regulating the disposal of wastes at sea, 1995 and 1996

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This report has been compiled by J. Jones, B.Sc. and A. Franklin, B.Sc. of the CEFAS Burnham Laboratory, Burnham-on-Crouch, Essex, CM0 8HA, from whom further copies can be obtained.

Staff responsible for the projects described in this report are listed in Annex 1.

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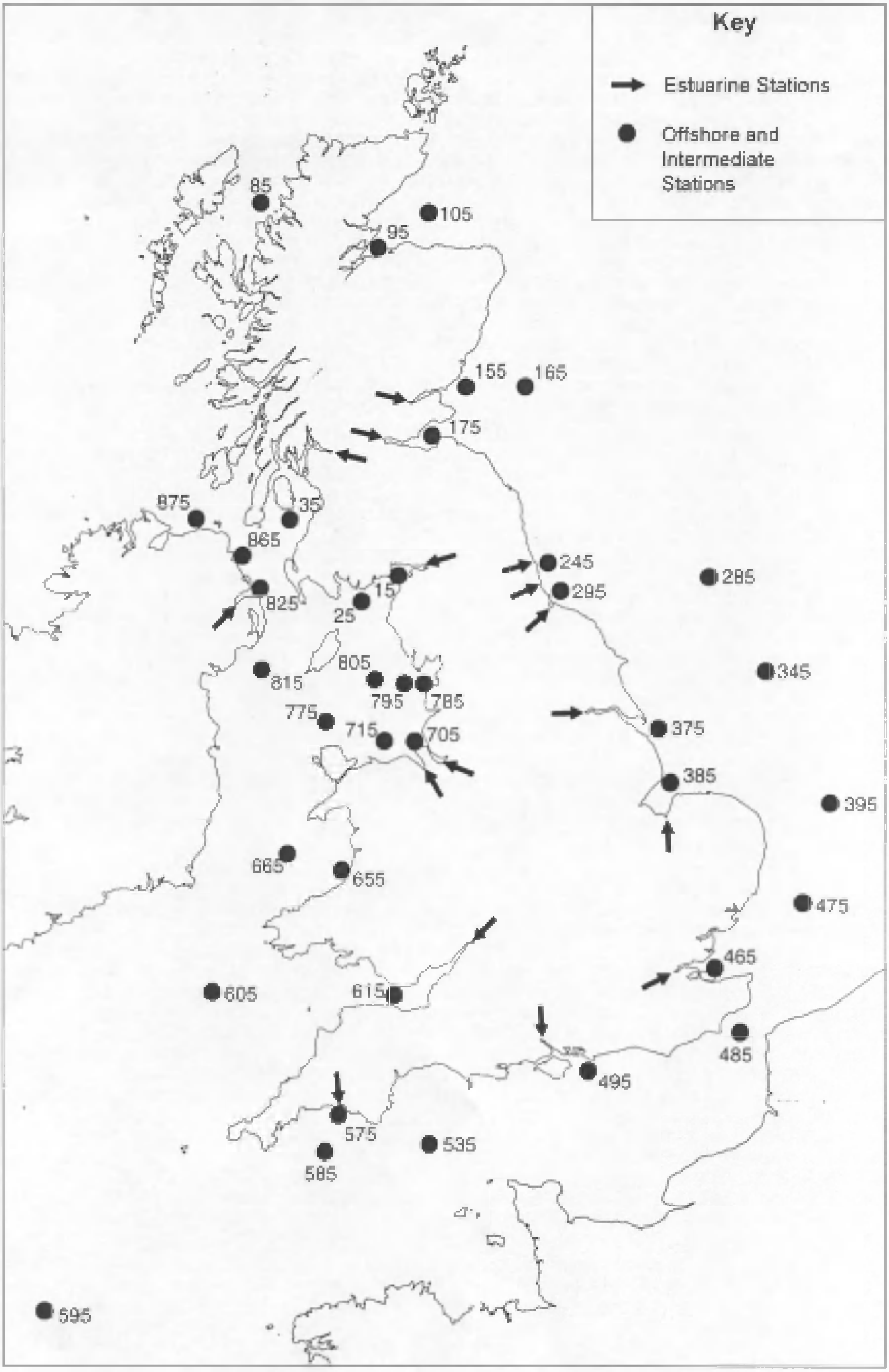


Figure 1. NMP Sampling Station Positions

FOREWORD

This is the eighth report in the MAFF/CEFAS series of publications on 'Monitoring and surveillance of non-radioactive contaminants in the aquatic environment'. The report describes work carried out, mainly by staff of the CEFAS, Burnham Laboratory, in 1995 and 1996. The majority of the sections of the report deal with work undertaken as part of the UK National Monitoring Programme (NMP) established by The Marine Pollution Monitoring Management Group (MPMMG).

The Marine Pollution Monitoring Management Group has representation from all Government organisations with statutory obligations for marine environmental protection. One of the main aims of the Group is to ensure that monitoring of the marine environment meets national and international requirements and is conducted in a co-ordinated, cost effective manner.

In 1987/88, the MPMMG reviewed the monitoring carried out in UK estuaries and coastal waters (Department of the Environment, 1991) and concluded that there would be considerable merit in the regular sampling of a network of coastal monitoring stations. Following Government agreement, around 90 such stations (Figure 1) were established in the early 1990s as the UK National Monitoring Plan – subsequently termed on execution, the UK National Monitoring Programme. Full details of the aims and strategy of the NMP are given in MPMMG, 1994.

The first objective of the NMP was to establish the spatial distribution of contaminants and current biological status of the different areas of UK waters represented by NMP stations. Monitoring for this purpose was undertaken principally between 1993 and 1995, by the relevant authorities in Scotland, Northern Ireland and England and Wales. An overall UK NMP report on the spatial survey is currently in production. Sections 1 to 15 of the present CEFAS report describe in more detail the NMP monitoring carried out by CEFAS around the coast of England and Wales.

In addition to describing the NMP work, this report includes information on investigative work on contaminants in marine mammals (Section 16 and 17) and examples of assessment studies at dredged material disposal sites (Sections 18, 19 and 20). Also included, as with earlier reports in the series, are details of the licensing of deposits in the sea during 1995 and 1996, under Part II of the Food and Environment Protection Act (1985) (Section 21) and a summary of activities carried out in 1995/96 in connection with the provision of advice on fishery implications of pipeline discharges (Section 22).

Dr Mike Waldock
Chairman of the Environment Group
CEFAS, Burnham Laboratory

UK NATIONAL MONITORING PROGRAMME

1. DISSOLVED TRACE METALS IN SEA WATER

1.1 Introduction

The aims of the initial spatial survey of the National Monitoring Programme were to describe geographical variations in contaminant concentrations and to identify any areas of 'special concern' because of high contaminant concentrations. The first stage will also provide a baseline for future trend studies in areas of concern, and in (relatively) uncontaminated areas, where the extent of natural variability may be estimated.

1.2 Methods

Of the dissolved metals analysed for in this programme, Cd, Cu, Ni, Pb and Zn were extracted using a mixed dithiocarbamate complexing agent into Freon TF, and back extracted into dilute nitric acid. The final extract was analysed by Graphite Furnace Atomic Absorption Spectrometry or Inductively Coupled Plasma-Mass Spectrometry.

Total dissolved Hg was analysed by atomic fluorescence after breaking down any Hg containing colloidal material with acidified brominating solution. The dissolved Hg was then reduced to mercury vapour with tin II chloride solution. The vapour was dried then swept into the fluorescence analyser for quantification.

Great care was taken to minimise the possibility of contamination during all stages of sampling, filtration, extraction and analysis.

1.3 Completeness of the sampling and analytical programme

For intermediate and offshore stations, a sampling frequency of once per year was required. Dissolved Cd, Cu, Ni, Pb and Zn were sampled at most stations during the period between 1991 and 1995. Mercury was sampled in 1991 and 1996 only. No results were obtained for dissolved Cr as a suitable method has yet to be developed. In most cases, detection limits were satisfactory. For Hg, however, environmental concentrations were frequently below the detection limit of 5 ng l^{-1} obtained in 1996. Such low concentrations are confirmed by the 1991 data, and in recent publications (Table 1).

Table 1. Concentrations of total dissolved Hg in UK coastal waters

Total dissolved Hg (ng l^{-1})	Area	Reference
0.18 - 0.96	North Sea	Coquery and Cossa (1995)
0.1 - 1.3	English Channel	Cossa *et al.* (1994)
0.3 - 0.5	English Channel	Cossa and Fileman (1991)
1.7 - 14	Mouth of Humber	Fileman (1987)
1.2 - 2.8	Mouth of Tees	Fileman (1987)
0.61 - 2.6	Mouth of Tyne	Fileman (1987)
0.19 - 0.42	Central North Sea (Dogger Bank)	Fileman *et al.* (1991)

Since so much of the Hg data presented here were below detection limits, the Hg results are not discussed any further.

1.4 Results

Since the first aim of the NMP was to identify any spatial variations in analyte concentrations, the stations were divided up into geochemically consistent areas, approximating to various water masses around the coast. Salinity and suspended particulate matter (SPM) distributions were therefore used as indicators of these water masses. Figure 2 shows these two parameters plotted against NMP station numbers in consecutive order - namely clockwise around the UK coast.

The North Sea stations are all of relatively high salinity. The SPM distribution however, indicates that the North Sea can be divided into two regions. Stations 245 to 345 are much less turbid than Stations from 375 to 475. The increased turbidity of the southern North Sea results from increased resuspension of the shallower bottom sediments here. Furthermore, the anticlockwise water circulation pattern within the North Sea causes the southern region to receive the run-off from the major English east coast estuaries. The less turbid North Atlantic water, flowing in from the north of Scotland, has a large influence on the northern North Sea. It is interesting to note that the division described here approximates to the position of the Flambrough front.

The English Channel stations are generally of higher salinity than either the North Sea or Irish Sea stations. The English Channel also has low SPM loadings, since it is little influenced by major riverine-transported particulate material. The division between the North

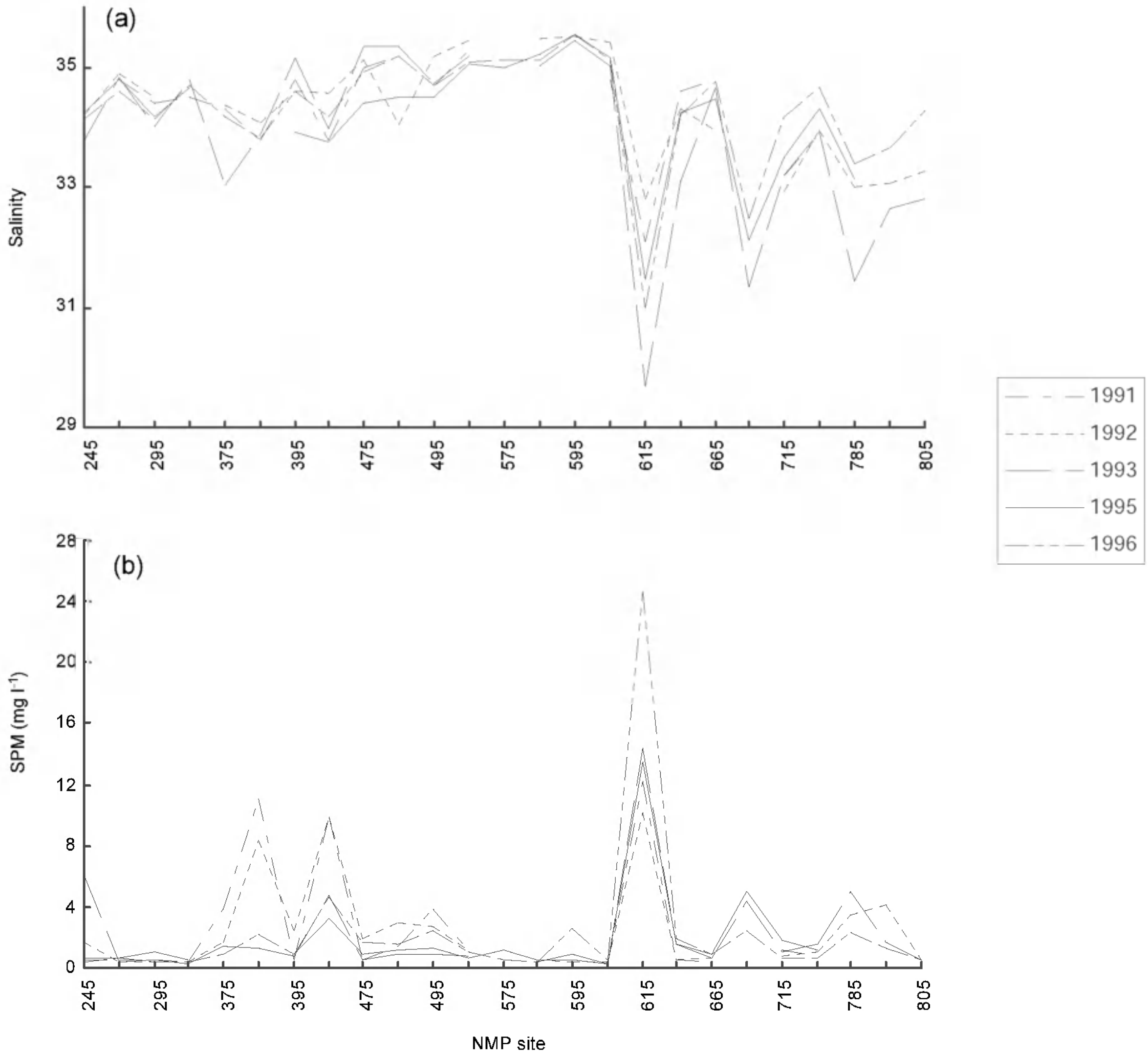


Figure 2. Distributions of (a) salinity and (b) SPM at NMP intermediate and offshore sites

Sea and the English Channel was made between Station 475 and 485, where the salinity starts to rise convincingly. From both salinity and SPM distributions, however, Station 475 could equally be considered an extension of English Channel water.

There is a clear break between the high salinity, low turbidity of the English Channel water and the lower salinity, higher turbidity water of the Irish Sea. This break occurs between Stations 605 and 615. Station 615 is Nash Point in the Severn Estuary. This is the station of lowest salinity and highest turbidity and can be described as the most estuarine of the intermediate/offshore stations described here. It is included with the Irish Sea stations, since these are also influenced by coastal run-off of low salinity, e.g. from the Mersey Estuary. The Irish Sea SPM distribution is more or less a mirror image of the salinity distribution. This is because the high energy regime of estuaries keeps sediment in suspension and because estuaries are important sources of weathered material to the oceans.

The divisions resulting from the above analysis are shown in Figure 3, along with the median suspended particulate matter (SPM) loadings observed at each station.

To give a general overview of the results, median values of all the data in each geographical area are plotted in Figure 4. Medians were used, since the data were not normally distributed. The following observations can be made from these histograms.

- Concentrations in the Irish Sea are generally greater than concentrations in the English Channel.
- Concentrations in the North Sea are generally greater than or equal to concentrations in the English Channel.
- For elements other than Pb, concentrations in the southern North Sea are greater than concentrations in the northern North Sea. The converse is true for Pb.

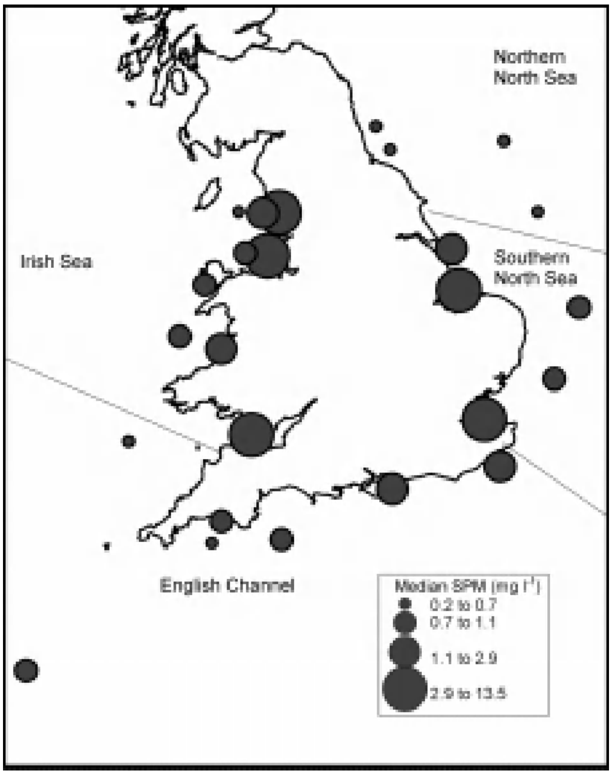


Figure 3. Map showing the divisions of NMP sites for geographical comparison, together with median SPM concentrations (mg l^{-1}) at each site for the five years sampled

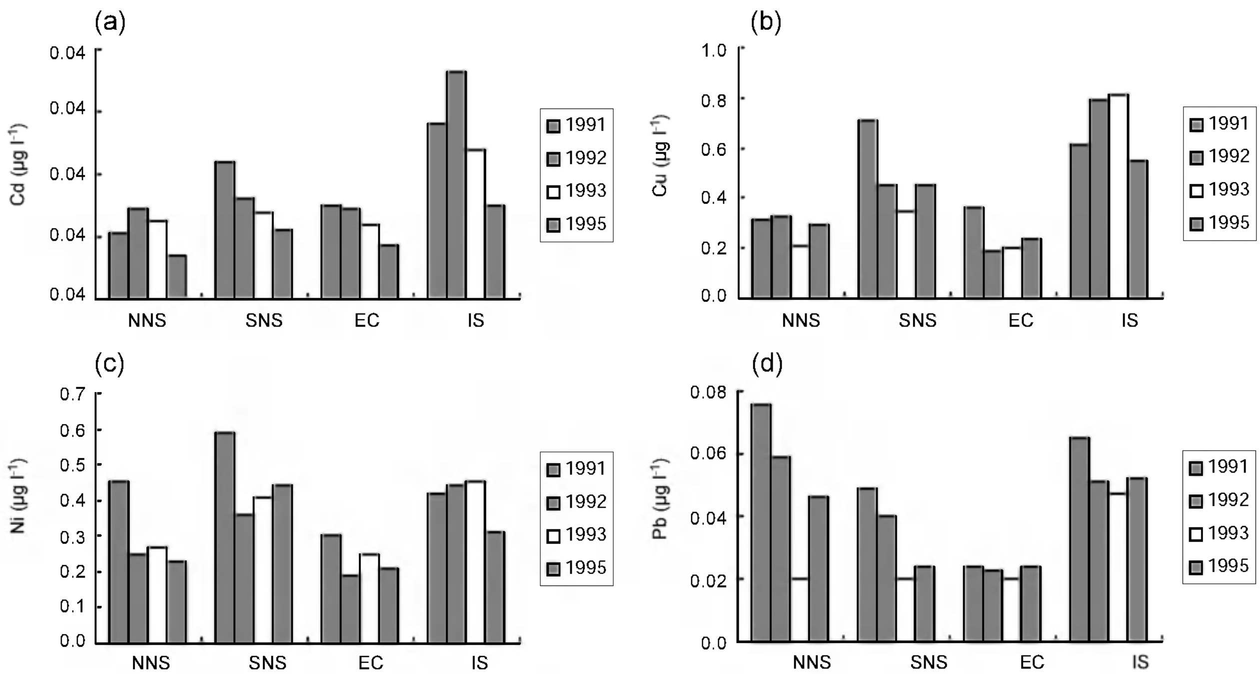
- There is no consistent trend in median concentrations throughout the six year period.

Since there is no consistent annual variation in metal concentrations, the data can be represented by plotting median concentrations at each site. Dissolved Cd, Cu, Ni, Pb and Zn are presented in this way in Figures 5-9 respectively.

1.5 Discussion

Concentrations in the Irish Sea are generally greater than concentrations in the English Channel.

To explain some of the geographical variations, salinity can be used as an indicator of how much coastal waters are influenced by fresh water inputs of metals. Figure 10 shows the median salinity values at each of the NMP stations over the six years sampled. It is very clear from this diagram that some of the lowest salinities occur in the Irish Sea region. These coincide with some of the high values of metals in this region, e.g. for Cu, Figure 6.



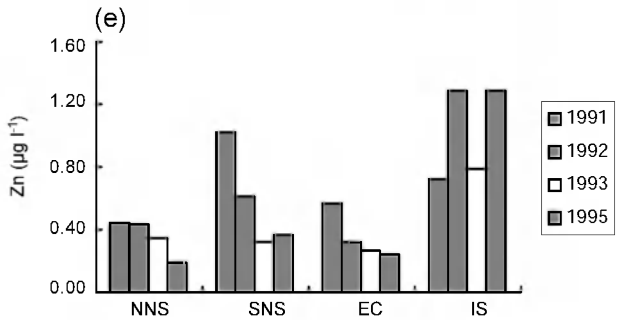


Figure 4. Histograms of median metal concentrations (µg l^{-1}) in each geographical area.
(a) cadmium, (b) copper, (c) nickel, (d) lead and (e) zinc

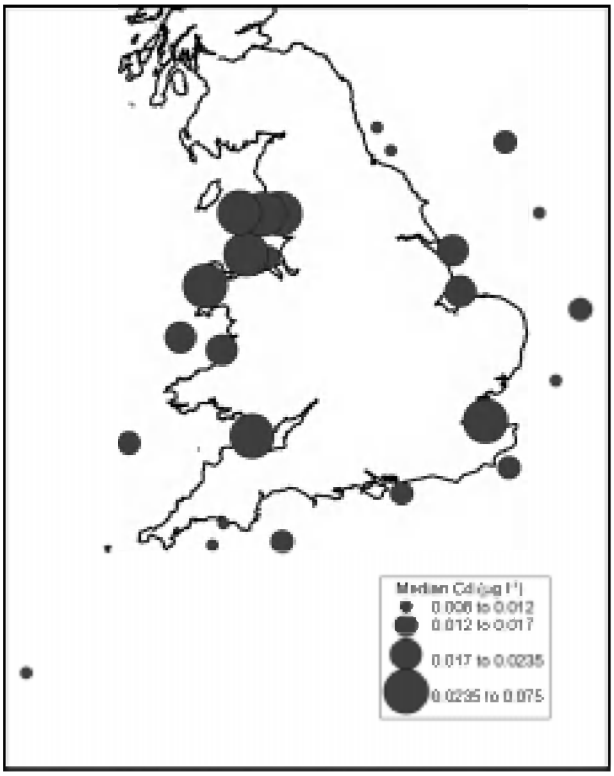


Figure 5. Median dissolved Cd concentrations ($\mu g\ l^{-1}$) at each site

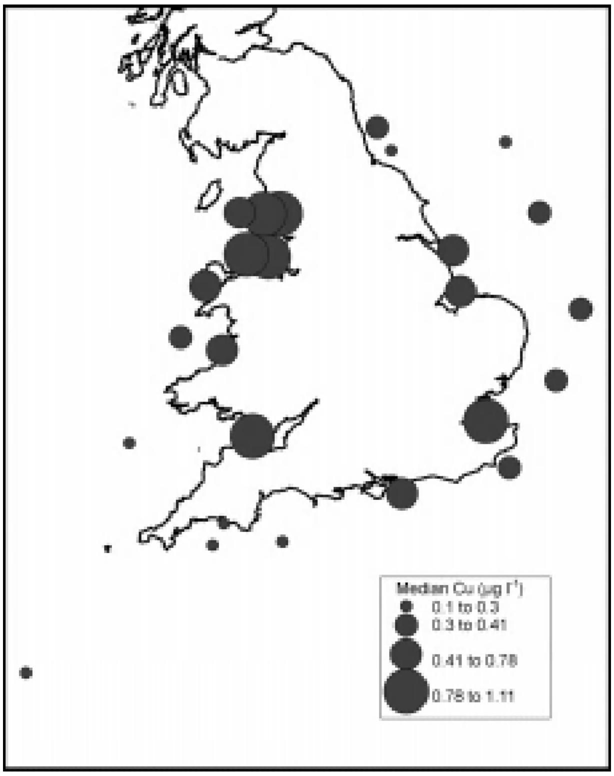


Figure 6. Median dissolved Cu concentrations ($\mu g\ l^{-1}$) at each site

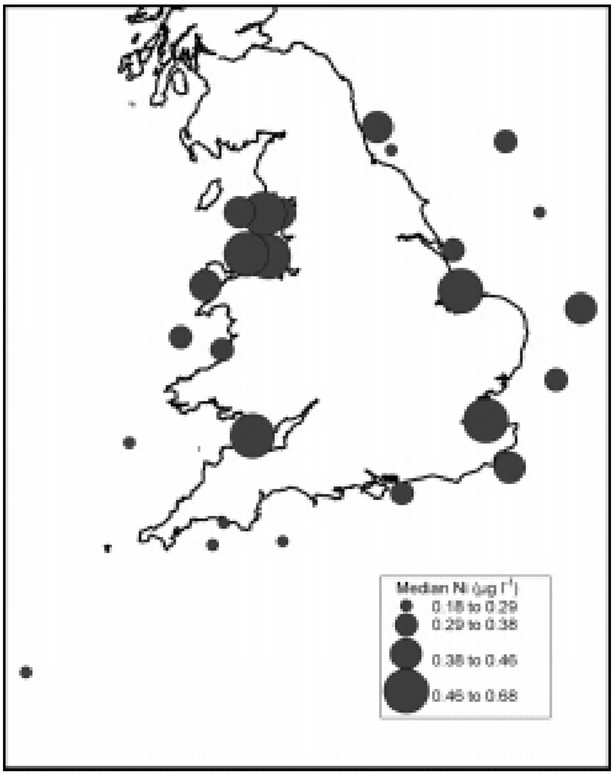


Figure 7. Median dissolved Ni concentrations ($\mu g\ l^{-1}$) at each site

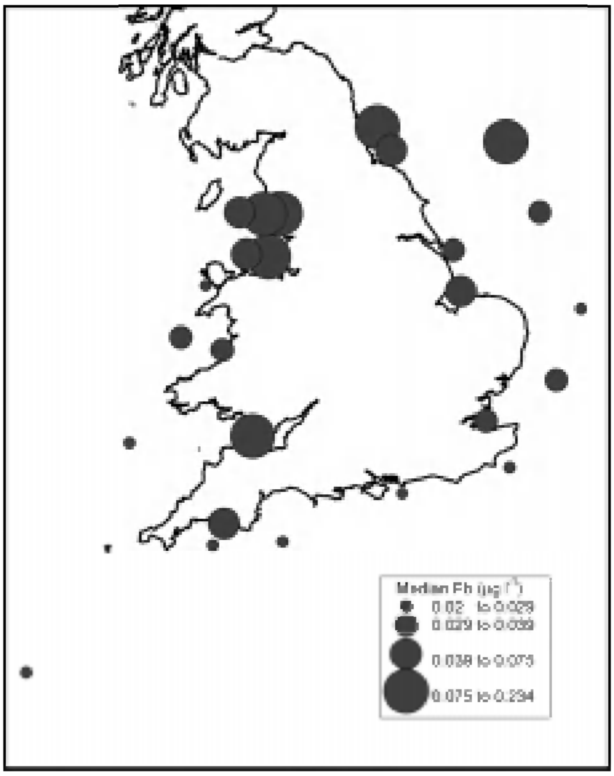


Figure 8. Median dissolved Pb concentrations ($\mu g\ l^{-1}$) at each site

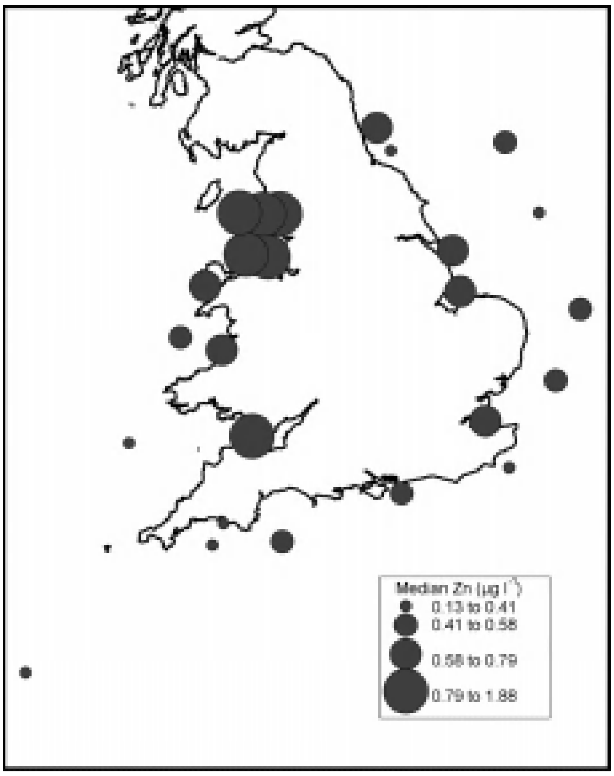


Figure 9. Median dissolved Zn concentrations (µg l^{-1}) at each site

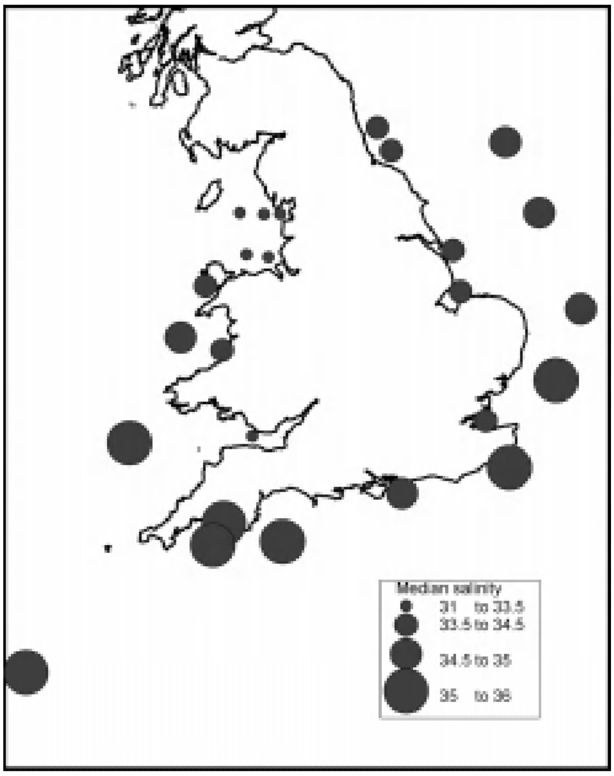


Figure 10. Median salinity values at each site

Further evidence for the importance of fresh water sources to the Irish Sea is obtained by considering plots of dissolved metal concentration vs. salinity for these stations. The salinity range of the Irish Sea stations was greatest in 1993, so data from this year were used (Figure 11). The three western stations in the English Channel region were also plotted to provide a clear end-member concentration at high salinity.

Figure 11 shows that for all five metals, higher dissolved concentrations generally occur in waters of lower salinity. This is evidence that the contamination is derived from land-based sources.

For a simple estuarine system with two end members, a straight contaminant/salinity plot indicates that concentrations within the mixing zone are conservative, i.e. they are a result only of the physical mixing of the waters of higher salinity with waters of lower salinity. The Irish Sea is not such a simple system however, partly because there are various sources of fresh water into the region. Despite this, the plots for dissolved Cu, Ni and Zn against salinity approximate to conservative mixing. For Cu and Ni, the low salinity end-members in both the Severn Estuary (marked by S on the plot) and the Mersey Estuary (marked by M) fortuitously lie on the same metal concentration/salinity line. Both estuaries are therefore contaminated with Cu and Ni with respect to the Irish Sea. Where dissolved contaminant/salinity plots are not clear straight lines, as is the case for Cd, factors other than pure physical mixing between the two end member waters are important. These would include additional sources of the dissolved metal in the region, or removal of the metal from the dissolved phase.

Concentrations in the North Sea are generally greater than or equal to concentrations in the English Channel.

As has previously been mentioned, the North Sea can be considered a mixing zone between run-off from land based sources, and North Atlantic water entering from the north of Scotland and via the English Channel. It is therefore not surprising that contaminant concentrations in the North Sea are generally higher than those in the English Channel (e.g. for Ni, Figure 7).

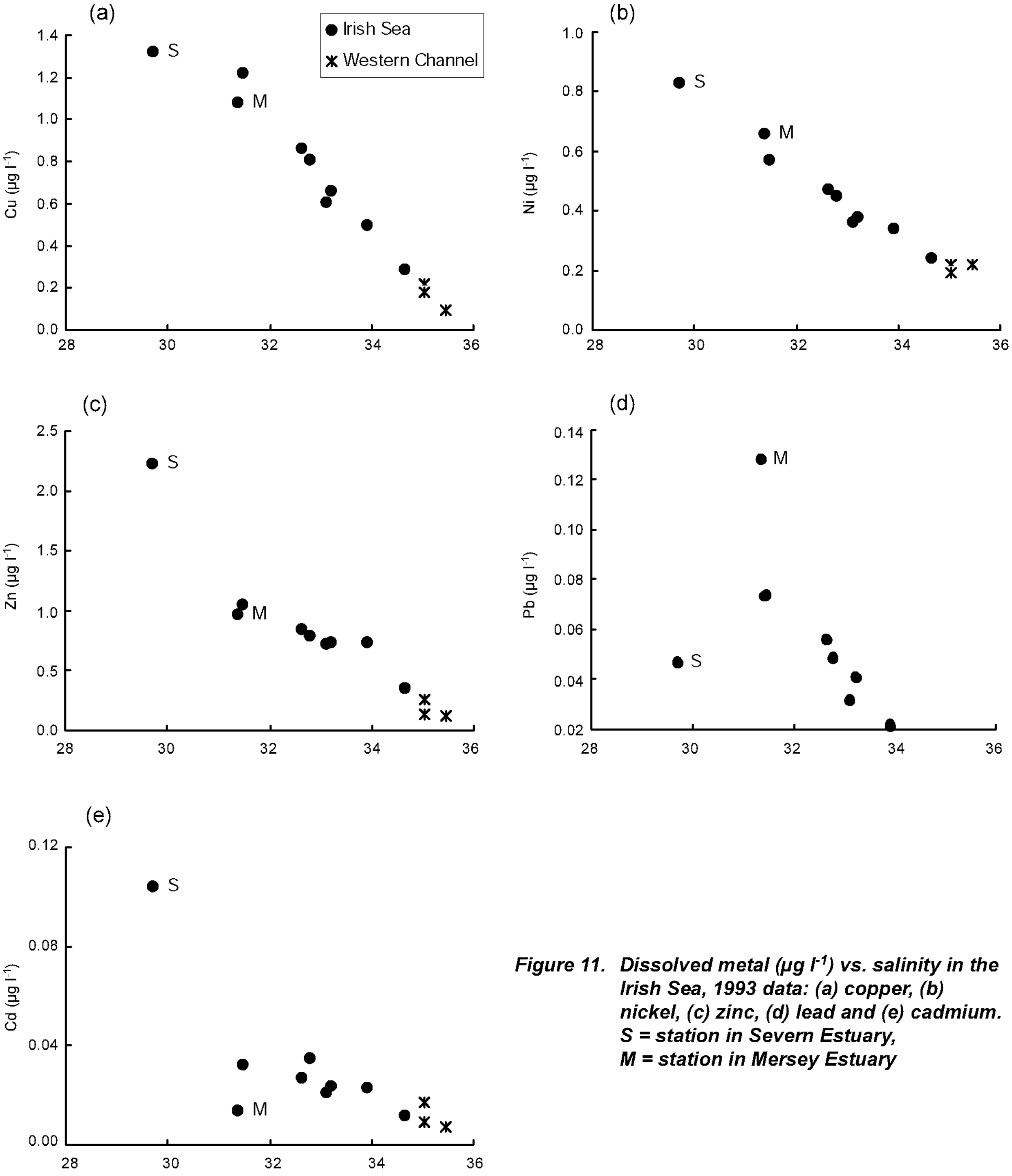


Figure 11. Dissolved metal (µg l^{-1}) vs. salinity in the Irish Sea, 1993 data: (a) copper, (b) nickel, (c) zinc, (d) lead and (e) cadmium. S = station in Severn Estuary, M = station in Mersey Estuary

For elements other than lead, concentrations in the southern North Sea are greater than concentrations in the northern North Sea. The converse is true for Pb. Water circulation patterns can also explain why riverine run-off from eastern Britain is mainly carried into the southern North Sea. For this reason, most dissolved metals (other than Pb) are more concentrated in the southern North Sea than in the northern North Sea (e.g. for Cd, Figure 5).

Lead, however, is the most particle reactive of these elements. In turbid estuaries, like those on the east coast of England, dissolved Pb is quickly removed onto the surfaces of suspended particulate matter. Meanwhile, the suspended particles become trapped in the estuarine/ coastal zone by hydrodynamic processes. Therefore, unlike the less particle reactive elements (Cd, Cu, Ni and Zn), Pb is not transported in dissolved phase to the southern North Sea by coastal circulation patterns.

Since Pb from estuarine sources tends to be trapped in nearshore areas, atmospheric inputs of Pb become increasingly important away from the coast. Concentration variations between the offshore northern North Sea and southern North Sea regions can be explained by differing removal rates of dissolved Pb from the water column. These, in turn, depend on the SPM loadings in each region. The lower dissolved Pb concentrations in the southern North Sea are therefore a consequence of the greater SPM loadings in this region.

Elevated concentrations of both dissolved and suspended particulate Pb have previously been reported in the Dogger Bank region of the northern North Sea (Laslett, 1995). Again, higher dissolved concentrations were explained by reduced removal of Pb by the lower concentrations of SPM here. Meanwhile, higher suspended particulate Pb concentrations resulted from a reduced 'dilution effect' of SPM on particulate Pb contents. A separate study has reported that the fine fraction of Dogger Bank bottom sediment had higher Pb concentrations than the equivalent fraction of coastal sediments from the eastern North Sea (Kersten and Kroncke, 1991). Taken together, these findings demonstrate the importance of SPM loadings on controlling Pb concentrations in the water, SPM and bottom sediments of offshore areas.

1.6 Conclusions and recommendations

Geographical variations in dissolved metal concentrations were observed in the intermediate and offshore stations sampled. These variations can be attributed to (a) freshwater inputs (b) water circulation patterns and (c) removal from the water column by suspended particulate matter.

No areas of concern were identified among the stations sampled here. It is anticipated that for dissolved metals, areas of concern will be among the estuarine sites, nearest the sources of contamination and anthropogenic discharges.

The Dogger Bank region is particularly interesting. Low SPM loadings reduce the removal of dissolved Pb from the water column here, so that both dissolved and suspended particulate Pb concentrations are higher here than in the rest of the North Sea. Consequently, the fine fraction of the bottom sediments at the Dogger Bank is more contaminated than the same fraction on the eastern North Sea coast (Kersten and Kroncke, 1991). Although not an 'area of concern' therefore, the Dogger Bank may be chosen for further monitoring. If so, it is recommended that the grid of stations is increased around this region for comparison sake. Other than this, the sampling grid seems adequate for the sort of geographical comparison described in this report.

The data set presented here did not lend itself to statistical analysis, since there was no measure of variability at the same site within each year. If statistical analysis is required in the future, it is recommended that more data are collected at, or close to, each station within the same year. The degree of replication required should be chosen after consulting statisticians.

No consistent obvious trends were observed for any of the dissolved metals within the sampling period. Even if anthropogenic inputs of trace metals were changing, any trend would be unlikely to be observed in the dissolved phase over the period described. There are two reasons for this. Firstly, the residence times at intermediate and offshore areas, for example, of the North Seas, are of the order of several years (Backhaus, 1984) so any changes occurring over time scales of a year or so would not be observed. Secondly, the efficient removal of dissolved trace metals onto suspended particulate matter is likely to mask any change that would otherwise be observed in the dissolved phase. It is therefore recommended that dissolved trace metal concentrations are not used for trend studies. It is also recommended that the frequency of sampling be reduced for intermediate and offshore stations. One thorough survey over a period of, say, five years should suffice for monitoring purposes.

As previously mentioned, there are gaps in the data set for dissolved Cr and Hg. It is recommended that these are filled. It is also recommended that methods are developed further for speciation information to be obtained for Cr and Hg, since not all forms of these elements are equally toxic. Since the dissolved phase is unlikely to be useful for trend monitoring, it is recommended that the metal contents of suspended particulate matter are monitored.

2. ORGANIC CONTAMINANTS IN SEA WATER

2.1 Introduction

Sampling, using NMP guidelines, was conducted at a total of twenty-nine NMP stations during three research cruises, *RV CIROLANA* Cruise 6/93, 9 June-1 July 1993, *RV CIROLANA* Cruise 7/94, 10 June-1 July 1994, and *RV CIROLANA* Cruise 6a/96, 10-28 June 1996. Unfiltered water samples were analysed for α- and γ-hexachlorocyclohexane (HCH) and the triazine herbicides simazine and atrazine. Salinity data was also recorded.

2.2 Methods

Analytical methods have been described elsewhere, in brief the HCH residues were determined by gas chromatography-electron capture detector (GC-ECD) after extraction of the sample with n-hexane and clean-up over partially deactivated alumina. Triazine herbicide residues were determined by gas chromatography-mass spectometry (GC-MS) after extraction of the pH adjusted sample into dichloromethane and then clean-up on partially deactivated alumina. The Burnham Laboratory took part in the National Marine Analytical Quality Control Scheme (NMAQC) intercalibration exercises during the course of this work however, because of the seasonality of sampling, these exercises did not coincide with the analysis of the real samples. Certified reference samples for sea water analysis do not exist, additional quality control was conducted in-house on the basis of spiked replicates and duplicate analysis which indicated the analytical method was in control.

2.3 Results

Results are presented in Table 2 and Figures 12-15.

Alpha HCH was detected in all samples although often close to the limit of detection. Typically, results were less than 1 ng l^{-1} (Figure 12). Higher values were detected in samples from the Tyne, Tees and Mersey estuaries. The profile from the Mersey area samples indicated the presence of a number of methyl hexachlorocyclohexanes which have a known local input.

Gamma HCH was also readily detected at all sites at concentrations often significantly higher than the α-form (Figure 13). The insecticidally active γ–HCH (Lindane) is expected to be the major input of HCH to the marine environment and has a higher water solubility than the α-form and is therefore expected to be present at higher concentrations. The pattern of distribution was similar to that of α-HCH with higher

Table 2. Trace organics (ng l^{-1}) in sea water

NMP Station	Estuary/Location	Site	Type	*CIROLANA* Cruise	α–HCH	γ–HCH	Simazine	Atrazine	Salinity (ppt)
225	Tyne	Hebburn	E	6/93	0.12	0.76	6.1	10.1	21
235	Tyne	Lloyds Hailing Station	E	6/93	0.15	1.5	5.2	13.6	24
245	Off Tyne	NSTF14	I	6/93	0.15	0.28	0.49	0.44	34.4
				7/94	0.24	0.42			34.05
265	Wear	Alexandra Bridge	E	6/93	0.14	3.8	1.7	6.5	NR
275	Wear	Sandy Point	E	6/93	0.12	2	4.5	26.9	NR
				7/94	1.5	6.7			NR
285	Off Tyne/Tees	NSTF43	O	6/93	0.15	0.33	0.46	0.33	34.3
				7/94	2	4.8			34.72
295	Off Tees	NSTF15	I	6/93	0.18	0.31	0.4	0.4	33.4
				7/94	1.9	3.1			34.14
315	Tees	Victoria Bridge	E	6/93	0.16	3.4			1.8
325	Tees	The Gares	E	6/93	0.15	1.9	11.5	18.7	NR
375	Humber	NSTF16 (JONUS OSP2)	I	6/93	0.19	0.79	0.84	0.85	32.4
385	Wash	NSTF17 (JONUS OSP6)	I	6/93	0.16	1.2	1.1	0.9	33.1
395	Southern Bight	Smiths Knoll	O	6/93	0.12	0.94	0.4	0.48	34.4
				7/94	1.6	8.8			34.2
455	Thames	Mucking	E	6/93	0.14	1.9	3.2	3.5	NR
465	Thames	Warp	I	7/94	1.2	14			33.95
				6/96	0.1	1.4			34.13
475	Thames	Gabbard	O	7/94	0.93	9.9			34.58
485	South Varne	NSTF 69	O	6/93	0.1	0.6	0.42	1	34.5
				7/94	1.7	16			34.93
				6/96	0.1	1.2			35.14
495	Selsey Bill	NSTF70	I	7/94	0.13	1.8	0.41	0.57	34
495	Selsey Bill	NSTF70	I	6/93	0.16	1.3	1.3	2.7	34.5
535	Central Channel	NSTF72	O	6/93	0.1	0.43	1.2	2.8	34.5
				7/94	0.91	5.4			34.5
575	Off Tamar		I	6/93	0.11	0.64			34.3
585	Off Plymouth Sound	NSTF73	O	6/93	0.14	0.28			34.3
705	Liverpool Bay	Burbo Bight	I	7/94	1.6	8.2			32.5
				7/94	1.7	9.3			31.99
				6/96	0.17	1.3			32.46
715	Liverpool Bay		O	7/94	1.3	5			33.88
745	Mersey	Brombrough E1 Buoy	E	7/94	1.9	18			22.96
755	Mersey	Seacombe Ferry	E	7/94	2.5	14			31.16
				7/94	2.5	30			31.16
				6/96	0.21	2.5			28.19
765	Mersey	Mersey Chnl C1 Buoy	E	7/94	1.7	11			31.14
775	Irish Sea		O	7/94	1.6	5.2			34.24
795	Off Morcambe Bay		O	7/94	2	7.9			31.1
805	SE Isle of Man		O	7/94	1.4	5			33.6

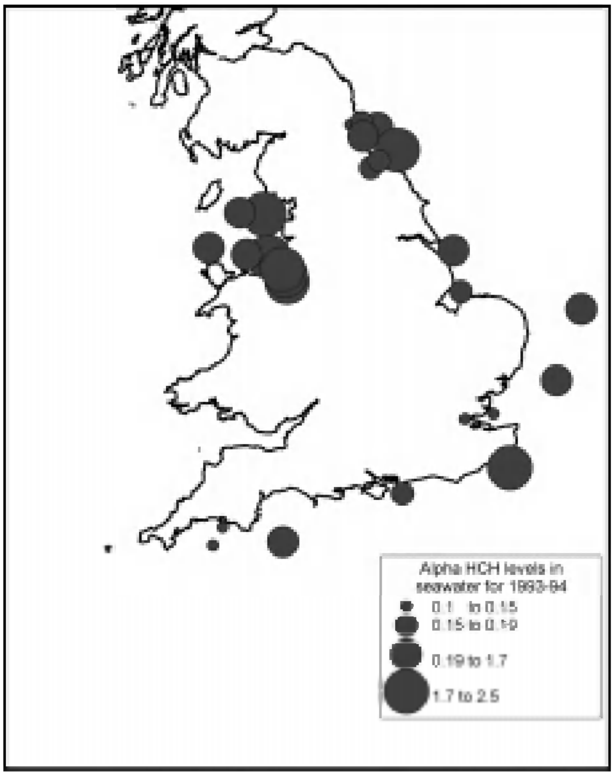


Figure 12. Concentrations of α-HCH (ng l^{-1}) in sea water

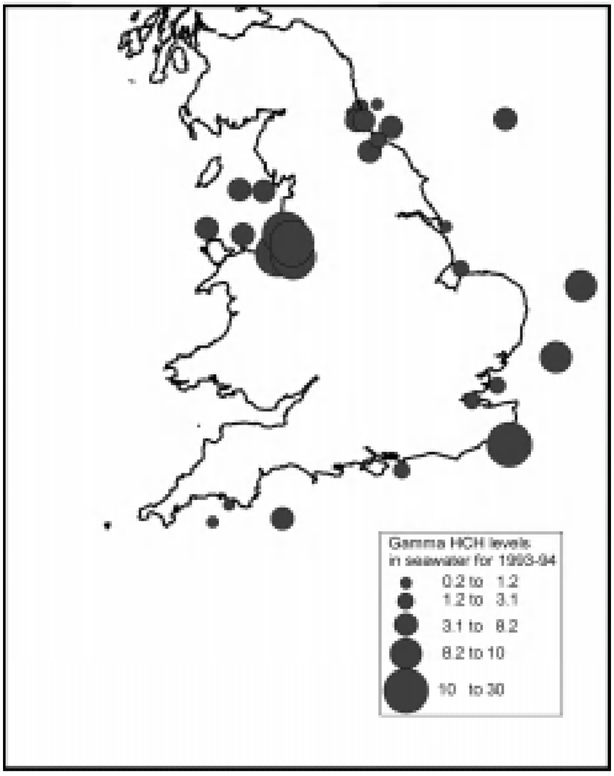


Figure 13. Concentrations of γ-HCH (ng l^{-1}) in sea water

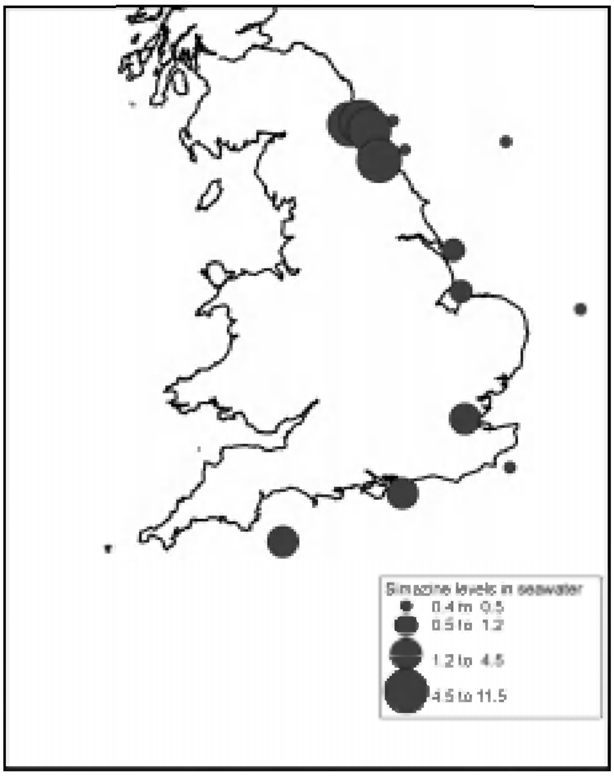


Figure 14. Concentrations of simazine (ng l^{-1}) in sea water

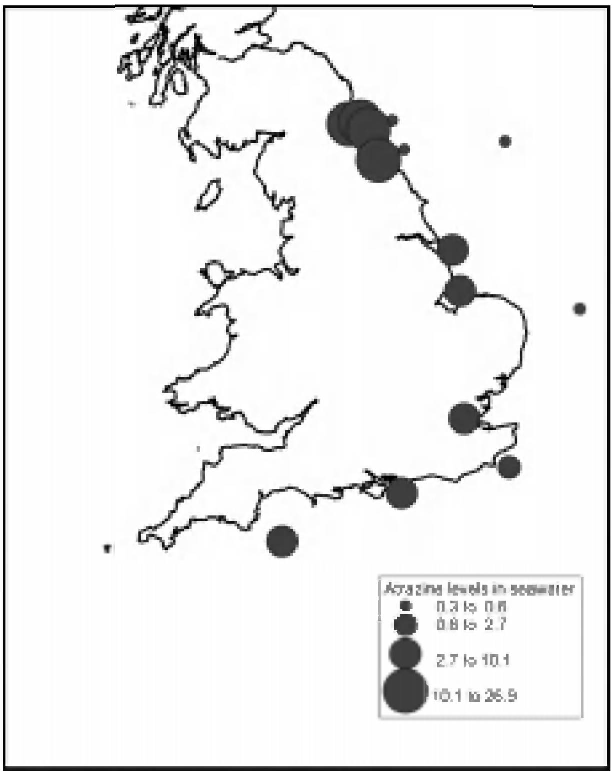


Figure 15. Concentrations of atrazine (ng l^{-1}) in sea water

concentrations in the Tees, Tyne and Mersey areas. The Mersey estuarine sites produced the highest values for γ-HCH with values up to 30 ng l^{-1}. These concentrations however, generally declined offshore.

Simazine (Figure 14) and atrazine (Figure 15) were readily detected at estuarine and inshore stations with the Wear, Humber, Tees and Tyne stations producing the highest values, up to 27 ng l^{-1} for atrazine in one sample from the Wear and 6 ng l^{-1} for simazine from the Tyne.

2.4 Discussion

The current NMP calls for the determination of trace organics in samples of unfiltered sea water. However, variable amounts of suspended particulate material are present in most samples and this is a particular problem from a technical viewpoint at a number of estuarine and inshore stations. The NMAQC sea water samples were generally distributed as filtered sea water samples, primarily to ensure homogeneity of samples. There appears to be an assumption that liquid-liquid extraction techniques will extract all the 'dissolved' fraction and possibly some of the 'total' fraction associated with suspended particulate material. The use of solid phase extraction procedures may well be very ineffective at extracting any of the organic fraction associated with suspended particulate material. If sea water sampling is to continue as part of the NMP then the effect of suspended particulate material on the efficacy of various extraction techniques will need to be more thoroughly characterised, or, consideration be given to the use of filtered sea water samples and the determination of trace organics in separate fractions.

Although residues of α- and γ-HCH and simazine and atrazine can be found at most sites the concentrations are generally low and generally decrease offshore. There would seem to be little justification for continuing to measure these compounds in sea water at intermediate and offshore sites. Determination of trace levels of organics in sea water is a demanding analysis and the effort maybe be more effectively deployed elsewhere on other aspects of the NMP. However, given that the higher and variable concentrations are most often found at estuarine sites there may be some justification for continuing to monitor a number of these sites.

3. PAH IN SEA WATER

3.1 Introduction

Polycyclic aromatic hydrocarbons (PAH) are ubiquitous environmental contaminants. Although they can be formed naturally (e.g. in forest fires), their predominant source is anthropogenic emissions and the highest concentrations of PAH are generally found around urban centres (Meador *et al.,* 1995). Their widespread occurrence results largely from formation and release during the incomplete combustion of coal, oil, petrol and wood (Jacob, 1995), but they are also components of petroleum and its products. PAH reach the marine environment via sewage discharges, surface run-off, industrial discharges, oil spillages and deposition from the atmosphere. The lower molecular weight PAH can be acutely toxic to aquatic organisms, but the major concern is that some PAH form carcinogenically-active metabolites (benzo[*a*]pyrene is the prime example) and PAH concentrations in sediments have been linked with liver neoplasms and other abnormalities in bottom-dwelling fish (Malins *et al.,* 1988; Vethaak and ap Rheinallt, 1992). Elevated PAH concentrations may therefore present a risk to aquatic organisms and potentially also to human consumers of fish and shellfish.

3.2 Methods

The methodology used is described in detail elsewhere (Law *et al.,* 1997(a)), but briefly involved liquid-liquid extraction (following filtration in the case of dissolved data), clean-up by automated solid-phase extraction, and analysis by HPLC with programmed fluorescence detection.

3.3 Analytical Quality Control

No certified reference materials (CRMs) are available for PAH in sea water. Quantification was by means of an internal (surrogate) standard (anthracene-d_{10}) added prior to extraction, and procedural blanks and spiked samples were run alongside each batch of samples. PAH were not a class of determinands included in the programme operated under the NMAQC scheme, and so no proficiency testing data are available.

3.4 Programme

PAH were listed within the initial phase of the NMP programme as additional determinands for which special restricted surveys should be undertaken in order to assess the need for their inclusion in wider scale studies. The NMP document suggests that analyses are undertaken in sediments, shellfish and fish muscle. Concentrations in fish muscle are generally low, however, as fish possess an effective enzyme system for metabolising PAH, and such analyses can generally only be recommended for food assurance purposes (Law and Biscaya, 1994). Recent analyses have also shown low concentrations in wild fish muscle in a variety of species taken from south-west Wales even after the *SEA EMPRESS* oilspill which released over 70,000 tonnes of crude oil (Law *et al.,* 1997(b)). This matrix does not therefore seem appropriate either for a nationwide spatial survey or for temporal trend monitoring. Shellfish are preferred, especially molluscs such as mussels which are frequently used as sessile bioindicators, and are of importance for human consumption. The majority of current NMP stations do not however support populations of mussels, or indeed other bivalve molluscs which could be substituted. An alternative network of sites should, however, be developed for this purpose.

Since 1993, analyses were undertaken in sediments and sea water alongside the routine NMP monitoring, and the sea water data are summarised here. In all, 172 samples of unfiltered water were analysed (Table 3), 78 of these from NMP sites. Samples were collected from 45 of the 60 offshore, intermediate and estuarine stations around England and Wales. Sixty-three samples were also analysed after filtration (Table 4), 24 of these from NMP stations.

The NMP protocol for special surveys also requires that initial studies should take place at sites believed to represent 'worst case' areas. Samples were therefore also collected from additional stations not defined under the NMP, some of which were selected as reference sites (e.g. the River Tweed) and others within heavily industrialised estuaries (e.g. the Rivers Tyne and Tees).

3.5 Results

The 10 PAH compounds for which data were considered within this assessment are a subset of those determined, and the full data are presented elsewhere (Law *et al.,* 1997(a)). PAH concentrations at offshore sites were generally low or undetectable. Of the 39 samples taken at offshore locations (10 miles or more from the coast) only one (NMP Station 245, off the River Tyne, sampled in 1993) showed a significant concentration of PAH, and this was only for naphthalene (263 ng l^{-1}). Apart from this sample, PAH were generally not detected in offshore waters. Higher concentrations were found in coastal and estuarine samples (although not in all), with ΣPAH concentrations ranging from none detected to 8.5 µg l^{-1}. ΣPAH concentrations greater than 1 µg l^{-1} were found at 14 sites, in the estuaries of the Rivers Tees, Humber, Great Ouse, and Thames. Of these 14 sites, 10 were in the lower reaches of the River Tees estuary, and particularly high concentrations were observed in the vicinity of Redcar Jetty (not an NMP site). The PAH profile observed in the five samples collected off Redcar Jetty was dominated by two- and three-ring PAH, probably derived from an adjacent steel plant. The other data probably reflect inputs from a wide range of combustion processes involving both industrial and domestic sources.

Comparison of samples for which duplicate filtered/ unfiltered concentrations were determined, indicate (perhaps unsurprisingly) that for the lower molecular weight PAH the major portion is present in the dissolved phase (e.g. samples from the River Tees), whilst for the higher molecular weight PAH the major portion is adsorbed to particulate material, as shown by a large reduction in concentration in the 'dissolved' sample (e.g. in the samples from West Thurrock and Mucking on the River Thames).

Figures 16 to 19 illustrate concentrations of PAH in unfiltered sea water. Figure 16 is for the sum of the 10 individual PAH determined, whilst Figures 17 to 19 present data for phenanthrene, pyrene and benzo[*a*]pyrene respectively. The highest concentrations generally occur in major estuaries, particularly those of the Humber, Great Ouse and Thames. As can be seen from the full dataset, however, this is to some extent an artefact of the sampling sites selected, as overall the highest levels were found in the River Tees at Redcar jetty, which is not an NMP site.

3.6 Significance of PAH data

There are considerable uncertainties in conducting a risk assessment of PAH in sea water, but evaluation of the data suggests that about 15% of the samples analysed in this study came from waters that may have the potential to affect the long-term wellbeing of a range of aquatic organisms. About double this number of samples were obtained from waters in which some human food items such as bivalve molluscs may be locally contaminated to an unacceptable level due to bioaccumulation. Almost all of these samples originated from industrialised estuaries rather than the open sea, often close to effluent outfalls. This indication of a biological effect highlights the need for a fully comprehensive survey within the NMP.

3.7 Future work

Coverage of NMP stations in this pilot study of PAH in sea water was not fully exhaustive, but a good spatial coverage was achieved and in some cases samples were replicated over 2 years. These data suggest that:

(i) Concentrations are low or undetectable at intermediate and offshore sites, and no further work need be undertaken in these areas.
(ii) Significant concentrations of PAH have been found in a number of estuaries, and a fully systematic coverage of UK estuaries should be undertaken.
(iii) The present network of NMP stations may need to be reconsidered in the light of these and other contaminant data, in particular so that PAH concentrations in bivalve molluscs (mussels) can be evaluated during the next phase of the NMP programme.

Table 3. Concentrations of PAH (ng l^{-1}) in unfiltered water

Location	NMP	Date	NAP	PA	ANT	FLU	PYR	BAA	CHR*	BEP	BAP	BGHIP	ΣPAH
R. Tyne: Hebburn	225	13/6/94	19	35	4	36	30	15	11	< 10	6	6	162
R. Tyne: Hebburn	225	13/6/94	25	46	8	76	69	33	24	< 10	15	16	311
R. Tyne: Lloyd's hailing station	235	14/6/93	<15	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	0
Off Tyne	245	11/6/93	<15	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	0
Off Tyne	245	29/6/93	263	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	263
Off Tyne	245	13/6/94	< 10	< 10	< 1	< 10	< 5	< 1	< 1	< 10	< 1	< 2	ND
R. Wear: Sandy Point	275	14/6/93	25	32	3	35	21	10	8	<1	4	5	143
R. Wear: Sandy Point	275	14/6/94	41	17	1	< 10	7	4	4	< 10	3	4	82
R. Wear: Sandy Point	275	14/6/94	42	16	1	< 10	9	6	6	< 10	3	4	87
Off Tyne/Tees	285	12/6/93	<15	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	ND
Off Tyne/Tees	285	15/6/94	< 10	< 10	< 1	< 10	< 5	< 1	< 1	< 10	< 1	< 2	ND
Off Tees	295	14/6//93	<15	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	ND
Off Tees	295	14/6/94	< 10	< 10	< 1	< 10	< 5	< 1	< 1	< 10	< 1	< 2	ND
R. Tees: Victoria Bridge	315	15/6/93	<15	22	2	27	26	10	8	<1	4	5	104
R. Humber: Spurn Head	335	14/6/93	<15	67	18	133	119	26	27	12	63	60	524
Off Humber/Wash	345	13/6/93	<15	< 8	< 1	< 1	< 1	<2	< 2	< 1	< 1	< 1	ND
Off Humber/Wash	345	16/6/94	< 10	< 10	< 1	< 10	< 5	< 1	< 1	< 10	< 1	< 2	ND
R. Humber: North Killingholme	365	15/6/93	72	296	90	624	719	121	106	139	167	319	2653
Off Humber	375	15/6/93	<15	< 8	< 1	< 1	< 1	<2	< 2	< 1	< 1	< 1	ND
Wash	385	15/6/93	<15	< 8	< 1	< 1	< 1	< 2	< 2	< 1	< 1	< 1	ND
Smiths Knoll	395	16/6/93	<15	< 8	< 1	< 1	< 1	< 2	< 2	< 1	< 1	< 1	ND
Smiths Knoll	395	16/6/94	< 6	< 3	< 1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	ND
R. Ouse: Stowe Bridge	405	13/6/93	<15	21	3	56	34	21	18	20	19	32	224
R. Ouse: Freebridge, King's Lynn	415	13/6/93	26	117	13	101	93	35	32	29	48	78	572
R. Ouse: The Point, King's Lynn	425	13/6/93	115	240	31	210	214	76	78	55	140	88	1249
R. Thames: West Thurrock	445	16/6/93	114	288	107	940	1090	609	726	207	909	627	5617
R. Thames: Mucking	455	16/6/93	346	304	26	390	373	245	170	60	216	223	2352
R. Thames: Warp	465	16/6/93	< 15	< 8	< 1	2	4	2	< 2	<1	2	1	11
R. Thames: Warp	465	17/6/94	< 6	< 3	< 1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	ND
Outer Gabbard	475	16/6/93	<15	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	ND
Outer Gabbard	475	16/6/94	< 6	< 3	< 1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	ND
South Varne	485	17/6/93	< 15	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	0
South Varne	485	17/6/94	< 6	< 3	< 1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	ND
Selsey Bill	495	17/6/93	< 15	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	ND
Selsey Bill	495	17/6/94	< 6	< 3	< 1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	ND
Southampton Water: Dock Head	505	17/6/93	< 15	< 8	< 1	10	11	6	3	1	2	3	36
Southampton Water: E. Brambles buoy	515	18/6/93	< 15	24	3	45	48	34	22	9	21	19	225
Southampton Water: Hook buoy	525	17/6/93	< 15	32	6	75	80	49	37	6	38	32	356
Central Channel	535	18/6/93	< 15	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	ND
Central Channel	535	18/6/94	< 6	< 3	< 1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	ND
R. Tamar: Warren Point	555	18/6/93	27	25	1	18	20	11	9	5	11	13	140
R. Tamar: Warren Point	555	19/6/94	31	< 3	< 1	6	4	< 6	< 4	< 2	< 4	< 17	41
R. Tamar: Warren Point	555	19/6/94	8	< 3	< 1	2	2	< 6	< 4	< 2	< 4	< 17	12
R. Tamar: Hamoaze	565	18/6//93	< 15	< 8	< 1	< 1	10	6	4	1	4	5	29
R. Tamar: Hamoaze	565	19/6/94	272	20	< 1	27	25	9	10	< 2	12	< 17	376
R. Tamar: Hamoaze	565	19/6/94	< 6	< 3	< 1	< 2	2	< 6	< 4	< 2	< 4	< 17	2
Off Tamar	575	19/6/94	< 6	< 3	< 1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	ND
Off Plymouth Sound	575	18/693	< 15	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	ND
Off Plymouth Sound	585	19/6/94	< 6	< 3	< 1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	ND
Western Approaches	595	19/6/93	< 15	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	ND
Western Approaches	595	20/6/94	< 6	< 3	< 1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	0
Celtic Deep	605	20/6/93	< 15	< 8	< 1	< 1	< 1	< 2	< 2	< 1	< 1	< 1	ND
Celtic Deep	605	25/6/94	< 6	< 3	< 1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	ND
R. Severn: Nash Point	615	20/6/93	< 15	17	3	27	25	13	15	7	15	14	138
R. Severn: Nash Point	615	21/6/94	6	< 3	3	30	18	5	9	6	11	< 17	88
Cardigan Bay	655	21/6/93	< 50	< 8	< 1	< 1	1	< 2	< 2	<1	< 1	< 1	1
Offshore Cardigan Bay	665	21/6/93	< 50	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	ND
R. Dee: no.2 buoy	695	24/6/94	25	< 3	2	24	20	9	11	< 2	14	< 17	106
Liverpool Bay: Burbo Bight	705	22/6/93	< 50	< 8	< 1	5	3	< 2	< 2	<1	1	1	10
Liverpool Bay: Burbo Bight (HW)	705	23/6/94	< 6	< 3	< 1	6	3	< 6	< 4	< 2	< 4	< 17	9
Liverpool Bay: Burbo Bight (LW)	705	23/6/94	< 6	< 3	1	12	7	< 6	< 4	< 2	4	< 17	24

Table 3. continued

Location	NMP	Date	NAP	PA	ANT	FLU	PYR	BAA	CHR*	BEP	BAP	BGHIP	ΣPAH
Offshore Liverpool Bay	715	22/6/93	< 50	< 8	< 1	1	< 1	< 2	< 2	<1	< 1	< 1	1
Offshore Liverpool Bay	715	22/6/94	< 6	< 3	< 1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	ND
R. Mersey: Bromborough E1 buoy	745	23/6/94	23	26	8	258	47	28	32	< 2	44	40	506
R. Mersey: Bromborough E1 buoy	745	23/6/94	22	13	6	58	58	18	22	< 2	31	18	246
R. Mersey: Seacombe Ferry	755	22/6/93	< 50	27	4	40	51	32	17	6	16	19	212
R. Mersey: Seacombe Ferry	755	23/6/94	42	59	13	85	89	43	51	< 2	20	53	455
R. Mersey: Seacombe Ferry	755	23/6/94	26	11	3	33	37	10	13	< 2	18	< 17	150
R. Mersey: Queen's Channel C1 buoy	765	22/6/93	< 50	21	2	21	23	15	9	4	10	13	118
R. Mersey: Queen's Channel C1 buoy	765	23/6/94	137	18	3	50	30	11	12	< 2	18	< 17	280
R. Mersey: Queen's Channel C1 buoy	765	23/6/94	18	20	4	44	35	13	15	< 2	23	< 17	172
Irish Sea	775	23/6/93	< 50	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	ND
Irish Sea	775	22/6/94	< 6	< 3	< 1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	ND
Off Lune/Wyre	785	24/6/93	< 50	< 8	< 1	6	4	3	2	<1	3	3	20
Off Morecambe Bay	795	24/6/93	< 50	< 8	< 1	3	2	< 2	< 2	<1	1	< 1	5
Off Morecambe Bay	795	24/6/94	< 6	< 3	< 1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	ND
SE Isle of Man	805	24/6/93	< 50	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	ND
SE Isle of Man	805	22/6/94	< 6	< 3	< 1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	ND
Off R. Tweed		10/6/93	< 15	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	ND
R. Tweed: Berwick/Tweed Bridges		10/6/93	< 15	< 8	1	< 1	6	2	3	<1	2	3	16
Off R. Tweed		28/6/93	< 50	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	ND
Off R. Tweed		28/6/93	< 50	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	ND
R. Tweed: Spittal Point		28/6/93	< 50	9	< 1	< 1	3	2	2	<1	1	< 1	16
R. Tweed: Berwick/Tweed Bridges		28/6/93	< 50	< 8	< 1	< 1	2	< 2	< 2	<1	1	< 1	2
Off R. Tweed		12/6/94	< 10	< 10	< 1	< 10	< 5	< 1	< 1	< 10	< 1	< 2	ND
R. Tweed: Spittal Point		12/6/94	10	< 10	< 1	< 10	< 5	2	22	< 10	1	4	40
R. Tweed: Berwick/Tweed Bridges		12/6/94	12	< 10	< 1	< 10	< 5	2	4	< 10	1	2	21
R. Blyth: South Harbour entrance		11/6/93	<15	< 8	1	11	< 1	6	5	<1	2	4	30
R. Blyth: North Blyth		11/6/93	<15	399	4	70	35	12	17	28	13	16	595
Off R. Blyth		29/6/93	236	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	236
R. Blyth: South Harbour entrance		29/6/93	< 50	19	1	9	6	5	4	2	2	3	52
R. Blyth: North Blyth		29/6/93	< 50	28	2	15	10	8	7	2	3	5	81
Off R. Blyth		12/6/94	< 10	< 10	< 1	< 10	< 5	< 1	< 1	< 10	1	< 2	1
R. Blyth: South Harbour entrance		12/6/94	24	< 10	< 1	< 10	< 5	< 1	1	< 10	1	< 2	26
R. Blyth: North Blyth		12/6/94	16	20	1	< 10	6	6	6	< 10	3	3	62
Off R. Tyne		12/6/93	<15	< 8	< 1	3	1	2	< 2	<1	< 1	< 1	6
Off R. Tyne		14/6/93	<15	< 8	< 1	< 1	1	< 2	< 2	<1	< 1	< 1	1
Off R. Tyne (high water)		13/6/94	< 10	< 10	< 1	< 10	< 5	< 1	< 1	< 10	0	< 2	ND
R. Tyne: South Ferry landing		13/6/94	13	< 10	1	< 10	< 5	3	9	< 10	1	4	29
R. Tyne: Jarrow Slake		13/6/94	36	31	4	20	17	10	7	< 10	4	4	133
R. Tyne: Tyne Bridge		13/6/94	10	76	14	112	99	60	38	< 10	25	19	453
Off R. Tyne (low water)		13/6/94	< 10	< 10	< 1	< 10	< 5	1	1	< 10	1	< 2	2
R. Tyne: South Ferry landing		13/6/94	735	57	15	42	52	23	14	< 10	11	15	964
R. Tyne: Jarrow Slake		13/6/94	186	107	13	63	61	33	24	< 10	13	15	515
R. Tyne: Tyne Bridge		13/6/94	20	68	13	98	93	52	38	< 10	23	26	431
Dogger Bank		13/6/93	<15	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	0
Friesland Junction (NSTF50)		13/6/93	<15	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	0
Off R. Wear		14/6/93	<15	9	1	7	4	3	2	<1	1	2	29
Off R. Wear (HW)		14/6/94	< 10	< 10	< 1	< 10	< 5	2	2	< 10	1	< 2	4
R. Wear: Wearmouth Bridge		14/6/94	21	16	1	< 10	8	5	5	< 10	3	3	61
R. Wear: Queen Alexandra Bridge		14/6/94	27	17	1	10	9	5	5	< 10	3	4	82
Off R. Wear (LW)		14/6/94	14	12	< 1	< 10	< 5	1	1	< 10	1	< 2	29
R. Wear: Wearmouth Bridge		14/6/94	210	27	4	17	17	10	9	< 10	7	7	308
R. Wear: Queen Alexandra Bridge		14/6/94	40	45	7	62	46	23	20	10	24	23	298
Off R. Tees		15/6/93	15	20	3	28	19	7	5	2	3	5	106
Off R. Tees		29/6/93	103	< 8	1	< 1	2	< 2	< 2	<1	< 1	< 1	107
R. Tees: no. 8 buoy		29/6/93	<15	72	7	45	27	< 2	5	<1	8	5	170
R. Tees: Redcar Jetty		29/6/93	2280	389	81	300	207	78	61	11	49	32	3488
R. Tees: ICI no. 4 buoy		29/6/93	300	172	20	57	55	16	14	4	7	6	651
R. Tees: no. 25 buoy		29/6/93	358	128	17	61	46	14	12	3	8	7	653
Off R. Tees		30/6/93	<15	24	3	18	11	< 2	3	1	2	1	62
R. Tees: no. 8 buoy		30/6/93	675	224	36	111	79	34	28	7	24	15	1232

Table 3. continued

Location	NMP	Date	NAP	PA	ANT	FLU	PYR	BAA	CHR*	BEP	BAP	BGHIP	ΣPAH
R. Tees: Redcar Jetty		30/6/93	6850	551	157	345	296	89	62	21	84	54	8510
R. Tees: ICI no. 4 buoy		30/6/93	417	145	21	59	63	14	10	2	5	4	740
R. Tees: no. 25 buoy		30/6/93	190	114	18	46	41	11	10	2	4	3	439
Off R. Tees (HW)		15/6/94	33	12	< 1	< 10	< 5	3	1	< 10	< 1	< 2	49
R. Tees: Phillips approach buoy		15/6/94	1040	213	16	100	73	10	8	< 10	25	24	1509
R. Tees: Redcar Jetty		15/6/94	555	98	7	40	32	12	10	< 10	10	10	775
R. Tees: ICI no. 4 buoy		15/6/94	905	316	24	112	101	53	43	14	38	37	1642
R. Tees: no. 23 buoy		15/6/94	951	215	25	91	84	40	34	11	35	31	1518
R. Tees: Transporter Bridge		15/6/94	281	102	12	48	45	18	17	< 10	14	13	551
R. Tees: Bamlett's Bight		15/6/94	426	126	19	80	73	37	32	9	30	30	861
Off R. Tees (LW)		15/6/94	11	< 10	< 1	< 10	< 5	2	2	< 10	1	< 2	16
R. Tees: Phillips approach buoy		15/6/94	1620	376	47	234	161	78	65	24	71	56	2733
R. Tees: Redcar Jetty		15/6/94	323	259	52	161	162	38	26	21	75	53	1170
R. Tees: ICI no. 4 buoy		15/6/94	88	205	45	199	237	91	66	32	125	96	1184
R. Tees: no. 23 buoy		15/6/94	42	106	24	159	147	31	23	12	62	51	656
R. Tees: Transporter Bridge		15/6/94	23	61	15	62	76	32	24	< 10	25	19	336
R. Tees: Bamlett's Bight		15/6/94	216	85	10	36	45	20	19	< 10	10	9	450
R. Tees: Portrack STW		7/7/95	< 9	10	2	37	22	8	7	< 1	9	< 7	95
R. Tees: ICI no. 4 buoy		7/7/95	18	< 10	9	132	81	23	19	< 1	11	< 7	293
R. Tees: Redcar Jetty		7/7/95	3990	1170	83	559	218	52	37	< 1	44	35	6189
Eastern Solent		9/7/95	< 9	< 10	< 2	< 1	< 2	< 5	< 3	< 1	< 5	< 7	0
Langstone Harbour: Stoke buoy		9/7/95	< 9	< 10	< 2	< 1	< 2	< 5	< 3	< 1	< 5	< 7	ND
Langstone Harbour: NW Sinah buoy		9/7/95	64	< 10	< 2	< 1	< 2	< 5	< 3	< 1	< 5	< 7	64
Langstone Harbour: Langstone fairway buoy		9/7/95	< 9	< 10	< 2	< 1	2	< 5	< 3	< 1	< 5	< 7	2
R. Hamble: Swanwick marina		18/795	< 9	< 10	< 2	< 1	7	< 5	3	< 1	< 5	< 7	10
R. Hamble: Hamble Spit		18/7/95	< 9	< 10	< 2	3	4	< 5	< 3	< 1	< 5	< 7	7
Poole Bay		17/6/93	< 15	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	ND
Poole Harbour: Holes Bay		17/6/93	< 15	10	1	13	13	6	5	<1	5	5	59
Poole Harbour: Brownsea Island		17/6/93	< 15	< 8	< 1	< 1	1	1	< 2	<1	< 1	1	2
Poole Bay		18/6/94	< 6	< 3	< 1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	ND
Poole Harbour: Brownsea Island		18/6//94	< 6	< 3	< 1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	ND
Poole Harbour: Stakes buoy, no. 55		18/6//94	< 6	< 3	< 1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	ND
Poole Harbour: Holes Bay		18/6//94	< 6	< 3	< 1	9	7	< 6	< 4	< 2	< 4	< 17	16
Plymouth Sound		18/6//93	< 15	< 8	< 1	< 1	4	3	< 2	<1	1	< 1	8
Plymouth Sound (LW)		19/6/94	< 6	< 3	< 1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	ND
R. Tamar: Royal Albert Bridge		19/6/94	< 6	< 3	< 1	< 2	4	< 6	< 4	5	< 4	< 17	9
Plymouth Sound (HW)		19/6/94	< 6	< 3	< 1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	ND
R. Tamar: Royal Albert Bridge		19/6/94	9	< 3	< 1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	9
Port Talbot		14/7/94	93	115	32	173	132	91	90	< 10	91	97	914
Cardigan		14/7/94	< 10	17	1	12	8	7	6	< 10	6	6	64
New Quay		21/6/93	< 50	< 8	< 1	< 1	< 1	< 2	< 2	<1	< 1	< 1	ND
Aberystwyth		14/7/94	11	18	5	23	36	15	12	< 10	22	18	160
Aberdyfi		13/7/94	10	13	1	< 10	6	5	2	< 10	3	3	43
Barmouth		13/7/94	< 10	< 10	< 1	< 10	6	3	3	< 10	2	< 2	14
R. Mersey: Eastham Lock		23/6/94	18	14	5	72	57	15	18	< 2	24	17	240
R. Mersey: Eastham Lock		23/6/94	53	73	21	156	158	65	76	75	118	83	879
R. Dee: HE2 buoy		23/6/93	< 50	< 8	< 1	8	3	2	< 2	<1	2	2	17
R. Dee: HE3 buoy		24/6/94	19	< 3	1	< 2	< 1	< 6	< 4	< 2	< 4	< 17	20
in Morecambe Bay		24/6/93	< 50	9	1	11	9	5	5	3	6	7	55
R.Lune: no. 1 buoy		24/6/93	< 50	27	2	26	21	16	12	4	13	13	135

Key:

NAP	*naphthalene*	*PA*	*phenanthrene*
ANT	*anthracene*	*FLU*	*fluoranthene*
PYR	*pyrene*	*CHR*	*chrysene*
BAA	*benz[a]anthracene*	*BEP*	*benzo[e]pyrene*
BAP	*benzo[a]pyrene*		
BGHIP	*benzo[ghi]perylene*		

** CHR is chrysene determined by HPLC (not CHRTR : chrysene/triphenylene by GC/MS)*

Table 4. Concentrations of dissolved PAH (ng l^{-1})

Location	NMP	Date	NAP	PA	ANT	FLU	PYR	BAA	CHR	BEP	BAP	BGHIP	ΣPAH
R. Tyne: Hebburn	225	14/6/93	26	23	1	26	27	5	4	< 1	< 1	1	113
R. Tyne: Hebburn	225	13/6/94	< 10	28	1	39	47	16	11	< 10	< 1	< 2	142
R. Tyne: Hebburn	225	13/6/94	< 10	29	2	83	94	27	18	< 10	< 1	< 2	253
R. Tyne: Lloyd's hailing station	235	14/6/93	< 15	23	1	17	17	5	3	< 1	< 1	< 1	65
R. Wear: Queen Alexandra bridge	265	14/6/93	24	38	1	16	16	3	3	< 1	< 1	1	101
R. Wear: Queen Alexandra bridge	265	14/6/94	35	23	2	15	9	3	3	< 10	1	< 2	91
R. Wear: Sandy Point	275	14/6/93	15	23	1	17	11	2	3	< 1	< 1	< 1	71
R. Wear: Sandy Point	275	14/6/94	24	22	< 1	<10	< 5	< 1	1	< 10	< 1	< 2	47
R. Tees: Victoria Bridge	315	15/6/93	< 15	17	2	14	15	5	4	< 1	1	2	59
R. Humber: Spurn Head	335	14/6/93	< 15	< 8	1	< 1	5	< 2	< 2	< 1	< 1	< 1	5
R. Humber: North Killingholme	365	15/6/93	77	< 8	< 1	< 1	6	< 2	< 2	< 1	< 1	< 1	83
R. Ouse: Stowe Bridge	405	13/6/93	< 15	< 8	1	< 1	5	< 2	< 2	< 1	< 1	< 1	6
R. Ouse: Freebridge, King's Lynn	415	13/6/93	17	< 8	1	< 1	5	< 2	< 2	< 1	< 1	< 1	22
R. Ouse: The Point, King's Lynn	425	13/6/93	82	30	4	15	13	6	5	< 1	< 1	< 1	155
R. Thames: West Thurrock	445	16/6/93	293	< 8	2	< 1	43	< 2	20	< 1	8	7	373
R. Thames: Mucking	455	16/6/93	< 15	< 8	< 1	< 1	9	< 2	< 2	< 1	< 1	< 1	9
Southampton Water: Dock Head	505	17/6/93	23	< 8	1	5	6	< 2	< 2	< 1	< 1	< 1	35
Southampton Water: E. Brambles buoy	515	18/6/93	64	< 8	< 1	< 1	3	< 2	< 2	< 1	< 1	< 1	67
R. Tamar: Warren Point	555	18/6/93	21	< 8	1	< 1	11	5	3	< 1	2	3	45
R. Tamar: Hamoaze	565	18/6/93	45	< 8	1	< 1	5	< 2	2	< 1	< 1	< 1	53
Liverpool Bay: Burbo Bight	705	22/6/93	< 50	< 8	< 1	4	2	< 2	< 2	< 1	< 1	1	6
R. Mersey: Queen's Channel C1 buoy	765	22/6/93	< 50	23	6	26	22	5	6	< 1	2	2	92
R. Mersey: Seacombe Ferry	755	22/6/93	< 50	< 8	5	20	28	14	2	< 1	1	< 1	71
Off Lune/Wyre	785	24/6/93	< 50	< 8	< 1	< 1	2	< 2	< 2	< 1	< 1	< 1	2
Off R. Tweed		10/6/93	< 15	< 8	< 1	< 1	< 1	< 2	< 2	< 1	< 1	< 1	ND
R. Tweed: Berwick/Tweed Bridges		10/6/93	< 15	< 8	< 1	< 1	2	< 2	< 2	< 1	< 1	< 1	2
R. Tweed: Spittal Point		28/6/93	< 50	11	< 1	< 1	1	< 2	< 2	< 1	< 1	< 1	12
Off R. Blyth		11/6/93	< 15	< 8	1	4	5	4	2	2	2	< 1	20
R. Blyth: North Blyth		11/6/93	24	262	1	14	11	2	3	< 1	< 1	<1	316
Off R. Tyne		14/6/93	< 15	< 8	< 1	< 1	< 1	< 2	< 2	< 1	< 1	< 1	ND
R. Tyne: South Ferry landing		13/6/94	< 10	< 10	< 1	< 10	< 5	4	2	< 10	< 1	< 2	6
R. Tyne: Jarrow Slake		13/6/94	24	19	2	15	18	6	4	< 10	< 1	< 2	88
R. Tyne: South Ferry landing		13/6/94	1130	47	9	23	34	12	8	< 10	< 1	< 2	1263
R. Tyne: Jarrow Slake		13/6/94	77	90	10	57	61	19	12	< 10	< 1	< 2	325
R. Tyne: Tyne Bridge		13/6/94	13	34	2	103	99	34	20	< 10	4	< 2	310
R. Wear: Wearmouth Bridge		14/6/94	62	18	1	10	7	2	1	< 10	< 1	< 2	101
Off R. Tees		15/6/93	< 15	< 8	< 1	5	4	< 2	< 2	< 1	< 1	< 1	10
R. Tees: Redcar Jetty		15/6/93	17300	2130	167	208	186	46	21	< 1	3	< 1	20061
Off R. Tees		29/6/93	56	< 8	< 1	< 1	2	< 2	< 2	< 1	< 1	< 1	58
R. Tees: no. 8 buoy		29/6/93	269	62	6	66	30	4	4	< 1	< 1	< 1	443
R. Tees: Redcar Jetty		29/6/93	4600	1030	88	313	205	< 2	< 2	< 1	< 1	< 1	6236
R. Tees: ICI no. 4 buoy		29/6/93	339	157	20	83	54	< 2	< 2	< 1	< 1	< 1	654
R. Tees: Phillips approach buoy		15/6/94	929	204	15	71	44	7	6	< 10	< 1	< 2	1277
R. Tees: Redcar Jetty		15/6/94	936	112	8	34	24	5	4	< 10	< 1	< 2	1122
R. Tees: ICI no. 4 buoy		15/6/94	1570	268	20	60	46	8	7	< 10	< 1	< 2	1980
R. Tees: no. 23 buoy		15/6/94	1170	192	20	64	44	7	6	< 10	< 1	2	1504
R. Tees: Bamlett's Bight		15/6/94	467	121	15	44	40	7	5	< 10	1	< 2	699
R. Tees: Redcar Jetty		15/6/94	1490	308	30	95	59	< 1	< 1	< 10	< 1	< 2	1981
R. Tees: ICI no. 4 buoy		15/6/94	10	30	4	51	40	8	6	< 10	1	< 2	150
R. Tees: no. 23 buoy		15/6/94	8	19	3	48	38	6	6	< 10	< 1	< 2	129
R. Tees: Transporter Bridge		15/6/94	< 10	26	7	30	37	8	3	< 10	1	< 2	112
R. Tees: Bamlett's Bight		15/6/94	185	81	9	23	31	6	3	< 10	1	< 2	338
R. Tees: Portrack STW		7/7/95	< 4	7	< 2	20	12	< 4	< 3	< 1	< 5	< 7	39
R. Tees: ICI no. 4 buoy		7/7/95	19	39	5	64	33	4	3	< 1	< 5	< 7	166
R. Tees: Redcar Jetty		7/7/95	1670	376	22	77	24	10	8	< 6	< 5	9	2196
Eastern Solent		9/7/95	< 4	< 6	< 2	3	< 2	< 4	< 3	< 1	< 5	< 7	3
Langstone Harbour: Stoke buoy		9/7/95	< 4	< 6	< 2	< 1	< 2	< 4	< 3	< 1	< 5	< 7	ND
Langstone Harbour: NW Sinah buoy		9/7/95	< 4	< 6	< 2	1	< 2	< 4	< 3	< 1	< 5	< 7	1
Langstone Harbour: Langstone fairway buoy		9/7/95	7	< 6	< 2	2	< 2	< 4	< 3	< 1	< 5	< 7	9
Poole Harbour: Holes Bay		17/6/93	23	< 8	1	8	3	< 2	< 2	< 1	< 1	< 1	35
Celtic Sea: Haddock Bank		12/7/95	< 4	< 6	< 2	< 1	< 2	< 4	< 3	< 1	< 5	< 7	ND
R. Dee: HE2 buoy		23/6/93	< 50	< 8	< 1	< 1	1	< 2	< 2	< 1	< 1	< 1	1
R. Lune: no. 1 buoy		24/6/93	< 50	< 8	< 1	< 1	3	< 2	< 2	< 1	< 1	< 1	3

Key as for Table 3

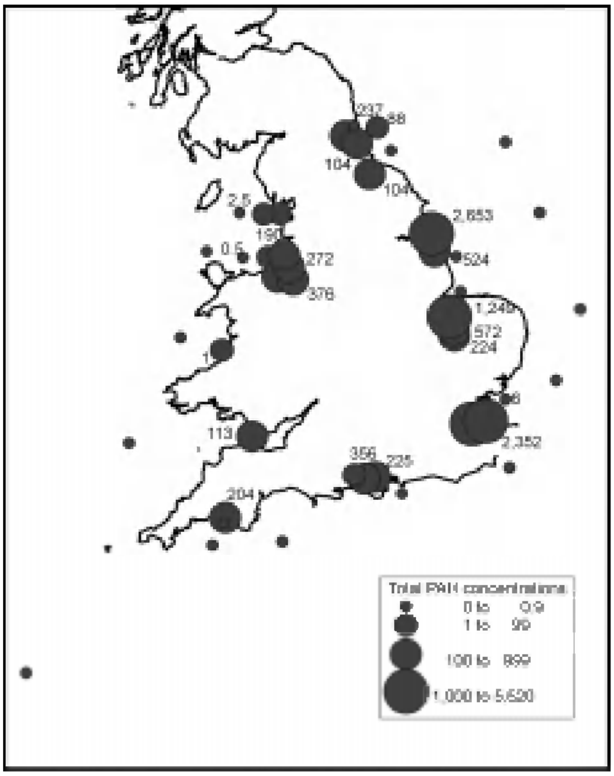


Figure 16. Total PAH concentrations (ng l^{-1}) in unfiltered sea water

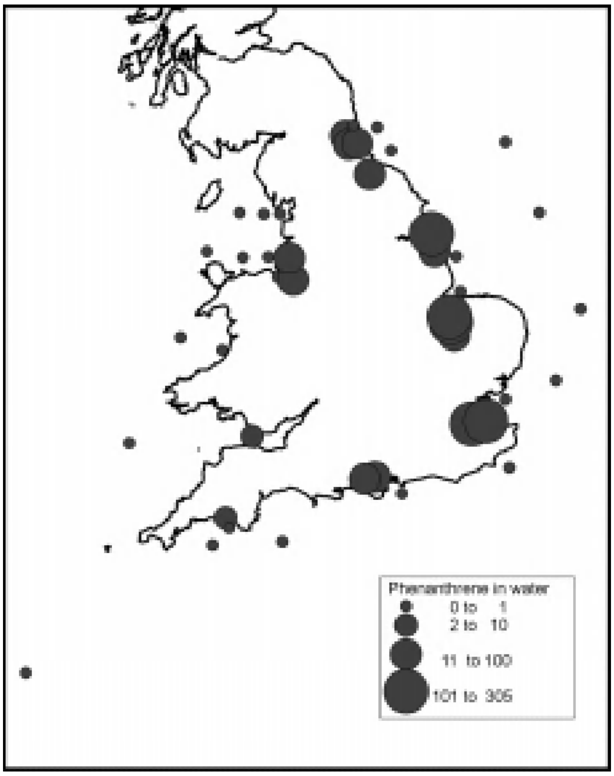


Figure 17. Concentrations of phenanthrene (ng l^{-1}) in unfiltered sea water

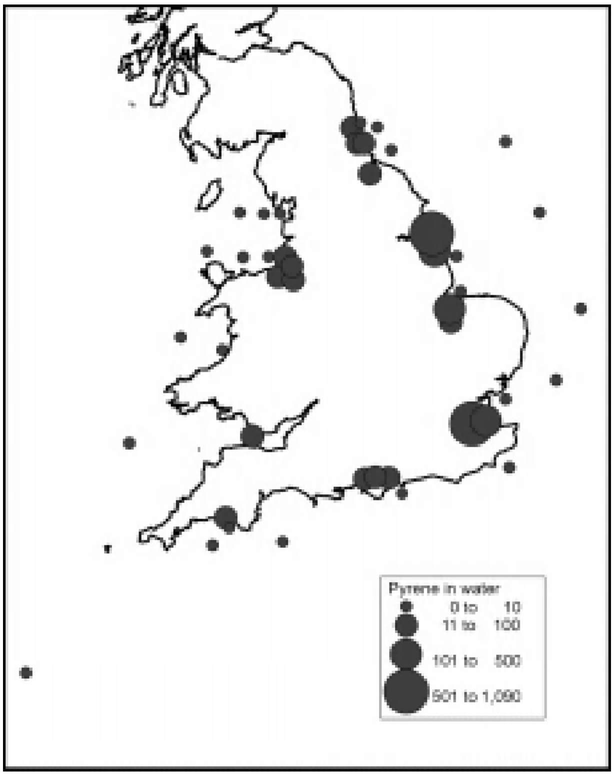


Figure 18. Concentrations of pyrene (ng l^{-1}) in unfiltered sea water

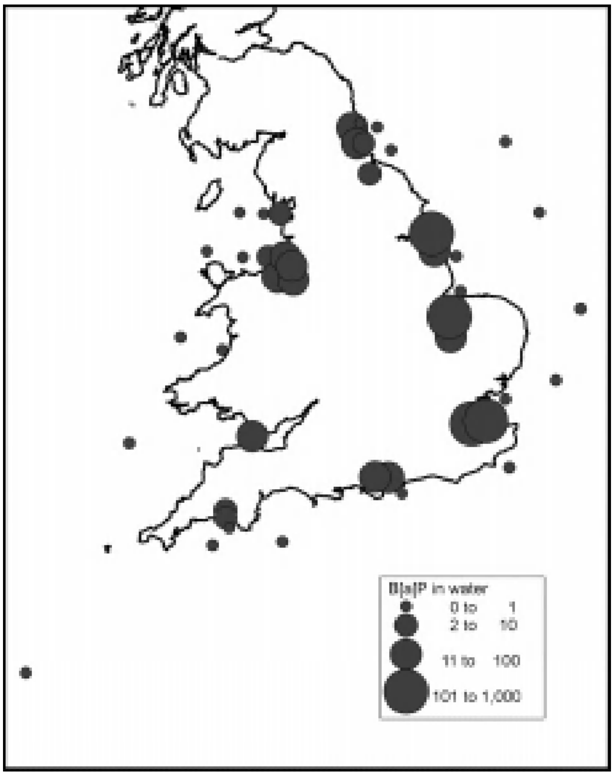


Figure 19. Concentrations of B[a]P (ng l^{-1}) in unfiltered sea water

4. NUTRIENTS IN SEA WATER

4.1 Introduction

Nutrients concentrations were measured in the coastal and offshore waters of England and Wales on monitoring cruises undertaken by *RV CIROLANA* during 1995 and 1996. These cruises were intended to provide data in support of the UK NMP and the monitoring programme of the Oslo and Paris Commission. The objectives were primarily to achieve a wide spatial coverage of typical winter concentrations of nutrients (nitrate, nitrite, ammonia, phosphate and silicate) at coastal and offshore sites and, when sufficient years data are available, to contribute to the monitoring of long-term trends.

The cruise surveys covered the NMP-designated sites in January 1995 and January 1996. In addition to the NMP sites, data were obtained for nutrients and a range of supporting data from surface water samples taken *en route* via the ship's pumped supply.

4.2 Quality assurance of the analytical chemistry

The quality of the analytical chemistry used for these surveys is now demonstrable and transparent, due to participation in two Quality Assurance initiatives: the UK NMAQC Scheme and the Quality Assurance of Information of Marine Environmental Monitoring in Europe (QUASIMEME) project.

The period covered by these monitoring activities coincided with the latter part of the QUASIMEME Project (Aminot and Kirkwood, 1994: Kirkwood, Aminot and Carlberg, in press). The CEFAS Lowestoft Laboratory participated in all five rounds of proficiency testing for nutrients in sea water and demonstrated an excellant performance throughout. (Laboratory Code No. L800).

Likewise for the UK NMAQC Scheme conducted by The Water Research Centre (WRc) Medmenham, a highly satisfactory overall performance for sea water and estuarine water. (Laboratory Code No. 20).

The colorimetric techniques used by CEFAS are fully described by Kirkwood (1996).

4.3 Trend monitoring

In any trend-monitoring activity, it is essential to ensure that like is compared with like. In UK coastal waters, where nutrients concentrations show a strong seasonal signal, this makes the 'like with like' requirement especially difficult to achieve.

Nutrients concentrations are dependent on the balance between the competitive processes of input, consumption and remineralisation. During periods of high primary productivity, removal of inorganic nutrients from surface and shallow waters is virtually complete. This situation is self-evident when measured concentrations fall below the detection limits of the analytical chemistry. At other times when consumption processes are less dominant, the state of affairs is far less obvious.

In an 'ideal' winter, concentrations of nutrients would be expected to increase steadily with shortening day-length, then decrease when production resumed, thereby giving rise to a well-defined maximum in mid-winter. Long-term (inter-annual) time-trend monitoring at a given location would then consist of comparison of winter-maximum concentrations from successive years.

In practice, the winter-maximum is elusive. For operational reasons there are usually no cruises in the latter half of December, and so mid-winter cruises are undertaken in January on the assumption that primary production is then at a minimum, therefore nutrients concentrations at a maximum. However, in some winters a maximum may occur in December or February, in which case synoptic data from a January cruise would be totally misleading if simply *defined* as winter-maximum data. In some locations there can sometimes be, in effect, no winter, i.e. a mild winter when primary production, though variable in its extent, is virtually continuous throughout the winter months. In such a case, a series of measurements might show that multiple sub-maxima occurred, and none of these would provide admissible data for long-term trend monitoring because they do not describe a single well-defined mid-winter maximum.

With these uncertainties in mind, extensive cruises are necessarily planned many months in advance, to collect samples on days that may or may not provide characteristic winter-maximum concentrations. The data so produced are necessarily sparse and temporally inadequate, but there remains the fundamental problem that there is no way of knowing whether they represent winter-maximum concentrations or not, short of occupying a single station for several weeks and sampling hourly. Clearly, the future for nutrients monitoring lies in moored autonomous analysers. These will provide a virtually continuous record of concentration over extended time intervals, e.g. several weeks. Commercial instruments have become available in recent years but they have been shown generally to lack the robustness required of them, and until such time as they have improved sufficiently, January cruises remain the best available technology.

The data-set is not yet long enough to allow any meaningful trend analysis to be undertaken. The NMP sampling will continue for a number of years to allow trends to be established with certainty.

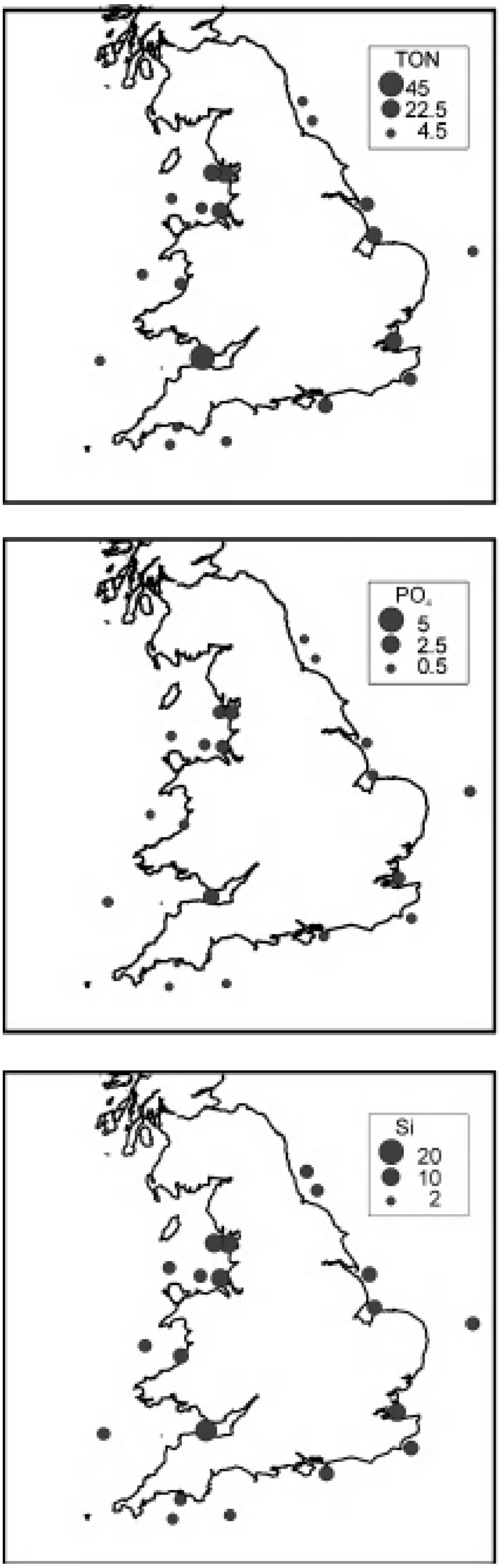


Figure 20. Concentrations (µmol^{-1}) of nitrate, phosphate and silicate at offshore and intermediate NMP sampling stations 1995. Concentrations are presented as area proportional symbols; scale symbols are shown in the legend

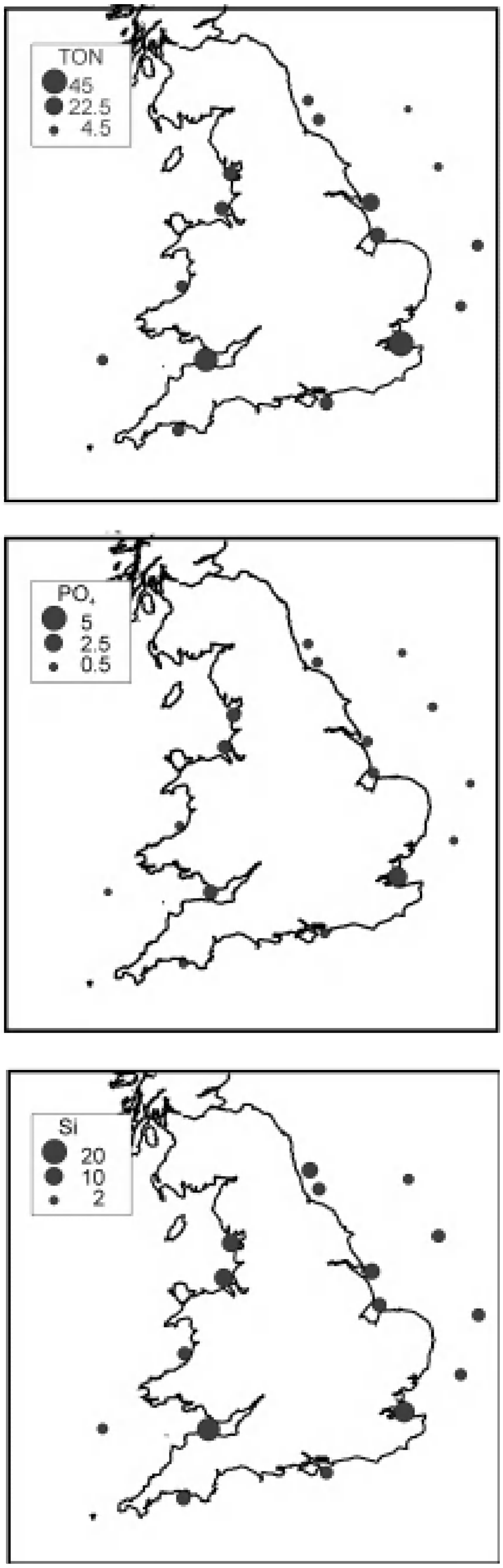


Figure 21. Concentrations (µmol^{-1}) of nitrate, phosphate and silicate at offshore and intermediate NMP sampling stations 1996. Concentrations are presented as area proportional symbols; scale symbols are shown in the legend

4.4 Spatial variations

At a given location, there can be substantial variation in nutrients concentrations throughout a tidal cycle. This is most noticeable in the vicinity of major estuaries, and detailed spatial comparisons should take account of this by comparing only data from samples having equivalent salinity.

Samples taken at high water generally represent a satisfactory 'like with like' basis, therefore, where possible, and particularly for temporal comparisons at a given location, the ship remains on station for a tidal cycle to ensure that a high-water sample is obtained. In some locations, however, there may be significant differences in nutrients concentrations between high-water neaps and high-water springs; normalising to salinity may help to overcome these effects.

Figures 20 and 21 show surface nutrients concentrations for NMP sites around England and Wales in 1995 and 1996 respectively. At anchor stations, where a tidal cycle was sampled, the data used are that of the high-water sample, or of that nearest to high-water. Sampling sites include the major estuaries: Tyne, Tees, Humber, Wash, Thames, Solent, Tamar, Bristol Channel, Cardigan Bay, Liverpool Bay and Morecambe Bay. Tables 1 and 2 contain the abridged data for 1995 and 1996, respectively.

Tables 5 and 6 also contain the salinity data which should be taken into account in any attempted comparisons. For example, the nitrate concentrations at NMP 465 (Thames: Warp) must not be taken to indicate a two-fold increase (21 to 42 µmol l^{-1}) between 1995 and 1996. The respective salinities for these samples were 34.38 and 33.62 showing that the samples were

Table 5. Concentrations of nutrients (µmol l^{-1}) at NMP sites in January 1995 (RV CIROLANA Cruise 1/95)

TON	PO_4	NH_4	NO_2	Si	Salinity	NMP Site
6.3	0.59	0.4	<0.02	5.5	34.530	245
6.1	0.59	0.4	<0.02	5.3	34.559	295
15.4	0.80	1.1	0.10	7.5	33.962	375
23.1	0.93	0.3	0.08	8.6	33.581	385
6.7	0.63	1.1	<0.02	5.4	34.565	395
21.3	1.54	1.8	0.55	9.8	34.331	465
13.3	0.83	1.4	0.54	7.7	34.664	485
15.8	0.76	1.5	0.28	9.0	34.338	495
7.1	0.51	0.3	0.07	3.9	35.186	535
7.5	0.41	2.8	0.12	4.4	34.950	575
7.5	0.52	2.5	0.15	3.9	35.133	585
6.8	0.46	0.3	0.06	3.0	35.461	595
6.6	0.67	1.7	0.04	5.4	35.110	605
43.9	1.96	0.9	0.06	17.1	30.984	615
11.8	0.65	1.5	0.06	9.1	32.478	655
7.7	0.61	2.0	0.05	5.4	34.573	665
23.0	1.35	7.5	0.55	11.8	31.888	705
10.9	0.90	1.8	0.22	6.0	33.476	715
7.9	0.70	2.7	0.04	5.8	31.166	775
24.7	1.64	2.5	0.35	13.0	31.036	785
21.0	1.52	1.1	0.11	11.0	32.019	795

Table 6. Concentrations of nutrients (µmol l^{-1}) at NMP sites in January 1996 (RV CIROLANA Cruise 1/96)

TON	PO_4	NH_4	NO_2	Si	Salinity	NMP Site
9.0	0.66	<0.1	0.06	6.6	34.299	245
3.8	0.38	<0.1	0.04	3.0	34.614	285
7.7	0.64	0.3	0.08	6.1	34.386	295
4.5	0.53	<0.1	<0.02	4.5	34.565	345
22.1	0.83	<0.1	0.07	7.3	33.750	375
15.2	0.84	0.1	0.06	5.9	34.157	385
9.5	0.56	<0.1	<0.02	4.5	34.954	395
42.3	2.97	0.6	0.33	13.1	33.619	465
8.2	0.48	0.1	0.09	4.0	35.104	475
14.3	0.57	0.5	0.24	5.5	34.564	495
10.0	0.51	<0.1	0.14	5.2	34.621	575
6.0	0.43	<0.1	<0.02	3.3	35.263	605
40.7	1.85	0.2	<0.02	15.8	32.346	615
10.5	0.57	<0.1	0.10	6.4	34.402	655
16.4	1.59	0.5	0.26	9.6	33.490	705
17.1	1.55	2.3	0.17	10.3	32.732	785

taken at different states of the tide and perhaps different river flow rates. This serves to illustrate the complexities of fixed point monitoring in coastal waters.

The data show the inshore areas where the highest concentrations are to be expected, and their relationships with offshore sites. In general, data are consistent with those obtained in earlier surveys, e.g. the Quality Status Report for the North Sea (NSTF, 1993) (1989 data) and the Northern Seas Action Programme of the EC (NORSAP) initiative in the Irish Sea (1991 data).

5. ASSESSMENT OF WATER QUALITY: OYSTER EMBRYO BIOASSAY

5.1 Introduction

CEFAS have used this bioassay for over 20 years, initially in surveying water quality associated with the disposal of industrial wastes at sea and in 1990 in accordance with the requirements of the North Sea Task Force Monitoring Master Plan (NSTF, 1990). The method used in the NSTF programme (Thain, 1991) was subsequently adopted for use in the UK NMP (MPMMG, 1994). The results reported here were obtained during research cruises between 1990 and 1994.

5.2 Method

The method is described in detail in Thain (1991). In summary, adult oysters (*Crassostrea gigas*) are conditioned for spawning in the laboratory and taken to sea where the bioassay is deployed on-board a research vessel. For each assay, eggs and sperm are stripped from the oysters and the eggs artificially fertilised. Developing embryos are added to the test samples where they remain for 24 hours. During this time the embryos develop into D-shaped larvae. Failure to develop in this way implies that the water quality is poor.

For water samples, 2.5 l of water are taken from 0.5 to 1.0 m below the surface, from this at least 4 x 30 ml replicate sub samples are tested.

Each result is expressed as a Percent Net Response (PNR):

$$PNR = \frac{(\%\ \text{test abnormal} - \%\ \text{control abnormal})}{100 - \%\ \text{control abnormal}} \times 100$$

A value of 0 or close to 0 indicates the measured response of the sample is similar to that of the controls. A negative value indicates the water quality is better than the control. Poor water quality is defined when PNR values (usually >20) are statistically different from the reference sea water. Experience has shown that the inherent biological variability associated with embryo-larval development dictates that there are occasions when normal embryo development to D-larvae may be high e.g. 90% and the variance in the control is also high, with the net result that PNR values as high as 20 are required for statistical significance. A PNR value of 100 occurs when the sample is highly toxic and all the embryos have either died or shown abnormal development over the 24 h exposure period.

In the discussion of the results that follow, water quality may be regarded as; good, PNR 0-20; slightly impaired, PNR 21-49; substantial deterioration, PNR 50-99; very poor, PNR 100.

5.3 Results and discussion

Sampling at all intermediate and offshore sites was carried out once per year (minimum requirement) during the period May to July. Estuarine samples were taken coincident with the intermediate and offshore sampling; these were taken at low water with the assumption that this would provide a worst case scenario for poor water quality (the minimum requirement for estuarine sampling is at high water and twice per year).

The sampling stations and results are shown in Table 7. Samples were taken at 29, 27, 21, 64, and 47 stations in each of the years 1990 to 1994 respectively. The most comprehensive coverage of the NMP stations over the five year period occurs in the North Sea and English Channel. NMP stations on the south coast of England, Celtic Sea and Irish Sea were sampled only in 1993 and 1994. In addition to the intermediate and offshore NMP stations the data set contains results from estuarine samples; these include the Tweed, Blyth, Tyne, Wear, Tees, Humber, Poole Harbour, Tamar, Mersey and Dee.

The River Tweed was the northern most estuary sampled and with no significant industrial inputs may be regarded as a 'clean' estuary. It was sampled in 1990, 1991, 1993 and 1994 at three locations. On only one occasion was impaired water quality measured, in 1994 at Berwick Bridge (PNR of 31).

Three stations were sampled at Blyth in 1993 and 1994, two by the harbour entrance and one at north Blyth. Impaired water quality was measured in 1994 at each location (PNR values of 31, 34 and 40).

On the River Tyne, eight stations were sampled over a five year period; five of which were sampled on at least three or more years. On six occasions PNR values were greater than 20; three of which measured significant

Table 7. Oyster embryo bioassay results

Station	NMP	Actual Position	Location	PNR 1990	1991	1992	1993	1994
1		55° 45.75' N 1° 57.61' W	Tweed (anchor)	-10	3.2		-6.1	5.4
2		55° 45.83' N 1° 59.58' W	Tweed (buoy off Spittal Point)	1.2	13.3		-6.4	-22
3		55° 46.12' N 2° 00.35' W	Tweed (Berwick / Tweed Bridges)	-7.6	7.5		5.1	30.7
4		55° 07.26' N 1° 28.21' W	Blyth (anchor)				0.7	30.7
5		55° 07.30' N 1° 29.70' W	Blyth (South Harbour entrance)				0.7	33.5
6		55° 08.10' N 1° 30.75' W	Blyth (North Blyth)				11.8	39.6
7		55° 01.48' N 1° 23.24' W	Tyne (anchor)	4	8.2	-5.5	-11.1	37.6
8	235	55° 00.47' N 1° 25.84' W	Lloyds Hailing	1.2	10.4	0	-7.8	
9	TY3	54° 59.82' N 1° 26.47' W	Tyne (by South Ferry landing)					20
10		54° 59.17' N 1° 27.86' W	Tyne (buoy off Jarrow Slake)	3.2	11.8	-4.2		97.6
11	225	54° 59.09' N 1° 31.49' W	Tyne (Hebburn)	10	54.5		22.6	8.8
12		54° 58.25' N 1° 35.2' W	Ouse Burn	-9.2	71	3.7		
13		54° 58.09' N 1° 36.25' W	Tyne (Tyne Bridge)					24.9
14		54° 57.45' N 1° 38.1' W	Team Confluence			-1.1		
15	245	55° 00.45' N 1° 07.85' W	off Tyne	-5.2	-0.7	5.2	-3	51.5
16		54° 56.24' N 1° 19.70' W	Wear (anchor)	3.2	12.2	4.9	-5.1	8
17		54° 54.66' N 1° 23.4' W	Wear (Hetton Staiths)			5.9		
18		54° 54.99' N 1° 23.55' W	Wear (Deptford Quay)			-4.2		
19	275	54° 55.05' N 1° 21.43' W	Wear (Sandy Point)	-2	-6.5		16.6	-2.6
20		54° 54.58' N 1° 22.87' W	Wear (Wearmouth Bridge)	9.2	0.4	-0.1		52.8
21	265	54° 54.80' N 1° 24.24' W	Wear (Queen Alexandra Bridge)			5.5	52.4	-3.1
22	295	54° 44.03' N 0° 53.13' W	off Tees	14.4	1.8	7.7	-16.2	-6.6
23		54° 39.85' N 1° 04.56' W	Tees (anchor)	-7.2	9		3.4	
24		54° 38.52' N 1° 08.66' W	Tees (No. 8 buoy)	3.6	6.5		9.1	14.4
25	TS3	54° 37.79' N 1° 09.72' W	Tees (Phillips approach buoy)					47.9
26	325	54° 37.40' N 1° 09.34' W	Tees (Redcar jetty)	71	71	-0.4	79.4	59.1
27		54° 36.22' N 1° 09.90' W	Tees (ICI No. 4 buoy)	100	35.8		100	54.4
28	TS2	54° 35.66' N 1° 10.84' W	Tees (No. 23 buoy)					32.6
29		54° 35.30' N 1° 11.40' W	Tees (No. 25 buoy)			-5.5	45.9	
30		54° 35.07' N 1° 13.57' W	Tees (Transporter bridge)					100
31	TS1	54° 35.53' N 1° 15.03' W	Tees (Bamlett's Bight)					37.7
32	315	54° 33.52' N 1° 18.33' W	Tees (Victoria bridge)				20.9	
33		53° 33.33' N 0° 6.05' E	Humber (Bull anchorage)	4	8.6	-3.6		
34		53° 36.0' N 0° 3.6' W	Humber (Pyewipe outfall)	10.4		5.5		
35		53° 36.1' N 0° 5.9' W	Humber (Diffuse)		2.2	-7.7		
36		53° 36.6' N 0° 4.6' W	Hunber (No. 6B buoy)		15.8	8.7		
37		53° 37.4' N 0° 8.7' W	Humber (No. 10A buoy)		-1.1	-3		
38		53° 38.6' N 0° 11.0' W	Humber (No. 11A buoy)	-4		3.3		
39	285	54° 49.95' N 1° 20.05' E	off Tyne/Tees	-4	-3.2		-1.4	8.8
40	NSTF 47	55° 10.23' N 3° 09.50' E	Dogger bank	-4.2	6.1	-4.8	-8.8	
41	345	54° 00.09' N 1° 59.99' E	off Humber/Wash (Silver Pit)	0	12.2		-14.2	13
42	375	53° 31.97' N 0° 19.95' E	off Humber	-2.8	-0.7		-7.1	
43	385	53° 03.96' N 0° 29.35' E	Wash	9.6	2.5		2.4	
44	395	52° 49.93' N 2° 49.82' E	Southern Bight (Smiths Knoll)	-1.6	-6.8		1	2.3
45	475	51° 59.99' N 2° 19.90' E	Thames (Outer Gabbard)	-2.4			12.5	12.6
46	465	51° 30.70' N 0° 58.01' E	Thames (Warp)	-0.1			1.4	47
47	485	51° 55.98' N 1° 16.64' E	South Varne	10.8			6.8	16.3
48	495	50° 39.01' N 0° 50.06' W	Selsey Bill				-13.7	12.6
49		50° 39.29' N 1° 54.15' W	Poole Harbour (anchor)				12	
50		50° 41.15' N 1° 57.35' W	Poole Harbour (Brownsea buoy: No. 42)				-7.4	
51		50° 42.40' N 1° 58.95' W	Poole Harbour (Stakes buoy: No. 55)					
52		50° 43.30' N 1° 59.93' W	Poole Harbour (Holes Bay: Cobb's Quay marina)				27.3	
53	535	50° 04.86' N 3° 00.12' W	Central Channel				-6	23.3
54		50° 20.81' N 4° 08.95' W	Plymouth Sound (anchor)				6.1	
55	565	50° 22.93' N 4° 11.60' W	Tamar (Hamoaze)				17.9	39.2
56		50° 24.37' N 4° 12.05' W	Tamar (Royal Albert Bridge)					10.8
57	555	50° 25.45' N 4° 11.99' W	Tamar (E. Tamar north buoy)				10.2	22.9
58	575	50° 17.71' N 4° 09.73' W	off Tamar					23.9
59	585	50° 01.98' N 4° 21.99' W	off Plymouth Sound				-12.4	
60	595	48° 30.04' N 7° 59.98' W	Western Approaches				-13.3	8.3
61	615	51° 18.06' N 3° 32.95' W	Severn (Nash Point)				0.7	
62		52° 13.96' N 4° 21.22' W	New Quay				2.5	
63	655	52° 21.45' N 4° 10.56' W	Cardigan Bay (inshore)				6.6	
64	665	52° 30.31' N 4° 59.99' W	Cardigan Bay (offshore)				-3.3	
65	775	53° 37.66' N 4° 30.32' W	Irish Sea				3.9	
66	715	53° 30.06' N 3° 41.76' W	Liverpool Bay				14.7	
67	805	54° 00.05' N 3° 50.12' W	SE Isle of Man				-8.3	
68	795	53° 58.02' N 3° 19.88' W	off Morecambe Bay				-7.4	

Table 7. continued

Station	NMP	Actual Position	Location	PNR 1990	1991	1992	1993	1994
69		53° 58.73' N 3° 03.38' W	Morecambe Bay (anchor)				-8.3	
70		53° 58.6' N 3° 00.00' W	Off Lune (No. 1 buoy)				6.1	
71	785	53° 57.70' N 3° 02.50' W	Off Lune/Wyre (Fleetwood No1 buoy)				6.6	
72	705	53° 28.76' N 3° 16.03' W	Burbo Bight / Mersey (anchor)				25.5	17.7
73	765	53° 31.83' N 3° 08.80' W	Mersey (C1 buoy)				36.8	14.1
74		53° 28.00' N 3° 02.90' W	Mersey (C20 buoy)					10
74	755	53° 24.56' N 3° 00.48' W	Mersey (Seacombe Ferry)				25.1	49.1
76		53° 23.70' N 2° 59.70' W	Mersey (Tranmere oil terminal)				34.6	30.5
77	745	53° 20.11' N 2° 57.22' W	Mersey (Bromborough E1 buoy)					61.4
78		53° 19.40' N 2° 56.85' W	Mersey (Eastham Lock)				7	58.2
79		53° 40.36' N 3° 10.05' W	Ribble (anchor)				1.6	
80	705	53° 28.68' N 3° 16.09' W	Burbo Bight / Mersey (anchor)				26	
81		53° 23.35' N 3° 14.25' W	Dee (buoy HE3 / Hilbre Island)					5.1
82	695	53° 19.98' N 3° 12.08' W	Dee (No.2 buoy)					39.5
83		53° 26.10' N 3° 17.00' W	Dee (HE2 buoy)				10.6	
84	25	54° 45.00' N 3° 59.56' W	Solway				-2.4	
85	35	55° 20.04' N 5° 05.12' W	Firth of Clyde				-3.8	
86	85	51° 59.97' N 5° 40.03' W	Minches				-8.8	
87	105	58° 00.04' N 3° 00.00' W	Moray Firth				5.7	
88	165	56° 29.96' N 1° 30.00' W	Tay/Forth (offshore)				0.3	
89	605	51° 14.98' N 5° 59.88' W	Celtic Deep				-10.6	-7.3

deterioration in water quality with PNRs of 98, 55 and 71 and these were associated with sites in the middle to upper estuary, Jarrow Slake, Hebburn and Ouse Burn respectively.

To the south of the River Tyne lies another heavily urbanised and industrialised estuary, the River Wear. Water samples were taken from six sites, four of which were sampled on three or more years between 1990 and 1994. Poor water quality was measured at two sites, Wearmouth Bridge and Alexandra Bridge with PNR values of 53 and 52 respectively.

On the River Tees, water samples were taken from ten stations, four of which were sampled on three or more years from 1990 to 1994 inclusive. Of the total of twenty three water samples assayed over this period, fourteen were greater than 20 PNR, of which eight were greater than 50 PNR and three were very poor (PNR of 100); in 1990 and 1993 at ICI No 4 buoy and in 1994 at the Transporter Bridge. It is also notable that on four out of five sampling occasions at ICI No 4 buoy and four out of five occasions at Redcar Jetty, PNR values were in excess of 50. This indicates that water quality is severely impaired in the middle estuary and is probably associated with the inputs of industrial effluents into the river.

Water samples were taken from up to six sites on the lower Humber estuary in 1990, 1991 and 1992. PNR values were all less than 20. In 1993, three water samples were taken in Poole Harbour, one of which showed a slight impairment in water quality; a PNR of 27 at Holes Bay. Elevated PNRs of 39 and 23 were also measured in water samples from two of the four stations sampled in 1993 and 1994 on the River Tamar.

In 1993 and 1994, water samples were taken from three sites on the River Dee estuary and seven sites on the River Mersey estuary. Impaired water quality was measured in two of the three samples from the River Dee estuary. Eight of the twelve samples from the River Mersey estuary had PNR values in excess of 20, of which two were 61 and 58, at Bromborough E1 buoy and Eastham Lock. The latter was the most easterly site sampled.

From 1990 to 1994, water samples were taken at least twice from each of the twelve intermediate and offshore stations in the North Sea and eastern English Channel; as far north as Off Tyne (NMP 245), east to the Dogger Bank and south to Selsey Bill (NMP 495). Of the forty-three samples bioassayed only two measured reduced water quality; in 1994, Off Tyne and Thames Warp with PNR values of 52 and 47 respectively.

A further twenty-one intermediate and offshore water samples were bioassayed in 1993, from the Central Channel, Western Approaches, West coast of England and the coast of Wales and five around the coast of Scotland. PNR values were all less than 20 indicating good water quality. Four of the stations were sampled in a follow-up survey in 1994 and on this occasion PNRs of 23 and 24 were measured in water from the Central Channel and Off Tamar stations.

5.4 Conclusions

PNR values of 100 were recorded in three samples, taken in 1990, 1993 and 1994 respectively and on each occasion the samples were from the River Tees estuary. PNR values in excess of 50 were measured in 13 estuarine samples from the Tyne, Wear, Tees and

Mersey in several years and at one intermediate NMP station (Off Tyne), in 1994. No obvious explanation other than chemical contamination can be given for the poor water quality observed at this intermediate station - physical variables were 'normal' and no algal blooms were present at the time of sampling.

Bioassays carried out on spot water samples have the disadvantage of occasionally identifying patches of poor water quality that originate from a variety of transient sources, e.g. ships bilge's and waste discharges. The same problem exists to a greater extent in estuaries and may account for high PNR values being measured on isolated occasions in several estuaries. However, it is clear that in the River Tees, poor water quality was measured consistently from year to year; in 4 out of 5 years at Redcar Jetty and 3 out of 4 years at ICI No 4 buoy, PNR values were in excess of 50. In general terms the bioassay has unequivocally shown that impaired, and sometimes very poor, water quality exists in several estuaries, particularly those associated with high inputs of urban, chemical and industrial wastes - the Tees, Tyne, Mersey and Wear. This is also borne out in the survey work using liquid/liquid extraction techniques (see Section 6). For example, in the Tees estuary, toxicity thresholds for hexane extractable contaminants require a concentration factor of x10 or less, i.e. the estuarine water is likely to be toxic. Similarly, in coastal and offshore waters concentration factors well in excess of x100 were measured and this corresponds with the good water quality, measured using the oyster embryo bioassay.

The oyster embryo bioassay has successfully been deployed for 5 years as a general water quality monitoring tool and has identified poor water quality in a number of industrialised estuaries. Future studies should concentrate on these estuaries to examine and quantify the cause and extent of the observed effect. This should involve more extensive temporal and spatial sampling. In addition, a Toxicity Identification Evaluation (TIE) approach may be a useful addition to the programme in order to identify the causes of toxic effects.

6. BIOASSAY OF CONTAMINANTS IN SOLVENT EXTRACTS OF SEA WATER

6.1 Introduction

Reference to the data obtained with the oyster embryo bioassay (Section 5) shows that, in general, water from intermediate and offshore sites around the UK coastline does not produce a toxic response, because contaminants do not reach acute concentrations. This does not, of course, necessarily imply that contaminants at these sites are unable to exert some harmful effects, and this explains the use of EROD induction (Section 14) as a biomarker for detecting the exposure of fish to some classes of organic substances, and for providing early warning of possible chronic toxicity (e.g. carcinogenesis). A number of other more or less chemical-specific biomarkers (e.g. acetylcholine esterase inhibition, metallothionein induction, vitellogenin induction) have also been used to detect the exposure and/or response to sublethal contamination at sea, although not yet as part of the UK's routine monitoring programme. In addition, the incidence of fish disease (especially liver tumours) (Section 15) is being used in the NMP as a pointer to areas in which fish are experiencing stress due to chemical exposure (and other influences).

Since most UK waters are not contaminated to acutely toxic levels it is difficult to establish trends in water quality as the bioassay species do not respond during the test period. One way to ensure a positive response from low levels of contaminants is to concentrate them into solid- or liquid-phase media, and then to assess the toxicity of the extract by standard acute bioassays. This allows spatial and temporal comparison of water quality to determine whether the environment is improving or degrading, although care must be taken with interpretation of the data because some of the extracted material may not have been bioavailable in the original water sample (for example, due to adsorption to particulates). One of the first people to employ this strategy was Stebbing (1979), who used ion exchange resins, and subsequent investigations have employed both XAD polymeric resins (e.g. Bening *et al*., 1992) and organic solvents (e.g. Lukasewycz and Durhan, 1992). The work described here is based on hexane solvent extraction of non-polar organic contaminants, followed by bioassay with the sensitive harpacticoid copepod *Tisbe battagliai*, and has already been reported in part (Thain and Kirby, 1994; MAFF, 1995).

6.2 Methods

In essence, the method as finally developed for routine monitoring (Kirby *et al*. in prep.) involves extracting 40 l water samples (1 m depth) with 500 ml analytical reagent-grade hexane in a stainless steel vessel. After shaking at 100 rpm for 20 minutes, the hexane is decanted and dried with anhydrous sodium sulphate. It is then reduced to 5-10 ml by rotary evaporation at 40°C (after which it can be stored at -20°C), and further reduced to 40 µl which is taken up in 4 ml acetone that is again reduced to 40 µl. This is finally dissolved in 40 ml reference sea water. This stock solution represents a 1000-fold concentration of the non-polar organics in the original 40 l sample of sea water.

The stock solution is used to prepare a series of dilutions, 4 x 5 ml replicates each of which are bioassayed with *T. battagliai*, using five 4-6 day old copepodites (see Hutchinson and Williams, 1989, for details). The 24 and 48 h LC50 values are then calculated, expressed as concentration factors of the original sea water sample.

Samples were originally taken from a variety of estuarine, intermediate and offshore sites around the UK coastline in July and October 1992. A more comprehensive survey was conducted in June and October 1993, accompanied by analysis of water samples for total alkanes, and total hydrocarbons (THC). Volatile organic compounds (VOC) were also measured at the same sites but the bioassay is unable to assess the contribution of these compounds to toxicity due to the need to evaporate the extracting solvent close to dryness. These were chosen on the basis of prior knowledge of contaminant concentrations in UK coastal waters combined with the published toxicity of those contaminants to crustacea (*Daphnia magna*). Parallel water samples (2.5 l) to the water collected for bioassay were extracted with two 50 ml aliquots of hexane. After sample reduction by rotary evaporation, THC was measured by ultraviolet fluorescence spectrometry, results being expressed relative to an Ekofisk crude standard (Law *et al.*, 1988). After further reduction of sample volume in a stream of nitrogen, analysis of total alkanes was accomplished by gas chromatography with flame ionisation detection, using squalene and heptamethyl nonane internal standards (Law *et al.*, 1988). VOCs were analysed either by purge and trap gas chromatography - mass spectrometry (GC-MS) (Dawes and Waldock, 1994), or by full-scan GC-MS using a deuterated internal standard, following extraction of 2.5 l sea water with dichloromethane (DCM) (Law *et al.*, 1991).

6.3 Results

The results for samples collected in July and October 1992 are given in Tables 8 and 9 respectively. The July 1992 data show that concentration factors (CFs) required to attain the 48 h LC50 response (hereafter referred to as 48 h LC50 CFs) at intermediate and offshore stations were all in excess of 200-fold (215-560), while those from an enclosed bay with considerable anthropogenic inputs (Poole Harbour) ranged from 54 to 96-fold. The 48 h LC50 CFs were usually somewhat lower at low tide than at high tide. The more comprehensive data for October 1992 extend this picture, and show that industrialised and other heavily used estuaries generally had 48 h LC50 CF values below about 300. In the case of the Tyne and Wear estuaries, and Poole Harbour, 48 h LC50 CFs were as low as <10, 13 and 13 respectively, indicating that total non-polar organic concentrations in the original sea water were close to lethal levels. Indeed, oyster embryo bioassay data for the Wear and Tyne (Section 5) show that their waters are frequently acutely toxic. In contrast, 48 h LC50 CFs in intermediate and offshore waters generally exceeded 300, with the exception of the Tees intermediate site (145).

In June and October 1993 (Table 10), many of the 1992 stations were revisited, and a number of others were added. Once again, the general picture (Figure 22) is one of low (<300) 48 h LC50 CFs at industrialised estuarine sites, increasing to 100-600 at almost all nearshore sites, and to 350->1000 at offshore sites. The means and standard deviations for June and October 1993 are shown in Table 11.

If contaminant concentrations in sea water are regressed against 48 h LC50 CFs, correlations are not significant ($p > 0.05$) for total volatiles as expected due to the need to evaporate the extracts, but significant negative correlations exist for total alkanes (June only) and THC (June and October), although significance is not especially high ($p = 0.03$-0.05).

THC concentrations ranged from 200 to 13,000 ng l^{-1} in the June 1993 samples (mean = 2,164 ng l^{-1}, s.d. = 2,952 ng l^{-1}, n = 25). Highest values were measured at Tees - Victoria Bridge (13,000 ng l^{-1}), Burbo Bight (5,600 ng l^{-1}), River Lune - No. 1 Buoy (5,600 ng l^{-1}), River Tamar - Hamoaze (5,400 ng l^{-1}), Poole - Holes Bay (4,700 ng l^{-1}) and Tees Anchor (4,700 ng l^{-1}). The lowest value (200 ng l^{-1}) was measured in the Western Approaches to the English Channel. If one assumes that

Table 8. Toxicity of hexane extractable contaminants from sea water (July 1992) to the copepod Tisbe battagliai

Position	Location	Tide	LC50 24 hr	LC50 48 hr
53°28.92'N 3°17.11'W	Outer Mersey	H.W.	860x	380x
53°28.92'N 3°17.11'W	Outer Mersey	L.W.	750x	215x
52°50.00'N 5°16.40'W	Cardigan Bay	-	720x	470x
49°55.45'N 5°49.92'W	Lands End	-	720x	415x
50°20.89'N 4°09.00'W	Tamar Anchor	H.W.	760x	420x
50°20.89'N 4°09.00'W	Tamar Anchor	L.W.	550x	300x
50°38.90'N 1°54.60'W	Poole Harbour	H.W.	135x	96x
50°38.90'N 1°54.60'W	Poole Harbour	L.W.	75x	54x
50°42.70'N 1°02.92'W	Outer Solent	H.W.	880x	520x
50°42.70'N 1°02.92'W	Outer Solent	L.W.	820x	560x

Note: All LC50 figures are quoted as concentration factors
H.W. = High Water; L.W. = Low Water

Table 9. Toxicity of hexane extractable contaminants from sea water (October 1992) to the copepod Tisbe battagliai

Position		Location	Tide/Site	LC50 (95% confidence limits)	
				24 h	48 h
53° 32.96'N	0° 6.01'E	Humber mouth	H.W.	440 (594-326)	260 (364-186)
53° 32.96'N	0° 6.01'E	Humber mouth	L.W.	310 (434-221)	144 (210-99)
53° 36.0'N	0° 3.6'W	Humber estuary	Inner	134 (176-102)	103 (140-76)
54° 0.0'N	1° 59.48'E	Dogger Bank	Silver Pit	700 (1190-412)	420 (512-344)
55° 0.07'N	2° 00.17'E	Dogger Bank	-	790 (1007-620)	420 (491-359)
54° 39.1'N	1° 7.25'W	Tees mouth	L.W.	870 (1066-710)	650 (809-522)
54° 39.1'N	1° 7.25'W	Tees mouth	H.W.	190 (277-130)	66 (115-38)
54° 38.52'N	1° 8.66'W	Tees estuary	Inner	540 (599-486)	340 (428-270)
54° 44.12'N	0° 52.87'W	Tees offshore	Intermediate	590 (773-450)	145 (202-104)
55° 00.47'N	1° 23.40'W	Tyne mouth	H.W.	420 (500-353)	230 (266-199)
55° 00.47'N	1° 23.40'W	Tyne mouth	L.W.	<10	<10
54° 58.09'N	1° 36.25'W	Tyne estuary	Inner	<10	<10
54° 54.92'N	1° 20.23'W	Wear mouth	H.W.	440 (563-344)	180 (221-146)
54° 54.92'N	1° 20.23'W	Wear mouth	L.W.	145 (182-116)	91 (110-75)
54° 54.8'N	1° 24.24'W	Wear estuary	Inner	~ 16.5	~ 13
55° 46.08'N	1° 57.79'W	Tweed	-	285 (386-210)	185 (244-140)
56° 29.92'N	1° 29.96'W	Firth of Forth	-	640 (832-492)	530 (665-422)
57° 59.9'N	2° 59.76'W	Moray Firth	-	880 (942-822)	660 (838-520)
58° 00.05'N	5° 43.61'W	North Minch	-	650 (982-430)	360 (499-260)
55° 5.58'N	5° 43.59'W	East of Isle of Man	-	~910	670 (821-547)
53° 29.38'N	3° 17.02'W	Queens Channel Mersey	L.W.	300 (393-229)	225 (295-172)
51° 32.0'N	3° 55.0'W	Swansea Bay	Inner	>1000	760 (1186-487)
51° 32.0'N	3° 55.0'W	Swansea Bay	Outer	>1000	640 (742-552)
50° 9.20'N	5° 3.20'W	Fal estuary	Inner	710 (870-580)	280 (378-207)
50° 7.75'N	5° 3.2'W	Fal mouth	Outer	>1000	730 (883-603)
50° 38.99'N	1° 53.71'W	Poole Harbour	L.W.	135 (182-100)	92 (124-68)
50° 39.33'N	1° 54.14'W	Poole Harbour	H.W.	92 (127-67)	43 (73-25)
50° 42.70'N	2° 1.30'W	Poole Harbour	Inner	~16.5	~13.3

L.W. = Low Water
H.W. = High Water
All LC50 figures are quoted as concentration factors

about 8% of THC consists of polycyclic aromatic hydrocarbons (PAH) (Morishita, 1993), the most toxic components of THC, one can estimate the percentage of toxicity which is attributable to PAH on the basis of an average of the published crustacean toxicity data. This suggests that the contribution which PAHs made to measured toxicity ranged from 1.8% to 48% (mean = 10.1%, s.d. = 11.0%, n = 25). The sites where PAHs are estimated to have been contributing the largest proportions of measured toxicity are River Lune - No. 1 Buoy (48%), Burbo Bight (29%) and Tees - Victoria Bridge (29%).

6.4 Discussion

Even if one assumes that all the contaminants in the original sea water samples were fully bioavailable, these data show that concentrations of non-polar materials at nearshore and offshore sites are generally at least 2 orders of magnitude below levels acutely toxic to crustacea. Employing the standard empirical safety factor of 100 used in setting environmental quality standards for industrial chemicals, this suggests that many chronic effects in crustacea from non-polar substances are unlikely at these sites. This does not, of course, imply that nearshore and offshore environments are not experiencing any pollution impacts, because the effects of more polar materials such as heavy metals and water-soluble organics (and their combined action with the non-polars) have not been taken into account. Furthermore, these methods will not reveal the risks from substances which may biomagnify up food chains and/or cause carcinogenic effects, for example. Nevertheless, taken in conjunction with EROD measurements in fish (Section 14), and with other biomarker measurements made offshore, these data do not give serious cause for concern about the risks from contaminants in most nearshore and offshore areas.

On the other hand, the situation is very different in many English and Welsh estuaries (particularly those receiving substantial amounts of industrial effluent) where the data indicate clearly that organisms are at risk from chronic and even lethal effects. This is supported by the oyster embryo bioassay (Section 5) which routinely detects acute toxicity in several estuaries, including the Tees, Wear and Tyne. Matthiessen *et al.* (1993) found that this toxicity can rarely be attributed to any individual pollutant, and the present data confirmed that hydrocarbons generally account for only a small percentage of total toxicity.

Table 10. Toxicity of hexane extractable contaminants from sea water (June and October 1993) to the copepod Tisbe battagliai

Location	LC50 (95% confidence limits)			
	June 1993		October 1993	
	24 hr	48 hr	24 hr	48 hr
Estuarine sites				
Tyne (Hebburn)	520 (718-377)	190 (253-143)	315 (428-232)	164 (220-122)
Wear (Q.Alexandra Bridge)	56 (79-40)	16 (25-10)	102 (141-74)	31 (50-19)
Tees (Victoria Bridge)	210 (250-176)	140 (189-104)	78 (122-50)	27 (42-17)
Tees (ICI No. 4 Buoy)	98 (145-68)	50 (66-38)		
Poole Harbour (Holes Bay)	190 (268-135)	100 (139-72)	295 (378-230)	114 (155-84)
Poole Harbour (Brownsea Buoy)	500 (785-318)	270 (408-179)	295 (443-197)	103 (150-71)
Tamar (Hamoaze)	350 (459-267)	200 (264-152)		
Mersey (Tranmere Oil Terminal)	140 (172-114)	85 (103-70)	182 (222-149)	115 (171-77)
Mersey (Eastham Lock)	190 (225-160)	105 (124-89)	124 (169-91)	84 (107-66)
Dee (No. 2 Buoy)	500 (655-382)	280 (440-178)		
River Lune (No. 1 Buoy)	>1000	550 (715-423)		
Wear (Sandy Point)			135 (186-98)	51 (90-29)
Tyne (North Shields)			415 (598-288)	148 (188-117)
Blyth (North Harbour)			515 (585-454)	300 (363-248)
Blyth (South Harbour)			590 (743-468)	247 (358-170)
Tees (Redcar Jetty)			<10	<10
Southampton Water (Netley Buoy)			413 (525-325)	180 (225-144)
Southampton Water (Cadland Buoy)			260 (351-193)	125 (173-91)
Mersey (Canada Buoy)			320 (403-254)	141 (175-114)
Nearshore sites				
Tyne - (anchor high tide)	850 (1080-669)	660 (812-537)		
Tyne (anchor)	610 (714-521)	400 (548-345)	380 (452-319)	284 (440-183)
Wear (anchor)	620 (769-500)	320 (384-267)	165 (218-125)	108 (157-74)
Tees (anchor)	310 (388-248)	215 (260-178)	73 (93-57)	46 (59-36)
Solent			465 (605-358)	148 (203-108)
Poole Harbour (anchor)	>1000	440 (561-345)	395 (600-260)	200 (318-126)
Plymouth Sound (anchor)	250 (283-221)	190 (226-160)		
Ribble (anchor)	850 (1105-654)	425 (527-343)		
Dee (anchor)	800 (1048-611)	500 (680-368)		
Morcambe Bay (anchor)	580 (760-443)	470 (611-362)		
Blyth			260 (354-191)	198 (277-141)
Liverpool Bay (Burbo Bight)	795 (994-636)	340 (398-291)	740 (940-583)	210 (288-153)
Offshore sites				
off Tyne/Tees	>1000	450 (612-331)		
Dogger Bank	800 (968-661)	610 (738-504)		
Off Humber/Wash	800 (968-661)	485 (660-357)		
Off Tees	850 (1046-691)	570 (667-487)		
Off Humber	710 (859-587)	515 (577-460)		
Off Wash	460 (581-333)	345 (414-288)		
Southern Bight (Smiths Knoll)	560 (750-418)	360 (454-286)		
Thames (Outer Gabbard)	920 (1141-742)	560 (868-361)		
Thames (Warp)	>1000	540 (734-397)		
South Varne	>1000	760 (1131-538)		
Off Selsey Bill	>1000	>1000		
Central Channel	415 (515-335)	300 (369-244)		
Western Approaches	>1000	950 (1539-586)		
Celtic Deep	>1000	850 (1301-556)		
New Quay	>1000	740 (893-630)		
Cardigan Bay	>1000	860 (946-782)		
Off Cardigan Bay	930 (1032-838)	830 (1013-680)		
Irish Sea	>1000	850 (1216-594)		

Note: All LC50 figures are quoted as concentration factors. All samples were taken at low tide unless otherwise stated

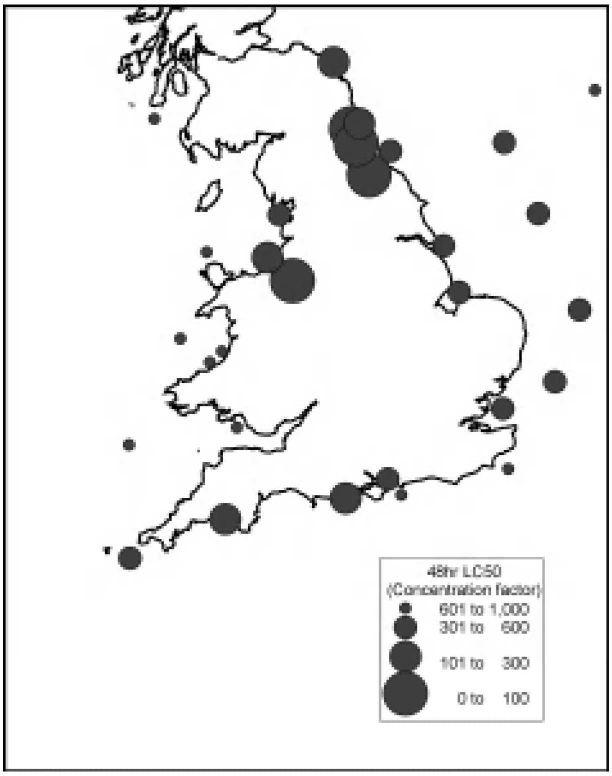


Figure 22. Liquid /Liquid extraction 48hr LC50 concentration factors for Tisbe battagliai

The overall conclusion from this work is that many organisms in industrialised estuaries are probably at risk from mixtures of non-polar organic contaminants. However, much further work is required to examine the contribution to toxicity made by the more polar materials, and to identify the most important substances which can then be subjected to discharge controls. In light of the fact that mixture effects are clearly very significant, an effective way in which the most toxic complex discharges to estuaries might be identified is through Direct Toxicity Assessment (DTA), a procedure which the Environment Agency is currently evaluating. However, the ultimate measure of environmental improvement must remain the use of direct biological assessment of estuaries themselves, in order to account for effects resulting from the interactions of multiple discharges.

7. METALS IN SEDIMENT

7.1 Introduction

Surface sediment samples were collected from various estuaries and all intermediate and offshore NMP stations around England and Wales. Sampling was conducted on a nine point grid wherever possible, in order to establish both sampling and natural variability. All samples were analysed using the same method; total digestion in hydrofluoric acid and nitric acid. This allows the comparison of metal contents from samples of differing geological composition.

Table 11. Mean 48 h LC50 values (expressed as concentration factors) for Tisbe battagliai in 1993

	Estuaries		Nearshore		Offshore	
	June	October	June	October	June	October
Mean*	180	122	396	170	643	No data
s.d.	149	81	138	77	217	no data
N	11	15	10	7	18	no data

** Values of <10 entered as 5, and values of >1000 entered as 1000*

7.2 Results

The following discussion and charts focus primarily on raw metal concentrations. The data are presented as median values.

Mercury
Relatively high Hg concentrations were present in sediments from the Tees, Thames and Tamar. The sediments from the Mersey do not all contain high concentrations of Hg, despite the known historical input of chlor-alkali works to the estuary and the suggestions of previous workers (e.g. Rowlatt, 1988).

All offshore samples contained relatively low concentrations of Hg.

Cadmium
Relatively high Cd concentrations were present in the Tyne, Tees, Thames, Tamar, and Mersey.

All offshore samples contained relatively low concentrations of Cd.

Arsenic
Relatively high As concentrations were present in sediments from the Tees, Humber and Tamar estuaries. Without the analysis of baseline samples it is impossible to tell the relative significance of natural and anthropogenic sources.

Most offshore samples contained relatively low concentrations of arsenic.

Chromium
As in the cases of most other metals, the estuarine sediment concentrations of Cr were higher than offshore concentrations. Of particular note are the relatively high concentrations in sediments from the Tees (Figure 23).

Copper
Relatively high concentrations of Cu were present in sediments from the Tyne, Tees and Tamar estuaries. Offshore concentrations were relatively low.

Lead
Relatively high concentrations of Pb were present in sediments in most estuaries, especially the Humber, Severn, Mersey and Thames (Figure 24). It is unclear how much of this material is from anthropogenic sources and how much from geological sources (e.g. from the mineralised parts of the Pennines in the case of the Tyne and Tees).

Nickel
Nickel concentrations in sediments were present at relatively high levels in estuaries compared to offshore, but there are no estuaries with notably high concentrations (Figure 25).

Zinc
Relatively high concentrations of Zn in sediments were present in the Tyne, Tees and Tamar estuaries. The Zn concentrations in the offshore samples were comparatively low.

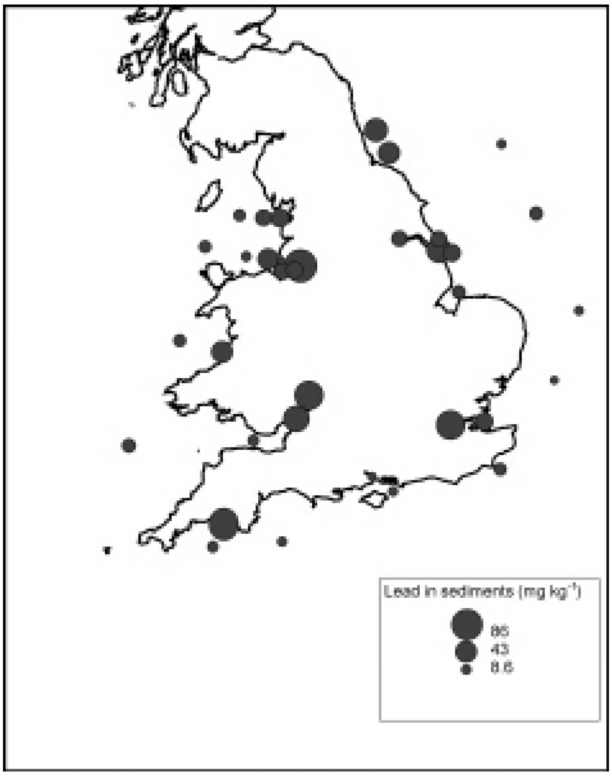


Figure 24. Concentrations of lead in sediments (mg kg^{-1}). Concentrations are presented as area proportional symbols; scale symbols are shown in the legend

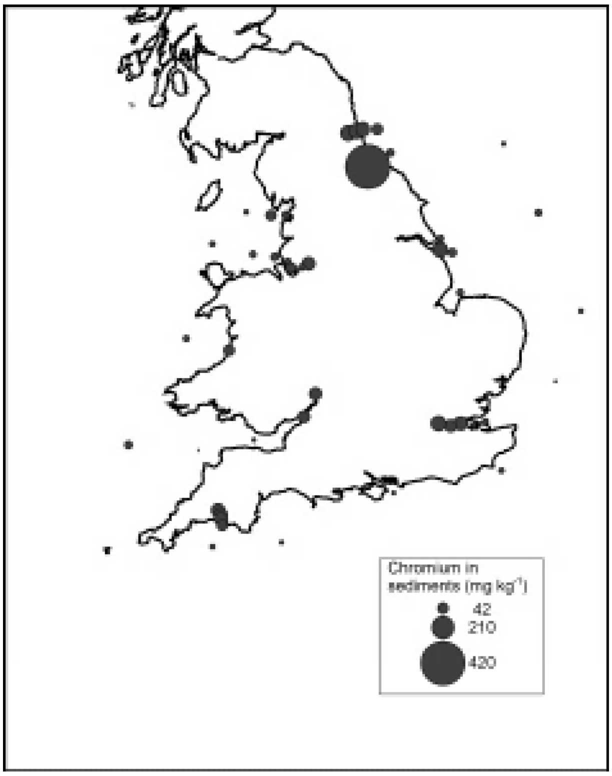


Figure 23. Concentrations of chromium in sediments (mg kg^{-1}). Concentrations are presented as area proportional symbols; scale symbols are shown in the legend

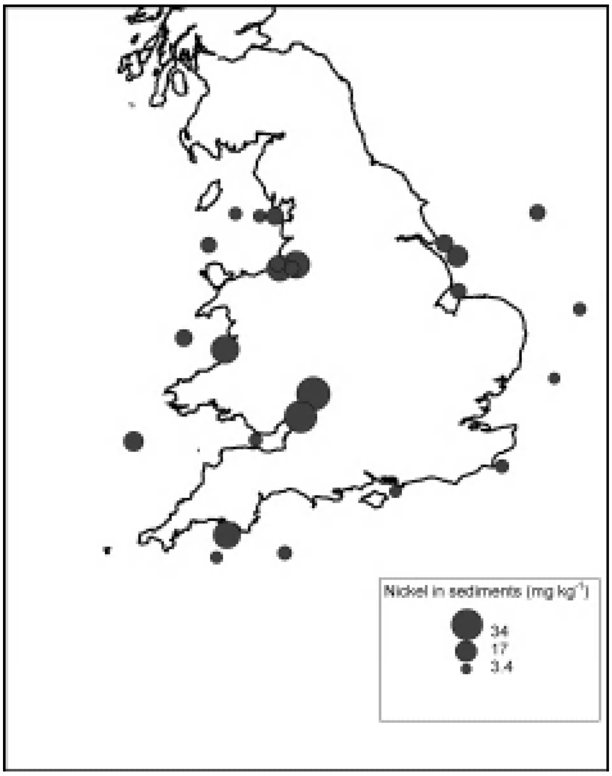


Figure 25. Concentrations of nickel in sediments (mg kg^{-1}). Concentrations are presented as area proportional symbols; scale symbols are shown in the legend

7.3 Summary

The previous observations of metal concentrations in sediments generally show relatively high concentrations in the estuaries compared to those offshore. However, it must be borne in mind that the estuarine sediments are often quite muddy and the offshore sediments sandy. Thus, it is often the case that estuarine sediments contain more clay and will therefore contain naturally, relatively high trace metal concentrations. Therefore, without some normalisation, it is unclear what proportion of the sediment metal load would be expected to occur naturally.

7.4 Normalisation

Sediment Al is present largely in clay minerals and therefore acts as a surrogate for those minerals. As clay minerals generally contain the majority of binding sites for metals, sediments with a high clay content therefore contain more metal than sandier sediments which have been exposed to similar levels of environmental metal. Aluminium, therefore, may be used to correct metal concentrations for the high or low binding ability (clay content) of sediments. This correction procedure involves the calculation of the degree to which the sediments contain more or less metal than expected, given their aluminium content, and is referred to as normalisation. It relies on having an accurate measure of the normaliser (e.g. Al).

Figure 26 shows Pb in sediment at all NMP stations plotted against Al. The majority of the samples have been used to calculate a regression between Pb and Al. The residuals between the regression and all individual samples have been calculated and are plotted in Figure 27. This represents the amount of Pb in excess of that expected, although without further work does not indicate whether it is from natural or anthropogenic sources.

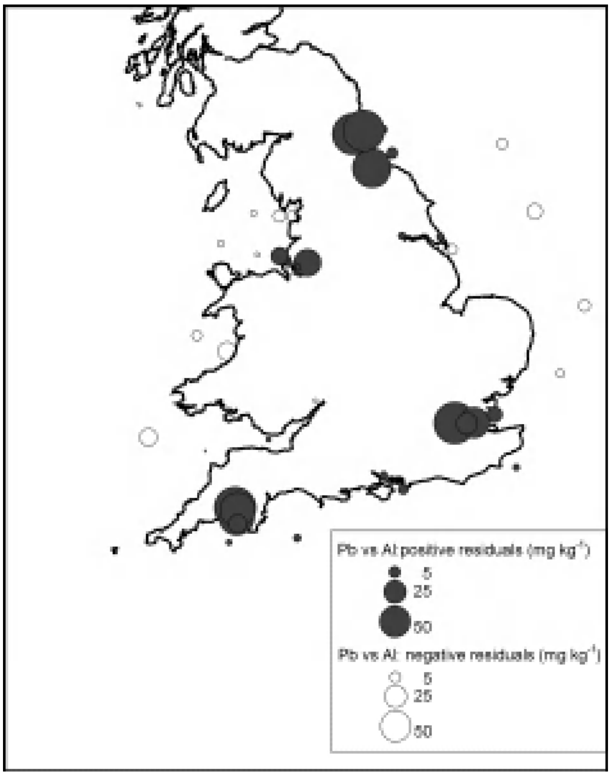


Figure 27. Lead vs. aluminium residuals (mg kg^{-1}). Concentrations are presented as area proportional symbols; scale symbols are shown in the legend

Figure 28 shows the relationship between Cr and Al, and Figure 29 shows the residuals at NMP stations. As Figure 29 is dominated by the Tees sample, little detail can be seen at the offshore sites. Figure 30 shows the relationship between Ni and Al in sediments at NMP stations and Figure 31 shows the residuals at NMP stations.

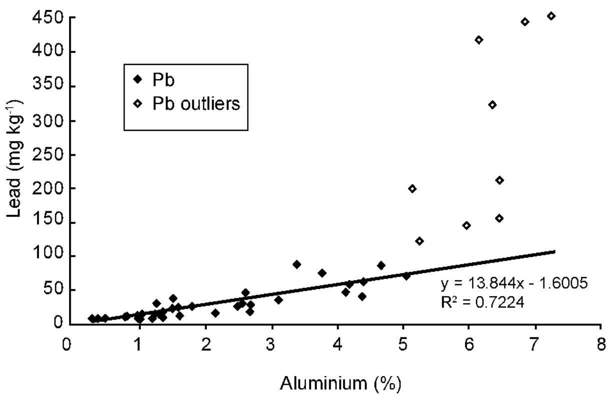


Figure 26. Lead (mg kg^{-1}) vs. aluminium (%) in sediment

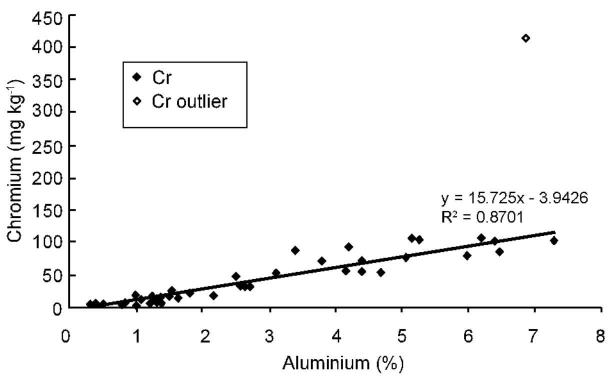


Figure 28. Chromium (mg kg^{-1}) vs. aluminium (%) in sediment

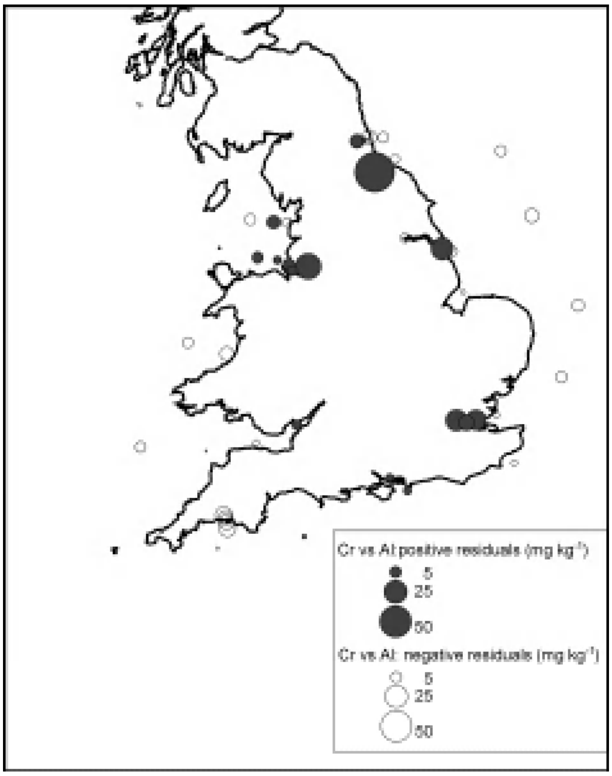


Figure 29. Chromium vs. aluminium residuals (mg kg^{-1}). Concentrations are presented as area proportional symbols; scale symbols are shown in the legend

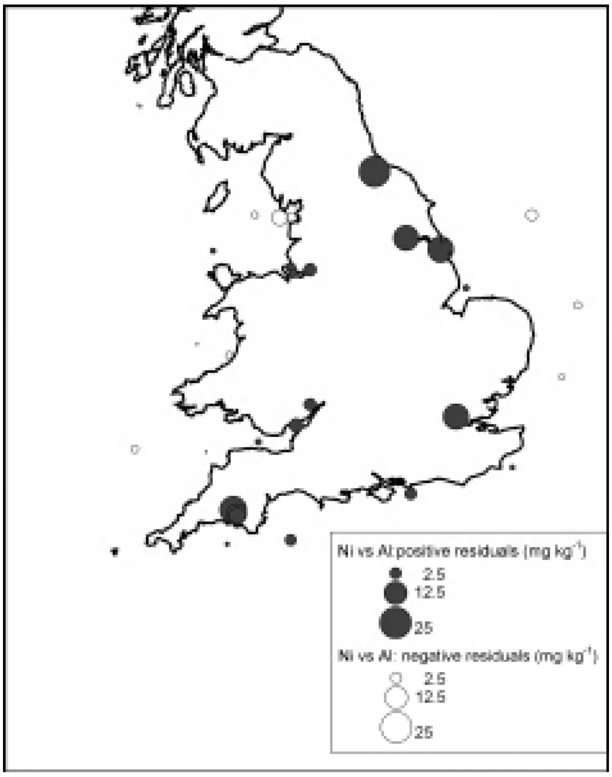


Figure 31. Nickel vs. aluminium residuals (mg kg^{-1}). Concentrations are presented as area proportional symbols; scale symbols are shown in the legend

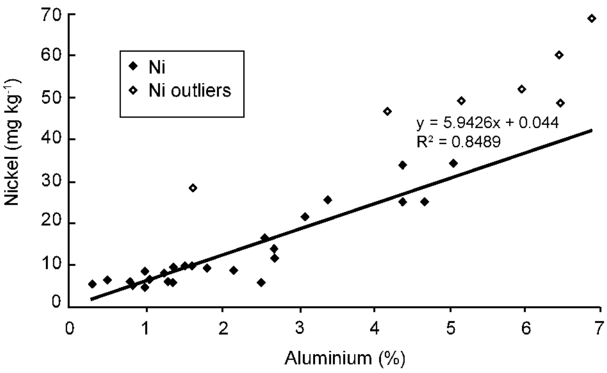


Figure 30. Nickel (mg kg^{-1}) vs. aluminium (%) in sediment

8. ORGANIC CONTAMINANTS IN SEDIMENTS

8.1 Introduction

Sampling was attempted at all intermediate and offshore NMP stations around England and Wales, on a number of occasions, using NMP guidelines. However, not all sites proved to have a suitable substrate for sampling using the preferred technique (Day grab), with some sites failing to provide any suitable material for analysis at all. Replicate samples (9) were however collected from the following stations: NMP605 Celtic Deep; NMP665 Off Cardigan Bay; NMP715 Liverpool Bay; and NMP795 Off Morecambe Bay.

The majority of samples were collected in 1993. Other samples were collected in 1994-6.

8.2 Methods

Analytical methods have been described elsewhere. NMP guidelines were followed and samples were analysed for dieldrin, pp'DDE, pp'TDE, pp'DDT. Supplementary information is provided for α- and γ-HCH. The eleven chlorobiphenyl congeners were determined and supplementary information is presented for a further 14 congeners. Total and organic carbon determinations were made at some sites, as was particle size analysis.

During the analytical stage the laboratory participated in both the NMAQC and the QUASIMEME programmes. Quality control was further supplemented by the analysis of certified reference material with each batch of samples.

8.3 Results and discussion

The full data set is presented in Table 12.

HCHs

Both α- and γ-HCH were below the limit of quantitation (0.04 $\mu g\ kg^{-1}$ dry weight) at the majority of sites. The highest concentration of α-HCH (0.22 $\mu g\ kg^{-1}$) was detected at NMP385 The Wash. This sample also had the second highest value for γ-HCH (0.21 $\mu g\ kg^{-1}$). The highest concentration of γ-HCH (0.29 $\mu g\ kg^{-1}$) was found at NMP376 the alternate Humber station.

Dieldrin

Dieldrin was detected at all sites, albeit at generally low concentrations (Figure 32). The highest concentrations were found at Stations 655, 665 and 575, Off Cardigan Bay, Cardigan Bay and Off Tamar respectively, with concentrations up to 0.9 $\mu g\ kg^{-1}$. Before restrictions, the use of dieldrin for moth proofing and timber treatment was widespread. The cluster of slightly elevated concentrations in the south west of England could be a result of the once widespread use of aldrin during narcissus cultivation.

DDT group

The DDT group compounds were commonly detected with 'total DDT' (the sum of DDE, TDE and DDT) reaching 2.44 $\mu g\ kg^{-1}$ at NMP705 Liverpool Bay. Concentrations above 1 $\mu g\ kg^{-1}$ for 'total DDT' were also detected at Stations 795 Off Morecambe Bay and 245 Off Tyne. In each case pp'TDE was the major compound detected which probably reflects historic input.

Chlorobiphenyls

Individual chlorobiphenyl congeners (CBs) were commonly detected although levels were generally low. Data are presented as the sum of the ICES7, the sum of the eleven selected CBs for the NMP and as the sum of the total of twenty-five CBs determined. The highest value for the sum of twenty-five CBs was 10.18 $\mu g\ kg^{-1}$ at NMP 575 Off Tamar. Concentrations above 5 $\mu g\ kg^{-1}$ were also found in the replicate samples from the Celtic Deep, confirming this offshore area as an accumulating site. Wells *et al*., (1989) defined a series of concentration guidelines:-

<0.2 $\mu g\ kg^{-1}$ contamination not detected

0.2- 20 $\mu g\ kg^{-1}$ slightly contaminated

21-100 $\mu g\ kg^{-1}$ contaminated

>100 $\mu g\ kg^{-1}$ heavily contaminated

The majority of the stations in this survey fall into the slightly contaminated category. Previous sampling at non-NMP stations have however demonstrated much higher concentrations and the question of site suitability for CB monitoring needs to be re-examined.

With the exception of CB#28, a trichlorobiphenyl, the CB profile was remarkably consistent at all sites when data was normalised to CB#153 (see Figures 33 and 34). However, no relationship could be found between CB concentration and levels of organic or total carbon (Figure 35).

9. PAH IN SURFACE SEDIMENTS

9.1 Methods

The methodology used is described in detail elsewhere (Woodhead *et al.,* in prep.), but briefly involved solvent extraction with ultrasonication, clean-up by automated solid-phase extraction, and analysis by HPLC with programmed fluorescence detection.

9.2 Analytical Quality Control (AQC)

A certified reference material (NIST 1941a) was analysed with each batch of 10 samples. This acted as an AQC sample for overall method control and extraction performance. Quantification was by means of an internal (surrogate) standard (anthracene-d_{10}) added prior to extraction. Procedural blanks and two external standard solutions containing the PAH to be determined (one an in-house mixed PAH standard) were also run alongside each batch of samples.

9.3 Programme

PAH are listed as additional determinands for which special surveys should be undertaken in order to assess the need for inclusion in wider scale studies. The NMP document suggests that analysis is undertaken in sediments, shellfish and fish muscle. Analyses were undertaken in surface sediments and sea water, and the sediment data are summarised here. In all, 95 samples of surficial sediment were analysed, 61 of which were from NMP stations. Forty-three different NMP sites were included, comprising offshore, intermediate and estuarine sites around England and Wales. Thirty-four other locations were also sampled, increasing coverage both within NMP estuaries and others not currently included in the programme. A number of the coastal/ estuarine sites were sampled at adjacent locations on the shore for logistical reasons, and these are indicated in Table 13. At the Celtic Deep site (NMP605), 9 samples were taken on a 250 m x 250 m grid to establish field variability as required by the NMP guidelines.

Table 12. Concentrations of organic contaminants (µg kg^{-1}) in sediments

NMP Station	Location	Date collected	Latitude	Longitude	Carbon		Concentrations µg kg^{-1}										
					(%) total	(%) organic	ΣICES7	NMPCBs	Σ25CBS	α–HCH	γ–HCH	HCB	DIELDRIN	PPDDE	PPTDE	PPDDT	ΣDDT
NMP245	Off Tyne//Tees	01/12/93	55° 0.50' N	1° 7.98' W	2.45	1.87	1.17	1.36	2.81	0.11	0.13	0.34	0.49	0.31	0.86	<0.04	1.17
NMP285	Off Tyne/Tees	10/05/94	54° 50.01' N	1° 19.98' W	-	-	<0.04	<0.04	0.26	0.08	0.1	0.21	0.14	<0.04	<0.04	<0.04	<0.04
NMP295	Off Tees	30/11/93	54° 44.03' N	0° 52.97' W	1.29	1.04	1.21	1.26	4.63	0.19	0.2	0.49	0.31	0.11	0.42	<0.04	0.53
NMP345	Off Humber/Wash	05/05/94	54° 0.00' N	1° 59.97' E	-	-	0.31	0.31	2.79	0.12	0.15	0.25	0.28	<0.04	0.05	<0.04	0.05
NMP375	Humber	14/05/94	53° 32.01' N	0° 20.01' W	3.88	0.77	0.05	0.05	0.42	0.15	0.17	0.32	0.49	0.08	0.63	<0.04	0.71
NMP376		14/05/93	53° 20.00' N	0° 34.98' E	2.6	0.68	1.02	1.11	2.07	0.12	0.29	0.22	0.39	0.19	1.2	<0.04	1.39
NMP385	Wash	15/05/94	53° 3.51' N	0° 28.51' W	-	-	0.38	0.38		0.22	0.21	0.3	0.25	0.09	0.44	<0.04	0.53
NMP395	Southern Bight	20/02/94	52° 50.00' N	2° 50.05' E	-	-	<0.04	<0.04	<0.04	0.21	<0.04	<0.04	0.18	<0.04	<0.04	<0.04	<0.04
NMP465	Thames	08/07/95	51° 30.80' N	0° 58.00' E	-	-	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.58	<0.04	<0.04	<0.04	<0.04
NMP465	Thames	15/06/96	51° 30.80' N	0° 58.00' E	-	-	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.23	<0.04	<0.04	<0.04	<0.04
NMP485	South Varne	19/02/94	50° 58.22' N	1° 14.00' W	0.9	0.12	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.15	<0.04	<0.04	0.07	0.07
NMP495	Selsey Bill	17/02/94	50° 39.00' N	0° 49.92' W	3.06	0.16	0.05	0.05	0.1	<0.04	0.09	<0.04	0.23	<0.04	<0.04	0.3	0.3
NMP535	Central Channel	29/05/93	50° 5.09' N	3° 0.01' W	5.47	0.17	0.05	0.05	0.11	<0.04	0.06	<0.04	0.24	<0.04	<0.04	<0.04	<0.04
NMP575	Off Tamar	14/02/94	50° 17.71' N	4° 9.68' W	3.34	0.78	4.4	5.41	10.18	0.07	0.15	0.19	0.67	0.09	0.22	<0.04	0.31
NMP585	Off Plymouth Sound	15/02/94	50° 2.01' N	4° 22.00' W	3.11	0.23	0.19	0.19	0.49	<0.04	0.09	0.08	0.15	<0.04	<0.04	<0.04	<0.04
NMP605	Celtic Deep	28/05/93	51° 14.99' N	5° 59.97' W			1.44	1.68	3.62	<0.04	0.16	0.07	0.56	0.08	0.1	<0.04	0.18
NMP605	Celtic Deep	28/05/93	51° 15.09' N	6° 0.14' W	5.68	1.12	1.92	2.26	4.47	<0.04	0.1	0.08	0.37	0.09	0.1	<0.04	0.19
NMP605	Celtic Deep	28/05/93	51° 14.98' N	6° 0.22' W	5.13	0.6	1.11	1.26	2.67	<0.04	0.11	0.06	0.42	0.07	0.07	<0.04	0.14
NMP605	Celtic Deep	28/05/93	51° 14.81' N	6° 0.17' W	5.2	0.69	2.56	3	6.75	<0.04	0.15	0.43	0.45	0.08	0.07	<0.04	0.15
NMP605	Celtic Deep	28/05/93	51° 15.15' N	5° 59.81' W	5.13	0.68	2.24	2.61	5.12	<0.04	0.08	0.06	0.4	0.07	0.1	<0.04	0.17
NMP605	Celtic Deep	28/05/93	51° 15.01' N	5° 59.73' W	5	0.63	1.31	1.53	3.18	<0.04	0.09	0.05	0.51	0.07	0.06	<0.04	0.13
NMP605	Celtic Deep	28/05/93	51° 14.82' N	5° 59.76' W	4.93	0.49	3.77	4.35	9.52	0.04	0.11	0.06	0.48	0.07	0.07	<0.04	0.14
NMP605	Celtic Deep	28/05/93	51° 15.13' N	6° 0.00' W	5.16	0.5	1.53	1.78	3.79	<0.04	0.1	0.21	0.57	0.08	0.11	<0.04	0.19
NMP605	Celtic Deep	28/05/93	51° 14.89' N	5° 59.96' W	5.08	0.5	1.3	1.53	3.02	<0.04	0.1	0.07	0.51	0.08	0.1	<0.04	0.18
NMP615	Severn	11/02/94	51° 26.04' N	3° 58.92' W	2.18	0.27	<0.04	<0.04	0.04	0.05	0.07	<0.04	0.18	<0.04	<0.04	<0.04	<0.04
NMP655	Cardigan Bay	27/05/93	52° 21.48' N	4° 10.45' W	-	-	1.17	1.32	2.77	0.06	0.15	0.09	0.89	0.11	0.1	<0.04	0.21
NMP665	Off Cardigan Bay	27/05/93	52° 30.08' N	4° 59.54' W	-	-	<0.04	<0.04	<0.04	<0.04	0.04	<0.04	0.3	<0.04	<0.04	<0.04	<0.04
NMP665	Off Cardigan Bay	27/05/93	52° 29.88' N	5° 0.21' W	1.04	0.15	0.36	0.41	0.79	<0.04	0.08	<0.04	0.58	<0.04	0.04	<0.04	0.04
NMP665	Off Cardigan Bay	27/05/93	52° 30.00' N	5° 0.21' W	0.81	0.07	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.32	<0.04	<0.04	<0.04	<0.04
NMP665	Off Cardigan Bay	27/05/93	52° 30.14' N	5° 0.21' W	1.39	0.28	0.64	0.69	1.64	<0.04	0.1	0.06	0.67	0.05	0.05	<0.04	0.1
NMP665	Off Cardigan Bay	27/05/93	52° 29.88' N	4° 59.79' W	1.33	0.68	0.88	1	1.92	<0.04	0.11	0.06	0.81	<0.04	<0.04	<0.04	<0.04
NMP665	Off Cardigan Bay	27/05/93	52° 30.02' N	4° 59.81' W	1.25	0.13	<0.04	<0.04	0.07	<0.04	0.06	<0.04	0.39	<0.04	<0.04	<0.04	<0.04
NMP665	Off Cardigan Bay	27/05/93	52° 30.16' N	4° 59.84' W	0.97	0.12	0.05	0.05	0.16	<0.04	0.06	<0.04	0.38	<0.04	<0.04	<0.04	<0.04
NMP665	Off Cardigan Bay	27/05/93	52° 29.89' N	4° 59.98' W	1.9	0.46	1.86	2.19	4.15	<0.04	0.12	0.08	0.9	0.07	0.07	<0.04	0.14
NMP665	Off Cardigan Bay	27/05/93	52° 30.15' N	4° 60.00' W	1.12	0.15	0.63	0.68	1.83	<0.04	0.1	<0.04	0.62	<0.04	<0.04	<0.04	<0.04

Table 12. continued

NMP Station	Location	Date collected	Latitude	Longitude	Carbon		Concentrations µg kg^{-1}										
					(%) total	(%) organic	ΣICES7	NMPCBs	Σ25CBS	α–HCH	γ–HCH	HCB	DIELDRIN	PPDDE	PPTDE	PPDDT	ΣDDT
NMP705	Liverpool Bay	20/06/96	53° 28.27' N	3° 15.61' W	-	-	1.66	1.93	2.48	<0.04	0.33	<0.04	0.88	0.37	1.4	0.67	2.44
NMP705	Liverpool Bay	26/05/93	53° 28.54' N	3° 19.18' W	-	-	0.72	0.76		0.17	0.39	0.15	0.17	0.1	0.46	<0.04	0.56
NMP715	Liverpool Bay	17/09/93	53° 29.99' N	3° 41.49' W	-	-	0.33	0.33	0.51	<0.04	<0.04	<0.04	0.2	0.09	0.06	<0.04	0.15
NMP715	Liverpool Bay	17/09/93	53° 30.00' N	3° 41.61' W	-	-	0.05	0.05	0.13	<0.04	<0.04	<0.04	0.16	<0.04	<0.04	<0.04	<0.04
NMP715	Liverpool Bay	17/09/93	53° 30.13' N	3° 41.65' W	-	-	0.06	0.06	0.15	<0.04	0.04	<0.04	0.2	<0.04	<0.04	<0.04	<0.04
NMP715	Liverpool Bay	17/09/93	53° 30.15' N	3° 41.53' W	-	-	0.37	0.47	0.74	<0.04	0.04	<0.04	0.24	0.06	0.08	0.22	0.36
NMP715	Liverpool Bay	17/09/93	53° 30.12' N	3° 41.25' W	-	-	0.3	0.3	0.48	<0.04	<0.04	<0.04	0.18	<0.04	<0.04	0.08	0.08
NMP715	Liverpool Bay	17/09/93	53° 29.99' N	3° 41.29' W	-	-	0.23	0.23	0.34	<0.04	<0.04	<0.04	0.21	<0.04	<0.04	<0.04	<0.04
NMP715	Liverpool Bay	17/09/93	53° 29.84' N	3° 41.29' W	-	-	0.17	0.17	0.27	<0.04	<0.04	<0.04	0.21	0.05	<0.04	0.12	0.17
NMP715	Liverpool Bay	17/09/93	53° 29.87' N	3° 41.52' W	-	-	1.97	2.41	4.16	<0.04	0.06	0.14	0.43	0.2	0.68	<0.04	0.88
NMP715	Liverpool Bay	17/09/93	53° 29.86' N	3° 41.67' W	-	-	0.04	0.04	0.09	<0.04	<0.04	<0.04	0.23	<0.04	<0.04	<0.04	<0.04
NMP785	Off Lune/Wyre	25/05/93	53° 58.18' N	3° 1.58' W	1.84	0.5	0.65	0.77	1.26	<0.04	0.1	0.06	0.17	0.09	0.32	<0.04	0.41
NMP785	Off Lune/Wyre	08/02/94	53° 57.68' N	3° 2.55' W	-	-	1.78	2.19	<0.04	0.08	0.25	0.43	0.55	0.32	1.7	<0.04	<0.04
NMP785	Off Lune/Wyre	08/02/94	53° 58.25' N	3° 3.13' W	1.22	0.35	<0.04	<0.04	<0.04	<0.04	0.09	0.07	0.16	<0.04	0.14	<0.04	<0.04
NMP785	Off Lune/Wyre	21/09/93	53° 58.29' N	3° 3.17' W	-	-	0.17	0.17		0.26	0.27	0.13	0.18	<0.04	0.2	<0.04	<0.04
NMP795	Off Morecambe Bay	25/05/93	53° 57.98' N	3° 20.00' W	-	-	0.96	1.15	2.22	<0.04	0.05	0.1	0.25	0.17	0.54	<0.04	0.71
NMP795	Off Morecambe Bay	25/05/93	53° 58.12' N	3° 20.08' W	1.69	0.25	0.91	1.1	2.03	<0.04	0.05	0.1	0.21	0.16	0.51	<0.04	0.67
NMP795	Off Morecambe Bay	25/05/93	53° 58.10' N	3° 20.20' W	1.55	0.3	1.63	2.02	4.9	<0.04	<0.04	0.19	0.16	0.17	0.55	0.11	0.83
NMP795	Off Morecambe Bay	25/05/93	53° 57.98' N	3° 20.31' W	1.71	0.45	1.74	2.14	3.91	<0.04	0.08	0.29	0.34	0.3	1.1	0.19	1.59
NMP795	Off Morecambe Bay	25/05/93	53° 58.16' N	3° 19.70' W	1.6	0.24	0.9	1.05	1.9	<0.04	0.04	0.08	0.19	0.13	0.43	0.1	0.66
NMP795	Off Morecambe Bay	25/05/93	53° 57.99' N	3° 19.82' W	1.67	0.29	1	1.16	2.01	<0.04	0.04	0.09	0.18	0.13	0.46	<0.04	0.59
NMP795	Off Morecambe Bay	25/05/93	53° 57.93' N	3° 19.76' W	1.54	0.24	1.45	2.05	3.29	<0.04	0.04	0.23	0.19	0.15	0.45	0.13	0.73
NMP795	Off Morecambe Bay	25/05/93	53° 57.90' N	3° 19.96' W	1.5	0.29	0.89	1.03	1.91	<0.04	0.05	0.13	0.21	0.15	0.54	0.15	0.84
NMP795	Off Morecambe Bay	25/05/93	53° 57.87' N	3° 20.18' W	1.5	0.31	1.36	1.66	2.88	<0.04	0.05	0.24	0.22	0.23	0.81	0.13	1.17
NMP805	SE of Isle of Man	17/09/93	53° 59.99' N	3° 49.94' W	-	-	0.24	0.24	0.3	<0.04	<0.04	<0.04	0.24	0.04	0.07	<0.04	0.11
NMP805	SE of Isle of Man	09/02/94	54° 0.02' N	3° 49.85' W	-	-	<0.04	<0.04	<0.04	0.06	0.12	<0.04	0.14	<0.04	<0.04	<0.04	<0.04

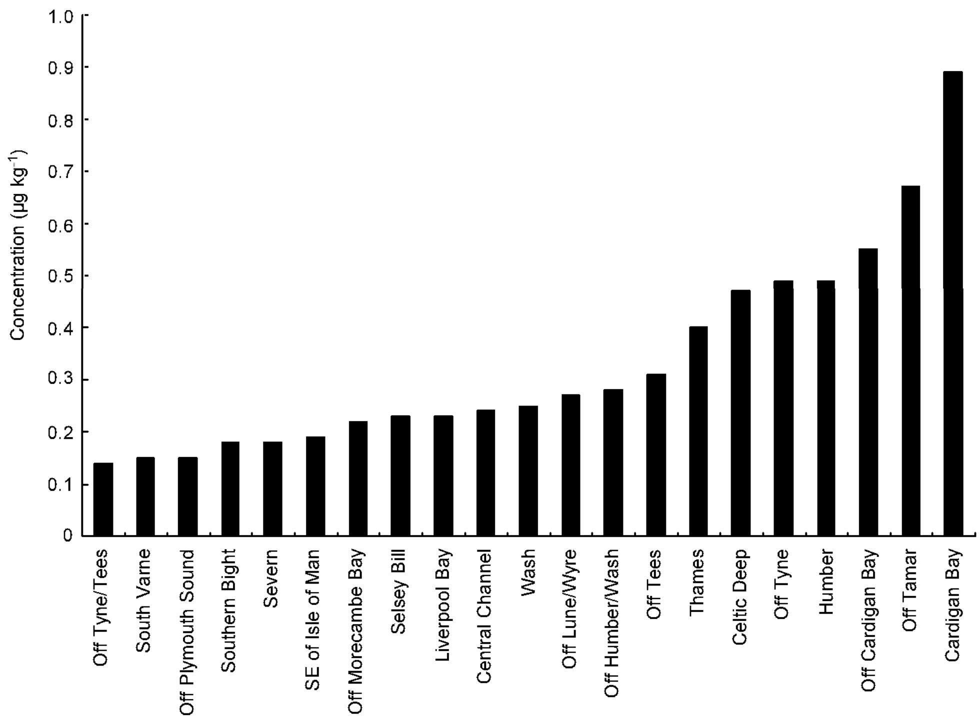


Figure 32. Concentrations of dieldrin (µg kg^{-1}) in NMP sediments

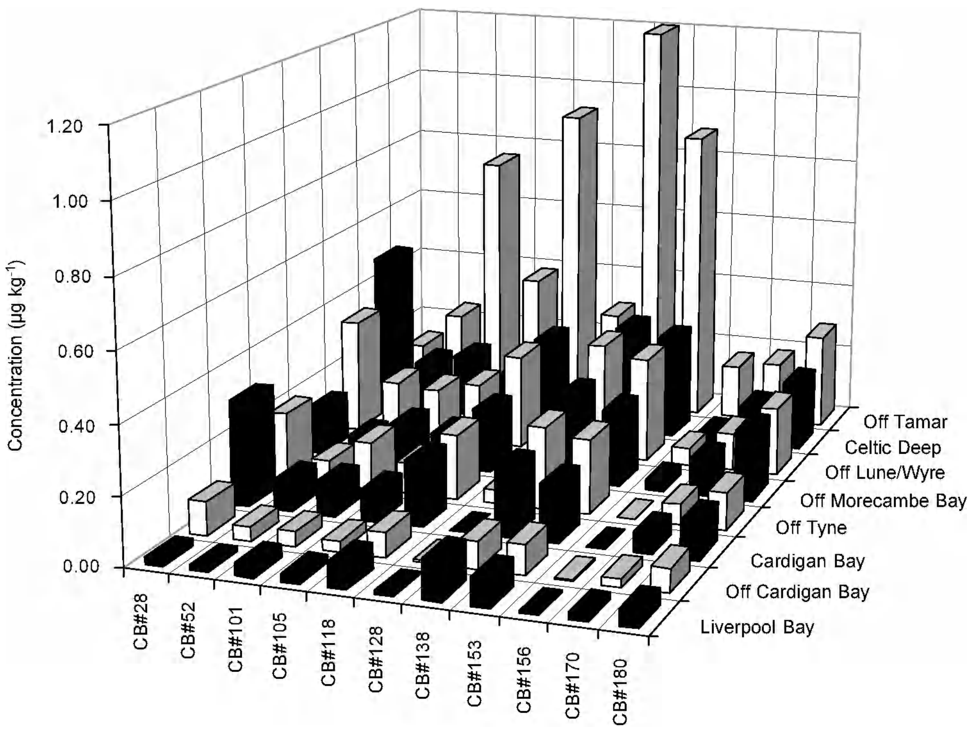


Figure 33. CB profile in NMP sediments

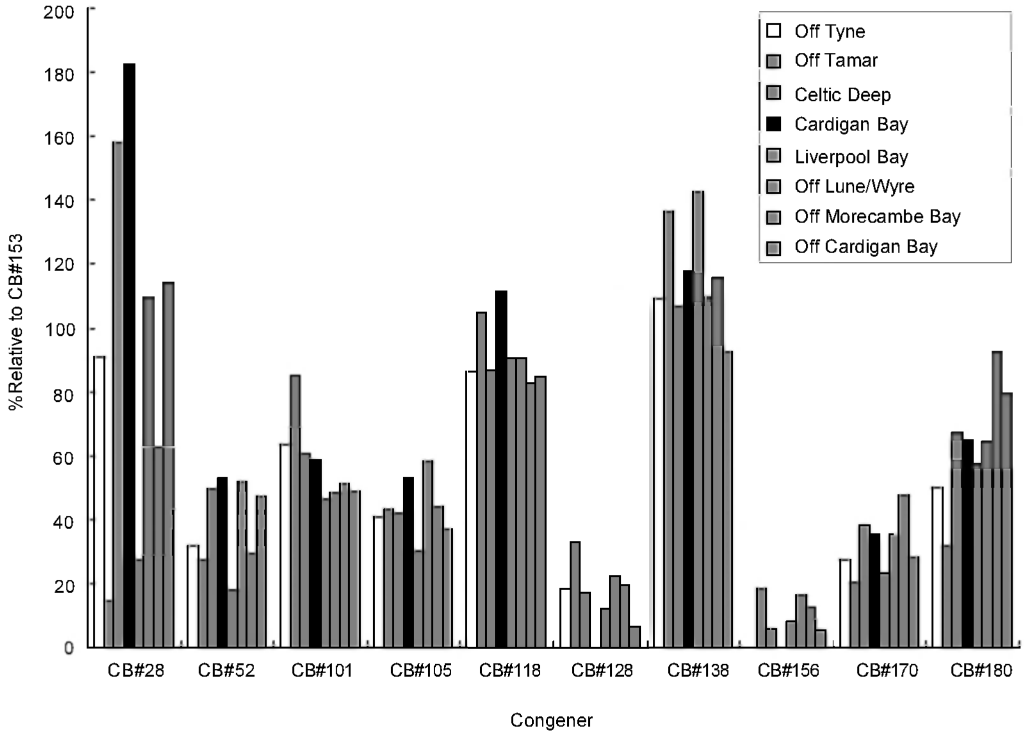


Figure 34. CB profile in NMP sediments normalised to CB#153

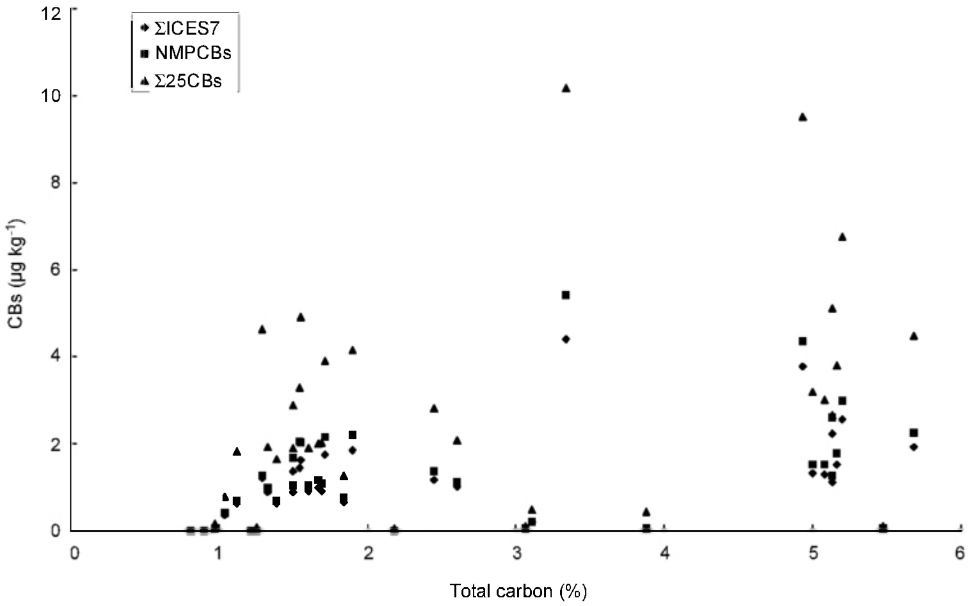


Figure 35. CBs in NMP sediments v Total carbon

9.4 Results

The results are presented in Table 13. The 10 PAH compounds for which data are listed are a subset of those determined, and the full data are presented elsewhere (Woodhead *et al.,* in prep.). The total concentration of the 10 PAH listed is also given as ΣPAH. In the Table, the data for NMP stations is given first, followed by data for other sites. In both cases data are presented in a clockwise manner from the north east of England.

The highest concentrations (ΣPAH >10 mg kg^{-1} dry weight) were found in the highly industrialised estuaries of north east England, particularly in muddy sediments from the Rivers Tyne and Wear (NMP225 and 265). ΣPAH concentrations between 1 and 10 mg kg^{-1} were found at sites in the Rivers Thames (NMP455), Tamar (NMP555, 565 and 575), Severn (NMP635); and also at two intermediate sites (NMP245 off the Tyne, and NMP295 off the Tees) (Figure 36).

Additional sediment samples taken at non-NMP sites indicate that fine sediments from the Rivers Blyth and Tees also yield ΣPAH concentrations above 10 mg kg^{-1} dry weight, as did samples from a further site in the River Tyne at Tyne Bridge. ΣPAH concentrations between 1 and 10 mg kg^{-1} were found at sites in Poole Harbour, the River Exe, Swansea Bay (Port Talbot, the Neath Channel and the entrance of the River Tawe), at Tenby, and in the River Mersey. Nine sediments taken on a 3 x 3 grid in the Celtic Deep yielded ΣPAH concentrations of 366 to 786 µg kg^{-1} dry weight, with both total and individual PAH concentrations varying by up to approximately a factor of 2.

9.5 Significance of PAH data

This data set is incomplete at present and so no ecotoxicological assessment has been undertaken as yet. This will be undertaken as a part of the preparation for journal publication (Woodhead *et al.* (in prep)).

9.6 Future work

Coverage of NMP stations in this pilot study of PAH in sediments was not fully exhaustive, but a good spatial coverage was achieved and in some cases replicated over 2 years. These data suggest that:

(i) concentrations are low or undetectable at most intermediate and offshore sites, and further work should be concentrated on fine sediments and depositional areas. Undisturbed sediments in deep water depositional areas also offer the possibility of analysing sediment cores in order to assess historical changes in PAH transport, but more needs to be known about sources of disturbance (e.g. bioturbation, fishing activity) in candidate areas such as the Celtic Deep before this can be confidently recommended. Preliminary studies are underway at six sites, five of which are current NMP stations.

(ii) significant concentrations of PAH have been found in a number of estuaries, and a fully systematic coverage of UK estuaries should be undertaken.

(iii) the bioavailability of PAH and their uptake by shellfish (particularly bivalve molluscs) should also be evaluated in the next phase of the NMP programme, so that the significance of these compounds can be fully assessed, both for marine animals and human consumers.

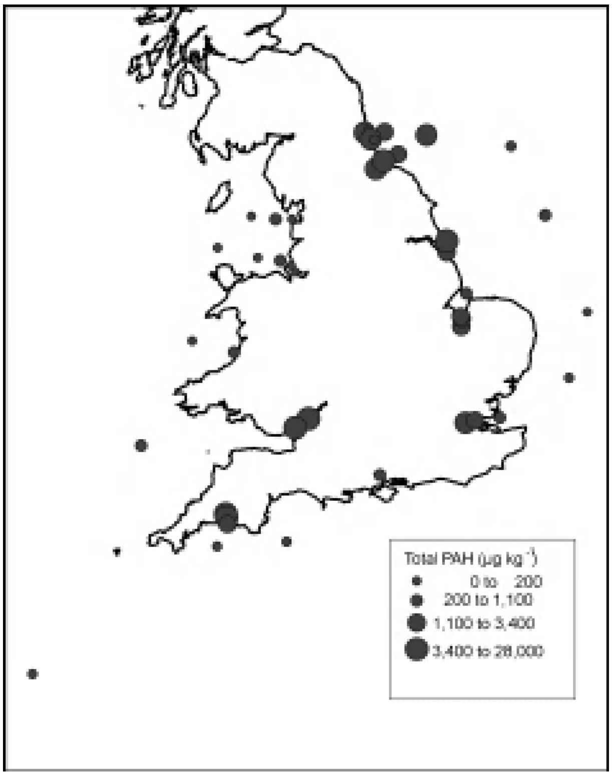


Figure 36. Concentrations (µg kg^{-1}) of PAH (sum of 10 individual PAH compounds) in sediments from NMP stations

Table 13. PAH concentrations in sediments (µg kg^{-1} dry weight)

NMPstation	Location	Date	Sediment type	Naph	Phen	Anth	Fluoranth	Pyr	BaA	Chrys	BeP	BaP	BghiP	ΣPAH
215	R. Tyne (u/s Scotswood Bridge)	28/08/96	mud	409	1157	251	1464	1721	945	753	2417	952	722	**10790**
225	R. Tyne (Hebburn)	14/06/93	mud	2430	6218	1467	6609	5904	4130	3412	N/D	3313	1927	**35410**
225	R. Tyne (Hebburn)	13/06/94	mud	1949	3082	785	2441	3127	1585	1425	3478	1432	1117	**20422**
235	R. Tyne (Littlehaven Beach)	28/08/96	sand	<17	67	21	26	39	16	20	30	16	<20	**236**
245	Off Tyne	11/06/93	mud	71	127	30	98	202	87	92	255	116	165	**1243**
265	R. Wear (Queen Alexandra Bridge)	14/06/93	mud	1225	1537	326	1401	1904	869	902	2264	1009	814	**12252**
265	R. Wear (Queen Alexandra Bridge)	14/06/94	mud	2027	3057	795	4195	4159	2054	1797	4935	2068	1848	**26934**
275	R. Wear (Sandy Point)	14/06/93	sand	20	22	7	16	32	10	14	22	11	12	**166**
275	R. Wear (Sandy Point)	14/06/94	sand	206	136	9	41	47	23	33	46	26	46	**613**
285	Off Tyne/Tees	15/06/94	fine sand & shell	166	175	27	151	122	26	42	N/D	18	27	**753**
295	Off Tees	14/06/94	mud	300	272	41	121	171	99	110	318	101	195	**1728**
305	R. Tees (Preston Park)	28/08/96	mud	83	159	3	77	29	20	22	72	23	94	**581**
315	R. Tees (Victoria Bridge)	28/08/96	gravel & mud	65	629	62	653	619	260	392	707	346	302	**4035**
325	R. Tees (North Gare)	28/08/96	mud	1576	1973	139	1401	811	269	269	798	311	269	**7817**
335	R. Humber (Spurn Head)	30/07/96	mud & sand	297	491	74	308	434	173	186	562	246	201	**2972**
345	Off Humber/Wash	13/06/93	mud	N/D	<17	N/D	N/D	17	10	9	30	19	96	**181**
345	Off Humber/Wash	16/06/94	sand & mud	N/D	N/D	N/D	N/D	N/D	6	5	N/D	3	25	**38**
365	R. Humber (Skitter Haven)	30/07/96	mud	543	900	169	490	981	369	354	1193	553	562	**6115**
375	R. Humber	13/07/96	shell, mud & gravel	77	108	8	57	60	24	38	104	28	41	**545**
385	Wash	13/07/96	sand	24	93	N/D	30	49	5	15	30	N/D	26	**272**
395	Southern Bight (Smiths Knoll)	16/06/94	fine sand	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	**0**
405	Great Ouse (Stowe Bridge)	31/07/96	mud	140	295	26	12	188	81	88	159	73	50	**1113**
415	Great Ouse (Freebridge, Kings Lynn)	31/07/96	mud	265	457	47	144	309	121	102	418	150	152	**2165**
425	Great Ouse (The Point, Kings Lynn)	31/07/96	mud	142	350	35	138	360	151	108	327	154	166	**1932**
445	R. Thames (West Thurrock)	16/07/96	mud	116	482	79	670	895	283	259	1071	717	777	**5350**
445	R. Thames (Mucking)	16/07/96	mud	80	253	64	485	482	227	196	777	395	419	**3377**
465	R. Thames (Warp)	16/06/93	mud & sand	N/D	83	11	83	69	68	72	N/D	123	94	**603**
465	R. Thames (Warp)	15/06/96	sand & mud	13	60	15	96	114	51	44	98	60	45	**597**
475	R. Thames (Outer Gabbard)	16/06/94	fine sand	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	**0**
505	Southampton Water (Dock Head)	11/09/96	fine sand	N/D	34	8	86	124	53	52	119	79	47	**600**
535	Central Channel	18/06/94	sand & shell	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	**0**
555	R.Tamar (Warren Point)	18/06/93	mud	37	398	139	926	1129	628	504	1048	1024	361	**6194**
565	R. Tamar (Hamoaze)	18/06/93	mud	<30	373	131	1111	1125	878	747	N/D	1102	558	**6025**
575	Off Tamar	19/06/94	mud	33	196	150	396	459	234	178	473	246	214	**2579**
575	Off Tamar	10/07/95	mud	60	219	74	336	401	262	177	579	286	197	**2591**
585	Off Plymouth Sound	19/06/94	sand & shell	N/D	N/D	N/D	N/D	N/D	<2	<2	N/D	N/D	N/D	**0**
595	Western Approaches	20/06/94	sand & shell	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	**0**
605	Celtic Deep	20/06/93	mud	<30	81	17	152	66	65	69	59	62	36	**607**
605	Celtic Deep	20/06/93	mud	38	94	18	81	119	57	68	81	69	161	**786**
605	Celtic Deep	20/06/93	mud	34	41	17	81	68	43	49	121	42	54	**550**
605	Celtic Deep	20/06/93	mud	31	117	23	150	88	63	82	126	66	N/D	**746**
605	Celtic Deep	20/06/93	mud	<25	58	15	40	60	36	45	84	28	<28	**366**
605	Celtic Deep	20/06/93	mud	<25	100	25	94	121	56	68	136	49	N/D	**649**
605	Celtic Deep	20/06/93	mud	39	81	20	146	108	54	68	104	56	<28	**676**
605	Celtic Deep	20/06/93	mud	<25	133	25	164	111	54	64	110	54	N/D	**715**
605	Celtic Deep	20/06/93	mud	42	64	15	119	80	41	52	85	51	23	**572**
635	Severn Beach	16/07/96	mud	291	471	128	821	599	330	349	773	357	391	**4511**
645	R. Severn (English Grounds)	16/07/96	mud	290	586	127	631	575	333	365	843	410	412	**4572**
655	Cardigan Bay	21/06/93	mud	<30	94	28	142	98	105	103	52	103	79	**804**
665	Outer Cardigan Bay	19/06/96	sand & shell	N/D	N/D	N/D	N/D	4	2	2	8	2	4	**21**
705	Burbo Bight	22/06/93	sand over mud	19	22	10	47	79	48	46	207	58	72	**607**
705	Burbo Bight	23/06/94	sand over mud	32	137	32	164	164	64	62	129	93	77	**954**

Table 13. continued

NMPstation	Location	Date	Sediment type	Naph	Phen	Anth	Fluoranth	Pyr	BaA	Chrys	BeP	BaP	BghiP	ΣPAH
715	Liverpool Bay	22/06/94	sand	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	**0**
745	R. Mersey (Bromborough E1 buoy)	23/06/94	sand	N/D	N/D	1	N/D	N/D	N/D	N/D	N/D	2	3	**6**
745	R. Mersey (Bromborough E1 buoy)	20/06/96	sand	N/D	N/D	1	<5	N/D	4	2	15	7	5	**35**
755	R. Mersey (Seacombe Ferry)	23/06/94	sand	N/D	24	5	49	39	16	14	24	14	11	**195**
775	Irish Sea	23/06/93	sand, stones & shell	N/D	N/D	N/D	N/D	N/D	1	<2	5	1	<2	**6**
785	Off Lune/Wyre	24/06/93	sand	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	**0**
795	Off Morecambe Bay	24/06/93	mud	N/D	<14	8	92	38	47	42	N/D	54	51	**332**
795	Off Morecambe Bay	22/06/94	mud	22	22	7	45	50	23	25	79	35	41	**348**
805	SE Isle of Man	22/06/94	sand & shell	N/D	N/D	1	N/D	4	2	3	8	3	5	**26**
	R. Tweed (buoy off Spittal Point)	10/06/93	sand	N/D	N/D	N/D	N/D	8	3	4	9	7	13	**45**
	R. Blyth (South Harbour entrance)	12/06/94	mud	1116	2491	318	259	1007	485	860	2051	533	802	**9921**
	R. Blyth (North Blyth)	12/06/94	mud	939	1968	392	574	1036	636	863	2493	694	916	**10511**
	R. Tyne (Tyne Bridge)	13/06/94	mud	1799	3353	785	3588	3235	1727	1559	3693	1686	1280	**22704**
	R. Wear (anchor outside piers)	12/06/96	mud	449	371	37	136	171	61	91	265	70	59	**1710**
	R. Tees (Bamlett's Bight)	15/06/94	mud	1909	2240	644	3233	3227	1702	1424	3881	1730	1588	**21578**
	R. Tees (Redcar jetty)	15/06/93	mud	2738	2174	437	1918	1898	1619	1381	521	1392	952	**15030**
	north of Friesland Junction (NSTF50)	13/06/93	mud	N/D	<17	N/D	N/D	18	7	8	37	16	<28	**86**
	Humber (Old Den)	30/07/96	mud & sand	297	336	69	226	454	192	173	551	253	252	**2803**
	R. Blackwater (Bradwell Waterside #1)	03/09/96	mud	91	782	121	1526	1759	664	573	1542	782	623	**8463**
	R. Blackwater (Bradwell Waterside #2)	03/09/96	mud	92	481	89	574	761	269	243	873	337	292	**4011**
	R. Crouch (West Quay Pontoon, Burnham #1)	05/09/96	mud	40	130	16	87	174	70	69	197	94	101	**979**
	R. Crouch (West Quay Pontoon, Burnham #2)	05/09/96	mud	43	176	24	151	201	78	85	260	108	107	**1233**
	Eastern Solent	09/07/95	mud	N/D	N/D	N/D	47	41	15	12	50	19	<10	**184**
	Langstone Harbour (NW Sinah buoy)	09/07/95	fine sand	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	**0**
	Poole Harbour (Stakes buoy : No. 55)	18/06/94	mud	<17	55	16	72	102	35	21	78	45	40	**464**
	Poole Harbour (Cobb's Quay marina)	18/06/94	mud	28	71	20	185	263	101	90	270	152	150	**1330**
	R. Exe (No. 39 Turf buoy)	10/07/95	mud	197	416	94	935	689	380	240	876	479	346	**4654**
	R. Exe (No. 21 buoy)	10/07/95	sand	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	**0**
	R. Exe (No. 13 buoy)	10/07/95	sand	N/D	42	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	**42**
	R. Tamar (E. Tamar north buoy)	19/06/94	mud	48	250	73	854	709	367	265	794	468	381	**4209**
	Plymouth Sound	19/06/94	sand, stones & shell	46	366	110	518	636	282	240	478	315	230	**3222**
	Western Approaches	20/06/94	sand & shell	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	**0**
	Port Talbot	18/06/96	mud	400	577	167	849	937	484	520	1010	502	477	**5922**
	Neath Channel	19/06/96	mud	261	224	58	313	270	122	97	247	114	47	**1753**
	R. Tawe entrance	19/06/96	mud	379	671	156	826	921	510	367	943	483	483	**5739**
	Mumbles Head	19/06/96	sand & shell	16	29	2	29	30	9	10	25	8	12	**169**
	Tenby	23/06/96	mud	84	116	22	135	132	70	90	246	84	93	**1073**
	Milford Haven (Neyland Spit)	21/06/96	mud	N/D	5689	6055	21280	22127	8502	6940	14599	5358	2759	**93309**
	St Bride's Bay	23/06/96	fine sand & mud	10	17	2	N/D	7	6	9	18	6	8	**84**
	New Quay	21/06/93	mud & gravel	<30	48	6	56	11	31	26	15	25	26	**244**
	R. Mersey (Eastham Lock)	22/06/93	mud	144	459	132	601	868	341	301	898	510	459	**4713**
	R. Mersey (Eastham Lock)	23/06/94	mud	156	491	135	620	831	359	350	1242	587	465	**5236**
	R. Mersey (Tranmere oil terminal)	23/06/94	mud	61	116	37	135	201	101	106	450	184	166	**1558**
	Off Selker Rocks	20/06/96	mud	39	102	16	98	147	68	68	231	98	114	**981**

Note: *Naph - napthalene* *Phen - phenanthrene* *Anth - anthracene*
Fluoranth - fluoranthene *Pyr - pyrene* *BaA - benz[a]anthracene*
Chrys - chrysene *BeP - benzo[e]pyrene* *BaP - benzo[a]pyrene*
BghiP - benzo[ghi]perylene *ΣPAH - sum of 10 PAH*

10. ASSESSMENT OF SEDIMENT QUALITY: OYSTER EMBRYO BIOASSAY

10.1 Introduction

The North Sea Task Force Master Monitoring Plan (NSTF, 1990) recommended the use of the oyster embryo sea water bioassay on elutriates of sediment for monitoring sediment quality. This recommendation was made in the absence of suitable and validated whole sediment tests. From the outset it was recognised by CEFAS that contaminants eluted from sediments and presented to water column organisms do not necessarily represent the exposure of those same contaminants in sediments to sediment dwelling organisms. This was also recognised by the NMP (MPMMG, 1994) which states that the elutriation method should be replaced by a whole-sediment bioassay as soon as appropriate methods had been developed and tested.

10.2 Method

The *modus operandi* involves; collecting the sediment, eluting the sediment with sea water, the preparation of a filtrate and finally, testing the filtrate using the oyster embryo bioassay.

Surface sediment samples (0 to 10 cm deep) are collected using a Reineck box corer, Day grab, or in estuaries a handheld Van Veen grab. The preferred sampling method is the box corer since this provides an undisturbed sample, but, on occasions it may not always be the most practical or available option. Sediment elutriates are prepared by mixing 200 ml of sediment with 500 ml of reference sea water (collected from the South Western Approaches) in a 1 litre container at 100 revolutions min^{-1} on an orbital shaker. After 3 hours, the slurry is filtered through Whatman GFC filter paper and the resultant filtrate (termed elutriate) is biossayed as described for water samples.

The oyster embryo bioassay procedure is described in detail in Thain (1991) and summarised in Section 5 of this report.

In the discussion of the results that follow, sediment elutriate quality may be regarded as: good, PNR 0-20; slightly impaired, PNR 21-49; substantial deterioration, PNR 50-99; very poor, PNR 100.

10.3 Results and discussion

Sampling at all intermediate, offshore and estuarine sites was carried out once per year between May and October. On occasions sampling was restricted because of inclement weather and at some sites sediments were difficult to obtain, e.g. Selsey Bill and Nash Point, because the seabed was unsuitable i.e. rock.

The sampling stations and results are shown in Table 14. Samples were taken at 26, 20, 21 and 30 stations in each of the years 1990, 1991 1992 and 1994 respectively. No samples were collected for bioassay in 1993. The most comprehensive coverage of NMP and estuarine stations over the five-year period occurred in the North Sea and Channel. Sediment samples off the south coast of England and in the Irish Sea were taken on twelve occasions only, in 1994. The data set contains results from a number of estuaries including; the Tweed, Tyne, Wear, Tees, Humber, Tamar and Mersey.

The Tweed estuary was sampled at three locations in 1990, 1991 and 1994. On only one occasion was impaired sediment elutriate quality measured, in 1994 at Berwick Bridge (PNR of 38).

On the Tyne estuary a total of eighteen sediment samples were taken over a four year period; eight locations were sampled, but only at the mouth of the Tyne estuary and at Jarrow Slake were samples taken annually. Nine sediment elutriates had PNR values greater than 20; of which two indicated significant deterioration in sediment quality with PNRs of 55 and 81 and four indicated very poor sediment quality with PNRs of 100. The latter measurements were made in sediment elutriates from the mouth of the Tyne estuary, Tyne Bridge and on two occasions at Jarrow Slake.

Thirteen sediment elutriates from the River Wear estuary were bioassayed between 1990 and 1994. Six locations were visited on one or more occasions; only Wearmouth Bridge was sampled in each of the four years. Impaired sediment quality was indicated in four samples; PNR values of 28, 27, 32 at Wearmouth Bridge in 1991, 1992 and 1994 and a PNR of 43 at Queen Alexandra Bridge in 1994.

On the River Tees estuary six sites were sampled between 1990 and 1994, of which three were only sampled once. On five occasions PNR values of elutriates were in excess of 20; a PNR of 29 at Bamlett's Bight (1994), 85 at No: 25 buoy and 66, 100 and 100 at Redcar Jetty in 1990, 1991 and 1992 respectively. It is notable that the very poor sediment quality indicated at Redcar Jetty occurred in three out of the four years in which samples were taken. The consistently toxic nature of elutriates from this sediment indicates that this site is probably heavily contaminated as a result of chemical discharges into the estuary.

On the lower Humber estuary two sediment samples were taken in 1990 and a further six samples in 1992, from the Bull anchorage at the mouth of the estuary and then west as far as No: 11A buoy. Sediment elutriate quality was good in all samples tested. No samples were taken from the middle and upper estuary.

Table 14. Sediment elutriate, oyster embryo bioassay results

Station	NMP	Actual Position	Location	PNR 1990	1991	1992	1994
1		55° 45.75' N 1° 57.61' W	Tweed (anchor)	-0.6	-0.7		11.7
2		55° 45.83' N 1° 59.58' W	Tweed (buoy Off Spittal Point)	-20	-13.6		1
3		55° 46.12' N 2° 00.35' W	Tweed (Berwick / Tweed Bridges)	3.9	8.2		38
4		55° 07.26' N 1° 28.21' W	Blyth (anchor)				
5		55° 07.30' N 1° 29.70' W	Blyth (South Harbour entrance)				
6		55° 08.10' N 1° 30.75' W	Blyth (North Blyth)				
7		55° 01.48' N 1° 23.24' W	Tyne (anchor)	3	-2.5	7.4	100
8	235	55° 00.47' N 1° 25.84' W	Lloyds Hailing	5.3	-2.2	11.2	
9	TY3	54° 59.82' N 1° 26.47' W	Tyne (by South Ferry landing)				33.2
10		54° 59.17' N 1° 27.86' W	Tyne (buoy Off Jarrow Slake)	100	30.8	13.4	100
11	225	54° 59.09' N 1° 31.49' W	Tyne (Hebburn)	81.4			30.2
12		54° 58.25' N 1° 35.2' W	Ouse Burn			11.5	
13		54° 58.09' N 1° 36.25' W	Tyne (Tyne Bridge)	100			54.6
14		54° 57.45' N 1° 38.1'W	Team Confluence			15	
15	245	55° 00.45' N 1° 07.85' W	Off Tyne	0.2	-1.4	-6.7	-8
16		54° 56.24' N 1° 19.70' W	Wear (anchor)	0.2	6.5		
17		54° 54.66' N 1° 23.4' W	Wear (Hetton Staiths)			7.1	
18		54° 54.99' N 1° 23.55' W	Wear (Deptford Quay)			6.8	
19	275	54° 55.05' N 1° 21.43' W	Wear (Sandy Point)	-8.4	1.4	2.7	
20		54° 54.58' N 1° 22.87' W	Wear (Wearmouth Bridge)	-5.5	27.6	27	31.5
21	265	54° 54.80' N 1° 24.24' W	Wear (Queen Alexandra Bridge)			-0.1	42.9
22	295	54° 44.03' N 0° 53.13' W	Off Tees	-15.5	-7.5	5.5	-24
23		54° 39.85' N 1° 04.56' W	Tees (anchor)	-12.1	-6.5		-10.6
24		54° 38.52' N 1° 08.66' W	Tees (No. 8 buoy)	11	2.9		
25	TS3	54° 37.79' N 1° 09.72' W	Tees (Phillips approach buoy)				
26	325	54° 37.40' N 1° 09.34' W	Tees (Redcar jetty)	66.1	100	100	16.8
27		54° 36.22' N 1° 09.90' W	Tees (ICI No. 4 buoy)		11.5		
28	TS2	54° 35.66' N 1° 10.84' W	Tees (No. 23 buoy)				
29		54° 35.30' N 1° 11.40' W	Tees (No. 25 buoy)			85.2	
30		54° 35.07' N 1° 13.57' W	Tees (Transporter bridge)				
31	TS1	54° 35.53' N 1° 15.03' W	Tees (Bamlett's Bight)				28.8
32	315	54° 33.52' N 1° 18.33' W	Tees (Victoria bridge)				
33		53° 33.33' N 0° 6.05' E	Humber (Bull anchorage)	-1.7		-7.1	
34		53° 36.0' N 0° 3.6' W	Humber (Pyewipe outfall)	7		10.5	
35		53° 36.1' N 0° 5.9' W	Humber (Diffuser)			3.3	
36		53° 36.6' N 0° 4.6' W	Hunber (No. 6B buoy)			5.9	
37		53° 37.4' N 0° 8.7' W	Humber (No. 10A buoy)			-0.1	
38		53° 38.6' N 0° 11.0' W	Humber (No. 11A buoy)			-1.1	
39	285	54° 49.95' N 1° 20.05' E	Off Tyne/Tees	-8.4	-5.4		16.7
40	NSTF 47	55° 10.23' N 3° 09.50' E	Dogger bank	-12	-2.9	-3.2	
41	345	54° 00.09' N 1° 59.99' E	Off Humber/Wash (Silver Pit)	-4.5	-12.9		
42	375	53° 31.97' N 0° 19.95' E	Off Humber				
43	385	53° 03.96' N 0° 29.35' E	Wash	-5	-15.3		
44	395	52° 49.93' N 2° 49.82' E	Southern Bight (Smith's Knoll)	-11.2	4.5		
45	475	51° 59.99' N 2° 19.90' E	Thames (Outer Gabbard)	-9.3			100
46	465	51° 30.70' N 0° 58.01' E	Thames (Warp)	11.6			7.5
47	485	50° 55.98' N 1° 16.64' E	South Varne	5.9			
48	495	50° 39.01' N 0° 50.06' W	Selsey Bill				
49		50° 39.29' N 1° 54.15' W	Poole Harbour (anchor)				
50		50° 41.15' N 1° 57.35' W	Poole Harbour (Brownsea buoy : No. 42)				
51		50° 42.40' N 1° 58.95' W	Poole Harbour (Stakes buoy : No. 55)				
52		50° 43.30' N 1° 59.93' W	Poole Harbour (Holes Bay : Cobb's Quay marina)				
53	535	50° 04.86' N 3° 00.12' W	Central Channel				29.2
54		50° 20.81' N 4° 08.95' W	Plymouth Sound (anchor)				
55	565	50° 22.93' N 4° 11.60' W	Tamar (Hamoaze)				14.2
56		50° 24.37' N 4° 12.05' W	Tamar (Royal Albert Bridge)				
57	555	50° 25.45' N 4° 11.99' W	Tamar (E. Tamar north buoy)				12.1
58	575	50° 17.71' N 4° 09.73' W	Off Tamar				
59	585	50° 01.98' N 4° 21.99' W	Off Plymouth Sound				38.3
60	595	48° 30.04' N 7° 59.98' W	Western Approaches				4.6
61	615	51° 18.06' N 3° 32.95' W	Severn (Nash Point)				
62		52° 13.96' N 4° 21.22' W	New Quay				
63	655	52.21.45' N 4° 10.56' W	Cardigan Bay (inshore)				
64	665	52° 30.31' N 4° 59.99' W	Cardigan Bay (Offshore)				
65	775	53° 37.66' N 4° 30.32' W	Irish Sea				
66	715	53° 30.06' N 3° 41.76' W	Liverpool Bay				-2.2
67	805	54° 00.05' N 3° 50.12' W	SE Isle of Man				-6.8
68	795	53° 58.02' N 3° 19.88' W	Off Morecambe Bay				-13.6
69		53° 58.73' N 3° 03.38' W	Morecambe Bay (anchor)				
70		53° 58.6' N 3° 00.00' W	Off Lune (No. 1 buoy)				
71	785	53° 57.70' N 3° 02.50' W	Off Lune/Wyre (Fleetwood No. 1 buoy)				
72	705	53° 28.76' N 3° 16.03' W	Burbo Bight / Mersey (anchor)				-6.8
73	765	53° 31.83' N 3° 08.80' W	Mersey (C1 buoy)				
74		53° 28.00' N 3° 02.90' W	Mersey (C20 buoy)				
74	755	53° 24.56' N 3° 00.48' W	Mersey (Seacombe Ferry)				18.3
76		53° 23.70' N 2° 59.70' W	Mersey (Tranmere oil terminal)				25.8
77	745	53° 20.11' N 2° 57.22' W	Mersey (Bromborough E1 buoy)				
78		53° 19.40' N 2° 56.85' W	Mersey (Eastham Lock)				100
79		53° 40.36' N 3° 10.05' W	Ribble (anchor)				
80	705	53° 28.68' N 3° 16.09' W	Burbo Bight / Mersey (anchor)				
81		53° 23.35' N 3° 14.25' W	Dee (buoy HE3 / Hilbre Island)				
82	695	53° 19.98' N 3° 12.08' W	Dee (No.2 buoy)				
83		53° 26.10' N 3° 17.00' W	Dee (HE2 buoy)				
84	15	54° 45.00' N 3° 59.56' W	Solway				
85	35	55° 20.04' N 5° 05.12' W	Firth of Clyde				
86	85	51° 59.97' N 5° 40.03' W	Minches				
87	105	58° 00.04' N 3° 00.00' W	Moray Firth				
88	165	56° 29.96' N 1° 30.00' W	Tay/Forth (Offshore)				
89	605	51° 14.98' N 5° 59.88' W	Celtic Deep				

In 1994, sediment samples were taken from two stations on the River Tamar estuary and four on the River Mersey estuary. Elevated PNRs of 26 and 100, were measured in sediment elutriates from Tranmere Oil Terminal and Eastham Lock on the Mersey estuary. Eastham Lock was the most easterly site sampled.

Sediment samples were taken at least once from the NMP stations in the North Sea and eastern Channel between 1990 and 1994, with the exception of Off Humber and Selsey Bill where repeated attempts at sampling were unsuccessful. At the Off Tyne and Off Tees stations, samples were taken on each of the four sampling years. Of a total of twenty-five sediment elutriate samples bioassayed, only one PNR above 20 was measured. This occurred at Outer Gabbard (Thames) with a PNR of 100 in 1994; although there are no major inputs of contaminants in the area the location (prior to 1994) was a major sewage sludge disposal site and it is also close to the South Falls dredged material disposal area. An elutriate sample bioassayed in 1990 suggested sediment quality to be good at that time.

A limited number of intermediate and offshore NMP stations were sampled on the south and west English and Welsh coasts. Only six sediment elutriate samples were bioassayed in 1994 of which only two, Central Channel and Off Plymouth Sound, suggested an impairment in sediment quality with a PNR of 29 and 38 respectively. A PNR of 5 was measured in the sediment taken from the Western Approaches offshore site.

10.4 Conclusions

PNR values of 100 were recorded in eight out of the total of ninety-seven sediment elutriates sampled, between 1990 and 1994. Seven of these very poor quality sediment elutriates came from estuaries (four on the Tyne, two on the Tees and one on the Mersey). On the Tyne estuary two of the four sediments were sampled at the same location, Jarrow Slake (1990 and 1994), and on the Tees estuary the two samples came from Redcar Jetty (1991 and 1992). The consistency of the results provides strong evidence that these sediments are probably sufficiently contaminated to be causing significant adverse biological effects.

PNR values in excess of 50 (but <100) were measured in sediment elutriates from four stations, two on the Tees estuary and two on the Tyne estuary. These locations were the same or close to the sites where PNR values of 100 were measured i.e. in the middle reaches of the estuary, and may be the result of both historical and current industrial contaminant inputs into the river.

A direct comparison between the oyster embryo bioassay water and sediment elutriate data cannot be made for a number of reasons (e.g. contaminant flux in water is changing but it is relatively static in sediments, bioavailability and matrix considerations). However, the data show that there is good agreement in the sites where both water quality and sediment elutriate quality are very poor: Jarrow Slake and Hebburn on the River Tyne estuary; Redcar Jetty on the River Tees estuary; and Eastham Lock on the River Mersey estuary. This provides strong support of the need for further investigative surveys on these estuaries.

The oyster embryo bioassay sediment elutriate results clearly show that this is a useful and rapid survey tool for sediment quality assessment and in particular for identifying areas that need further investigation. It has been a beneficial exercise and it was a sensible decision to include a sediment elutriation method in the NMP. However, it must be emphasised that results from elutriation techniques are difficult to interpret and should be used with caution and not used as a substitute for pore-water and/or whole-sediment tests.

11. ASSESSMENT OF SEDIMENT QUALITY: WHOLE SEDIMENT BIOASSAYS USING *ARENICOLA MARINA* AND *COROPHIUM* VOLUTATOR

11.1 Introduction

Prior to 1992, surveys to assess sediment toxicity had been carried out by exposing oyster embryos to sediment elutriates (see Section 10). Although this was the procedure recommended by the NMP (MPMMG, 1994) it was used because at that time there were no suitable whole sediment bioassays. In 1991 and 1992, CEFAS gave serious consideration to the development and deployment of whole sediment bioassays, i.e. with animals that live in and re-work sediments. A new technique needed to be at least as sensitive as the oyster embryo bioassay with elutriates and preferably be suitable for shipboard deployment, with well-defined end-points and availability of test organisms at any time of the year. The result was that in 1992, two such bioassays were ready for deployment using the species, *Arenicola marina* and *Corophium volutator*. After the success of the initial trials, reported in MAFF (1993 and 1994) and Thain *et al.* (1996), the bioassays were deployed between 1992 and 1994 at most of the intermediate and offshore NMP sites and some additional locations in estuaries.

11.2 Method

11.2.1 Sediment collection

Intermediate and offshore sediments are collected using a Reineck Box corer. From each undisturbed core the surface 10 cm layer of sediment is removed and hand mixed with a large scoop. A sample for bioassay is taken from the homogenised sample. A Day grab is occasionally used during periods of inclement weather or where the sediments are not suitable for coring. In estuaries, sediment samples are usually collected with a hand held Van Veen grab. The sediments are usually bioassayed within 2-4 days of collection and are stored at 4°C at all times prior to testing. Reference sediment was always derived from a clean site at Shoeburyness, Essex.

11.2.2 *Arenicola marina*

Arenicola marina, commonly known as the lugworm, is a surface deposit feeding polychaete which inhabits intertidal and subtidal areas. Animals of approximately 1 g in size are collected from the foreshore and maintained in tanks containing a layer of sand and running sea water until ready for use. For each assay, replicate (two or three) sediment samples of 2 kg in weight are placed in small tanks (polythene sandwich boxes) with 4 cm of static overlying water and aeration. Five worms are placed into each tank and the worms left to burrow into the sediment. After 10 days the contents of each tank are sieved and the number of surviving worms recorded. During the exposure period observations on feeding behaviour are recorded by making daily counts of the casts on the surface of the sediment. The casts are smoothed over after each counting period.

The results are expressed as percentage mortality after 10 days. For a test to be valid the control mortality must not exceed 10 percent over the 10-day exposure period. Dunnett's t-test is used to assess if the casting in the test sediment is significantly different from the casting in the control sediment.

11.2.3 *Corophium volutator*

Corophium volutator is a marine amphipod which can be found on the foreshore of most unpolluted estuaries. They are collected and sieved from their native sediment and maintained in 40 l aquaria with a layer of sediment, running sea water and aeration for a minimum period of 5 days before the start of a test. For each test, ten adults (<7 mm) are placed in each of three replicate 1 l glass beakers containing a 2 cm layer of sediment with overlying filtered sea water to the 800 ml mark and aeration. At the end of the ten-day exposure period, the sediment is sieved and the number of surviving amphipods recorded.

The results are expressed as percentage mortality after 10 days. For a test to be valid the control mortality must not exceed 20 percent over the 10-day exposure period. Statistical significance of the difference between the test and control mortality is assessed using ANOVA.

11.3 Results and discussion

11.3.1 *Arenicola marina*

In the discussion of the results that follow, sediment quality is assessed in terms of mortality (M) and reduction in casting (RC), i.e. feeding activity: sediment quality good - less than 20% M and less than 30% RC; slightly impaired - 21 to 50% M and 31 to 50% RC, substantial deterioration - 51 to 99% M and 51 to 89% RC; very poor - 100% M and 90 to 99% RC.

The *A. marina* whole sediment bioassay was used on research cruises in 1992, 1993, 1994 and 1995 and a total of 37, 38, 40 and 41 sediments were bioassayed in each year respectively (Table 15). Over the sampling period, sediments were collected from several intermediate and offshore NMP sites around England and Wales and the Tweed, Blyth, Wear, Tees, Humber, Dart and Mersey estuaries, Southampton Water and Poole Harbour. In addition, sediments were also sampled from stations on the Bremerhaven Transect (Stebbing and Dethlefsen, 1992) in 1992, 1993 and 1995.

In 1994, 31 of the 40 results were excluded from the data set because the control mortalities exceeded the test validity criteria; in two tests carried out the control mortality was 13% and 20%.

In 1993 three sediment samples were taken from the Tweed estuary. At only one station, Berwick/Tweed Bridges was a slight impairment of sediment quality measured (35% RC). Sediment quality was good in the two sediments from the Blyth estuary, bioassayed in 1993.

On the River Tyne estuary a total of seventeen sediment samples were bioassayed between 1992 and 1995. The samples were taken from twelve locations between the mouth of the estuary and the uppermost site at Scotswood. On only one occasion was a mortality in excess of 20% recorded (Scotswood 33% M). However, the results of casting activity identified very poor sediment quality at Downstream Howden (95% RC), Jarrow Slake (96% RC), Hebburn (97% RC), substantial deterioration in sediment quality at Rohm and Haas (84% RC) and Tyne anchor station (52% and 58% RC in 1992 and 1995 respectively). In addition, a slight reduction in feeding (statistically different, $p < 0.05$) was measured in five samples although one was associated with a high mortality (33% M).

Eleven sediment samples from seven locations were collected from the River Wear estuary over the three year sampling period. *A. marina* bioassays carried out on these sediments identified two very poor quality sediments, one from Alexandra Bridge (100% M), followed closely by a sediment from Sandy Point (93% M). Feeding activity was impaired in three sediment samples bioassayed; Sandy Point (53% RC),

Table 15. Results of whole sediment Arenicola marina bioassay

NMP station	Actual Position	Location	1992 % Mort	1992 Casts	1993 % Mort	1993 Casts	1994 % Mort	1994 Cast	1995 % Mort	1995 Casts
	55° 45.75' N 1° 57.61' W	Tweed (anchor)			0	0				
	55° 45.83' N 1° 59.58' W	Tweed (buoy Off Spittal Point)			7	8				
	55° 46.12' N 2° 00.35' W	Tweed (Berwick / Tweed Bridges)			0	35*				
	55° 07.30' N 1° 29.70' W	Blyth (South Harbour entrance)			7	19				
	55° 08.10' N 1° 30.75' W	Blyth (North Blyth)			7	7				
	55° 01.48' N 1° 23.24' W	Tyne (anchor)	0	52*	0	14			13	58*
235	55° 00.47' N 1° 25.84' W	Lloyds Hailing	0	7	0	0				
	54° 59.29' N 1° 28.28' W	Tyne (Howden Downstream)							0	95*
	54° 59.19' N 1° 29.16' W	Tyne (Rohn & Haas)							7	84*
	54° 59.17' N 1° 27.86' W	Tyne (buoy Off Jarrow Slake)	0	96*						
225	54° 59.09' N 1° 31.49' W	Tyne (Hebburn)			7	38*			13	97*
	54° 58.25' N 1° 35.2' W	Ouse Burn	10	37*						
	54° 58.09' N 1° 36.25' W	Tyne (Tyne Bridge)							7	18
	54° 57.45' N 1° 38.1'W	Team Confluence	0	4					0	32*
	54° 57.57' N 1° 32.94' W	Tyne (St Antonys)							13	0
215	54° 57.99' N 1° 41.34' W	Tyne (Scotswood)							33	43*
	54° 57.68' N 1° 32.10' W	Tyne (International Paints)							0	31*
245	55° 00.45' N 1° 07.85' W	Off Tyne	0	19	13	27*				
	54° 56.24' N 1° 19.70' W	Wear (anchor)			0	25*				
	54° 54.66' N 1° 23.4' W	Wear (Hetton Staiths)	0	30*						
	54° 54.99' N 1° 23.55'W	Wear (Deptford Quay)	0	7						
275	54° 55.05' N 1° 21.43' W	Wear (Sandy Point)	0	19	13	53*			93*	100*
	54° 54.58' N 1° 22.87' W	Wear (Wearmouth Bridge)	0	0					0	57*
265	54° 54.80' N 1° 24.24' W	Wear (Queen Alexandra Bridge)	0	19	100	95*				
255	54° 54.22' N 1° 27.43' W	Wear (South Hylton)							13	35*
295	54° 44.03' N 0° 53.13' W	Off Tees	0	0	0	16			13	57*
	54° 39.85' N 1° 04.56' W	Tees (anchor)							0	53*
	54° 38.52' N 1°08.66' W	Tees (No. 8 buoy)			0	29*				
325	54° 37.40' N 1° 09.34' W	Tees (Redcar jetty)	100	100*	100	100*			0	56*
	54° 36.22' N 1° 09.90' W	Tees (ICI No. 4 buoy)			33	100*				
	54° 35.30' N 1° 11.40' W	Tees (No. 25 buoy)	30	52*	0	26*				
315	54° 33.52' N 1° 18.33' W	Tees (Victoria bridge)			0	20			13	8
	53° 33.33' N 0° 6.05' E	Humber (Bull anchorage)	0	15						
	53° 36.0' N 0° 3.6' W	Humber (Pyewipe outfall)	0	15						
	53° 36.1' N 0° 5.9' W	Humber (Diffuse)	0	33*						
	53° 36.6' N 0° 4.6' W	Hunber (No. 6B buoy)	0	37*						
	53° 37.4' N 0° 8.7' W	Humber (No. 10A buoy)	0	56*						
	53° 38.6' N 0° 11.0' W	Humber (No. 11A buoy)	0	59*						
285	54° 49.95' N 1° 20.05' E	Off Tyne/Tees			13	0				
NSTF 47	55° 10.23' N 3° 09.50' E	Dogger bank	0	0	0	0				
	55° 25.00' N 3° 55.00' E	NE Dogger							10	73*
	54° 47.20' N 1° 17.10' E	West Dogger							7	31*
345	54° 00.09' N 1° 59.99' E	Off Humber/Wash (Silver Pit)			0	35*				
395	52° 49.93' N 2° 49.82' E	Southern Bight (Smiths Knoll)	0	0	0	58*				
475	51° 59.99' N 2° 19.90' E	Thames (Outer Gabbard)	0	15	0	82*				
465	51° 30.70' N 0° 58.01' E	Thames (Warp)	0	0	0	0				
485	50° 55.98' N 1° 16.64' E	South Varne	0	89*	0	54*				
495	50° 39.01' N 0° 50.06' W	Selsey Bill								
	50° 39.29' N 1° 54.15' W	Poole Harbour (anchor)							0	65*
	50° 41.15' N 1° 57.35' W	Poole Harbour (Brownsea buoy : No. 42)			0	56*				
	50° 43.30' N 1° 59.93' W	Poole Harbour (Holes Bay : Cobb's Quay marina)			0	22*			7	32*

Table 15. continued

NMP station	Actual Position	Location	1992 % Mort	1992 Casts	1993 % Mort	1993 Casts	1994 % Mort	1994 Cast	1995 % Mort	1995 Casts
535	50° 04.86' N 3° 00.12' W	Central Channel	0	15						
555	50° 25.45' N 4° 11.99' W	Tamar (E. Tamar north buoy)							0	10
	50° 18.96'N 3° 32.58' W	Dartmouth							0	17
	50° 23.11' N 3° 35.63' W	River Dart (Dittisham)							7	88*
	50° 20.85' N 3° 34.46' W	River Dart (Kings Wear)							7	25
655	52° 30.31' N 4° 59.99' W	Cardigan Bay (Offshore)							0	54*
775	53° 37.66' N 4° 30.32' W	Irish Sea							0	52*
715	53° 30.06' N 3° 41.76' W	Liverpool Bay	0	44*	0	0			13	33*
795	53° 58.02' N 3° 19.88' W	Off Morecambe Bay							0	18
705	53° 28.76' N 3° 16.03' W	Burbo Bight / Mersey (anchor)			0	2			0	0
765	53° 31.83' N 3° 08.80' W	Mersey (C1 buoy)							0	58*
	53° 30.50' N 3° 05.60' W	Mersey (C12 Buoy)	0	0						
755	53° 24.56' N 3° 00.48' W	Mersey (Seacombe Ferry)			13	5			0	5
	53° 23.70' N 2° 59.70' W	Mersey (Tranmere oil terminal)			0	0				
605	51° 14.98' N 5° 59.88' W	Celtic Deep							7	24
	54° 03.98' N 8° 07.51' E	Bremerhaven Transect: Station 1	0	37*			0	67*	20	93*
	54° 01.98' N 8° 02.85' E	Bremerhaven Transect: Station 2	0	52*			0	35*	47	99*
	54° 00.08' N 8° 00.06' E	Bremerhaven Transect: Station 3	0	37*			0	26*	13	62*
	54° 00.86' N 7° 48.85' E	Bremerhaven Transect: Station 4	0	22			0	19	67	35*
	54° 06.53' N 7° 24.02' E	Bremerhaven Transect: Station 5	0	0			0	0	13	20
	54° 25.01' N 6° 14.90' E	Bremerhaven Transect: Station 6	0	11			0	0	13	24
	54° 50.11' N 5° 34.96' E	Bremerhaven Transect: Station 7	0	11			0	0		
	55° 06.02' N 5° 00.07' E	Bremerhaven Transect: Station 8	0	4			0	0		
	55° 29.96' N 4°10.00' E	Bremerhaven Transect: Station 9	0	26			0	0		
405	52° 38.2' N 0° 22.15' E	Wash (Ouse, Stowe Bridge)			0	0				
415	52° 44.38' N 0° 23.38' E	Wash (Ouse, Freebridge)			20	57*				
425	52° 47.04' N 0° 22.45' E	Wash (Ouse, The Point)			0	0				
335	53° 33.75' N 0° 05.66' E	Humber (Spurn Head)			0	54*				
365	53° 41.57' N 0° 05.66' E	Humber (North Killingholme)			0	27*				
505	50° 52.95' N 1° 23.30' W	Southampton Water (Dock Head)							0	63*
515	50° 51.14' N 1° 12.77' W	Southampton Water (East Bramble buoy)			0	100*			0	13
525	50° 49.59' N 1° 18.29' W	Southampton Water (Hook buoy)			0	17			7	59*

*Note: * Comparisons significantly different from the control casting at the 0.05 level (Dunnetts t-test)*

Wearmouth Bridge (57% RC) and South Hylton (35% RC). At only one location (Sandy Point) was sediment collected on each of the sampling years; in 1992 no effects were observed, in 1993 feeding activity was impaired (53% RC), and in 1995 survival was severely affected (93% M).

On the River Tees estuary, sediments were collected from six locations and a total of ten sediments were successfully bioassayed, two in 1992, five in 1993 and three in 1995. At Redcar Jetty sediments were bioassayed every year and on two occasions, in 1992 and 1993, no animals survived and in 1995, although the animals survived, feeding activity was impaired (56% RC) showing substantial deterioration in sediment quality. Feeding activity was also adversely affected in sediments collected and bioassayed from No. 25 buoy (52% RC), Tees anchor (53% RC) and ICI No. 4 buoy (100% RC in association with a 33% M).

Sediment samples from the River Humber estuary were collected and bioassayed on one occasion, in 1992. Six stations were sampled on the lower estuary, from the Bull Anchorage westward as far as No. 11A buoy. *A. marina* survival was not reduced in any of the sediment samples but feeding activity was impaired (statistically different $p < 0.05$) in sediments from the four upper stations; Diffuser (33% RC), No. 6B buoy (37% RC), No. 10A buoy (56% RC) and No. 11A buoy (59% RC).

Twenty-one intermediate and offshore NMP stations in the North Sea and eastern Channel were sampled and bioassayed in 1992, 1993 and 1995. At only one site, Off Tees, was sediment collected on each of the three years. *A. marina* survival was good in all twenty-one samples. Reduced feeding activity was statistically different ($p < 0.05$) from the controls in nine sediments, of which six were greater than 50% RC. These were Off Tees (57% RC), NE Dogger (73% RC), Smiths Knoll (58% RC), Outer Gabbard (82% RC) and on two occasions, 1992 and 1993 at South Varne (89% RC and 54% RC respectively). On only one of the three sampling years was an effect on feeding activity measured in sediment from the Off Tees station. However, at South Varne, reduced feeding activity was measured in sediments on two consecutive sampling occasions, 1992 and 1993. The bioassay result (0% M and 88% RC) of the sediment sample collected at Thames Gabbard in 1994 was excluded from Table 1 for reasons of test validity criteria. However, it should be noted that the oyster embryo sediment elutriate bioassay on this same sample (see Section 10) gave 100% Percent Net Response. In addition, the sediment from Outer Gabbard in 1993 caused feeding activity to be substantially reduced (82 % RC). Three stations were sampled on the Dogger Bank: *A. marina* bioassays on sediments from two stations NE Dogger and West Dogger showed feeding activity was reduced (73% RC and 31% RC respectively). Sediment bioassays deployed in 1990 (Williams, 1992) also measured reduced sediment quality on the Dogger Bank, but, a direct comparison cannot be made because the sampling positions are not identical. However, the NE Dogger area is known to be an accumulating site for some contaminants, for example cadmium (see MAFF, 1993).

On the south coast of England, sediments were collected for bioassay with *A. marina* from Southampton Water and Poole Harbour in 1993 and 1995 and from the Dart and Tamar estuaries in 1995. Survival was good in each of the thirteen sediments bioassayed, but feeding activity was substantially reduced in six of the sediments indicating a substantial deterioration in sediment quality: Anchor (65% RC) and Brownsea buoy (56% RC) in Poole Harbour; Dittisham (88% RC) on the River Dart estuary; Dock Head (63% RC), East Bramble buoy (100% RC) and Hook buoy (59% RC) on Southampton Water.

Only seven sediment samples were collected from the Mersey estuary over the three years 1992, 1993 and 1995. The sediments were taken from five locations from the Burbo Bight east to Tranmere oil terminal. Feeding activity was reduced at one station, C1 buoy (58% RC).

Very few sediments were sampled at NMP stations in the Channel, Celtic Sea and Irish Sea. Eight bioassays were carried out on sediments from six locations over three years. Feeding activity was significantly reduced at four sites, two of which were greater than 50% RC; off shore Cardigan Bay (54% RC) and Irish Sea (52% RC).

In 1992, 1994 and 1995 nine samples were collected along a transect from the German Bight north-west to the Dogger Bank. This transect lies on a contaminant gradient (in sediments) and is known as the Bremerhaven Transect (see Stebbing *et al.,* 1992). In 1992 and 1994 survival was good in each of the sediment samples bioassayed but a statistically significant ($p < 0.05$) reduction in feeding activity was measured each year in Stations one to three. In 1995, bad weather prevented the sampling of sediments at Stations seven to nine. However, of the six sediments bioassayed, survival was reduced at Stations one, two and four and reduced feeding activity was measured at all four stations, most notably at Station one (93% RC) and Station two (99% RC). The results are in agreement with sediment bioassays carried out during the Bremerhaven Workshop in 1990 (Williams, 1992).

11.3.2 *Corophium volutator*

In the discussion of the results that follows, sediment quality is assessed in terms of mortality (M): good - less than 39% mortality; substantial deterioration - 40-99% mortality; and very poor - 100% mortality.

The *C. volutator* bioassay was used on research cruises from 1992 to 1995 inclusive, and a total of 28, 39, 53 and 41 sediment samples were bioassayed in each year respectively (Table 16). Nine results were excluded from the data set, six in 1993, and three in 1995, because the mortality in the control sediment was 43% and 33% respectively, i.e. exceeding the 20% test validity criteria. Sediments were collected for *C. volutator* bioassay from NMP intermediate and offshore sites and estuaries which included the Tweed, Blyth, Tyne, Wear, Tees, Humber, Ouse, Southampton Water, Poole Harbour, Tamar, Dart and the Mersey. In addition, sediments were also collected from stations along the Bremerhaven Transect (Stebbing and Dethlefsen, 1992) in 1992, 1993 and 1995.

In 1993 and 1994, sediments were collected and bioassayed from three stations on the Tweed estuary. On the Blyth estuary two sediment samples were collected in 1993 and a further sample collected from a different station in 1994. In the nine samples bioassayed, *C. volutator* mortality was less than 40% indicating that the sediment quality was good.

On the River Tyne estuary twenty-two sediment samples were collected and bioassayed from thirteen stations between 1992 and 1995. Only the Tyne anchor station was sampled on four consecutive years and Hebburn on three consecutive years (1993 to 1995). Substantial deterioration in sediment quality was apparently measured in two sediments, Lloyds Hailing (40% M) in 1992 and Tyne anchor (47% M) in 1994. However, the result at Tyne anchor station was not statistically different from the control.

Fifteen sediment samples were collected from seven locations on the River Wear estuary between 1992 and 1995, and only one station, Sandy Point, was sampled in four consecutive years. A substantial deterioration in

Table 16. Results of whole sediment Corophium volutator bioassay

NMP	Actual Position	Location	% Mortality 1992	1993	1994	1995
	55° 45.75' N 1° 57.61' W	Tweed (anchor)		13	23	
	55° 45.83' N 1° 59.58' W	Tweed (buoy off Spittal Point)		30	33	
	55° 46.12' N 2° 00.35' W	Tweed (Berwick / Tweed Bridges)		13	30	
	55° 07.26' N 1° 28.21' W	Blyth (anchor)			23	
	55° 07.30' N 1° 29.70' W	Blyth (South Harbour entrance)		23		
	55° 08.10' N 1° 30.75' W	Blyth (North Blyth)		13		
	55° 01.48' N 1° 23.24' W	Tyne (anchor)	33*	20	47	0
235	55° 00.47' N 1° 25.84 W	Lloyds Hailing	40*	27		
TY3	54° 59.82' N 1° 26.47' W	Tyne (by South Ferry landing)			17	
	54° 59.29' N 1° 28.28' W	Tyne (Howden Downstream)				10
	54° 59.19' N 1° 29.16' W	Tyne (Rohn & Haas)				7
	54° 59.17' N 1° 27.86' W	Tyne (buoy off Jarrow Slake)	23.3		20	
225	54° 59.09' N 1° 31.49' W	Tyne (Hebburn)		10	33	3
	54° 58.25' N 1° 35.2' W	Ouse Burn	6.7			
	54° 58.09' N 1° 36.25' W	Tyne (Tyne Bridge)			23	7
	54° 57.45' N 1° 38.1' W	Team Confluence	33.3*			10
	54° 57.57' N 1° 32.94' W	Tyne (St Antonys)				10
215	54° 57.99' N 1° 41.34' W	Tyne (Scotswood)				3
	54° 57.68' N 1° 32.10' W	Tyne (International Paints)				3
245	55° 00.45' N 1° 07.85' W	Off Tyne	16.7	10		
	54° 56.24' N 1° 19.70' W	Wear (anchor)		7	53	
	54° 54.66' N 1° 23.4' W	Wear (Hetton Staiths)	13.3			
	54 °54.99' N 1° 23.55' W	Wear (Deptford Quay)	26.7			
275	54° 55.05' N 1° 21.43' W	Wear (Sandy Point)	23.3	13	40	23
	54° 54.58' N 1° 22.87' W	Wear (Wearmouth Bridge)	20		57	13
265	54° 54.80' N 1° 24.24' W	Wear (Queen Alexandra Bridge)	30*	3	33	
255	54° 54.22' N 1° 27.43' W	Wear (South Hylton)				10
295	54° 44.03' N 0° 53.13' W	Off Tees	16.7	0	37	0
	54° 39.85' N 1° 04.56' W	Tees (anchor)			23	0
	54° 38.52' N 1° 08.66' W	Tees (No. 8 buoy)		37		
TS3	54° 37.79' N 1° 09.72' W	Tees (Phillips approach buoy)			30	
325	54° 37.40' N 1° 09.34' W	Tees (Redcar jetty)	23.3	100*	100*	3
	54° 36.22' N 1° 09.90' W	Tees (ICI No. 4 buoy)		93*		
	54° 35.30' N 1° 11.40' W	Tees (No. 25 buoy)	23.3	23		
TS1	54° 35.53' N 1° 15.03' W	Tees (Bamlett's Bight)			47	
315	54° 33.52' N 1° 18.33' W	Tees (Victoria bridge)		27		0
	53° 36.0' N 0° 3.6' W	Humber (Pyewipe outfall)	6.7			
	53° 36.1' N 0° 5.9' W	Humber (Diffuse)	30*			
	53° 36.6' N 0° 4.6' W	Hunber (No. 6B buoy)	3.3			
	53° 37.4' N 0° 8.7' W	Humber (No. 10A buoy)	16.7			
	53° 38.6' N 0° 11.0' W	Humber (No. 11A buoy)	20			
285	54° 49.95' N 1° 20.05' E	Off Tyne/Tees		30		
NSTF 47	55° 10.23' N 3° 09.50' E	Dogger bank		15		
	55° 25.00' N 3° 55.00' E	NE Dogger				23
	54° 47.20' N 1° 17.10' E	West Dogger				3
345	54° 00.09' N 1° 59.99' E	Off Humber/Wash (Silver Pit)		10	10	
395	52° 49.93' N 2° 49.82' E	Southern Bight (Smiths Knoll)			10	
475	51° 59.99' N 2° 19.90' E	Thames (Outer Gabbard)			17	
	50° 39.29' N 1° 54.15' W	Poole Harbour (anchor)			23	27
	50° 41.15' N 1° 57.35' W	Poole Harbour (Brownsea buoy : No. 42)		13	13	
	50° 43.30' N 1° 59.93' W	Poole Harbour (Holes Bay : Cobb's Quay marina)		13	13	3
535	50° 04.86' N 3° 00.12' W	Central Channel			7	
	50° 20.81' N 4° 08.95' W	Plymouth Sound (anchor)			0	
565	50° 22.93' N 4° 11.60' W	Tamar (Hamoaze)			3	
	50° 24.37' N 4° 12.05' W	Tamar (Royal Albert Bridge)			0	
555	50° 25.45' N 4° 11.99' W	Tamar (E. Tamar north buoy)			0	0

Table 16. continued

NMP	Actual Position	Location	% Mortality			
			1992	1993	1994	1995
	50° 18.96' N 3° 32.58' W	Dartmouth				17
	50° 23.11' N 3° 35.63' W	River Dart (Dittisham)				33
	50° 20.85' N 3° 34.46' W	River Dart (Kings Wear)				17
575	50° 17.71' N 4° 09.73' W	off Tamar			3	
585	50° 01.98' N 4° 21.99' W	off Plymouth Sound			7	
595	48° 30.04' N 7° 59.98' W	Western Approaches			17	
655	52° 30.31' N 4° 59.99' W	Cardigan Bay (offshore)				47
775	53° 37.66' N 4° 30.32' W	Irish Sea				30
715	53° 30.06' N 3° 41.76' W	Liverpool Bay		23	7	20
805	54° 00.05' N 3° 50.12' W	SE Isle of Man			0	
795	53° 58.02' N 3° 19.88' W	off Morecambe Bay			3	33
705	53° 28.76' N 3° 16.03' W	Burbo Bight / Mersey (anchor)		13	3	7
765	53° 31.83' N 3° 08.80' W	Mersey (C1 buoy)				20
	53° 28.00' N 3° 02.90' W	Mersey (C20 buoy)			3	
755	53° 24.56' N 3° 00.48' W	Mersey (Seacombe Ferry)		0	0	27
	53° 23.70' N 2° 59.70' W	Mersey (Tranmere oil terminal)		7		
745	53° 20.11' N 2° 57.22' W	Mersey (Bromborough E1 buoy)			10	
695	53° 19.98' N 3° 12.08' W	Dee (No.2 buoy)			0	
605	51° 14.98' N 5° 59.88' W	Celtic Deep			10	27
	54° 03.98' N 8° 07.51' E	Bremerhaven Transect: Station 1	27		0	0
	54° 01.98' N 8° 02.85' E	Bremerhaven Transect: Station 2	20		0	10
	54° 00.08' N 8° 00.06' E	Bremerhaven Transect: Station 3	23		0	10
	54° 00.86' N 7° 48.85' W	Bremerhaven Transect: Station 4	25		7	10
	54° 06.53' N 7° 24.02' E	Bremerhaven Transect: Station 5	22		3	0
	54° 25.01' N 6° 14.90' E	Bremerhaven Transect: Station 6	38		3	10
	54° 50.11' N 5° 34.96' E	Bremerhaven Transect: Station 7	35		0	
	55° 06.02' N 5° 00.07' E	Bremerhaven Transect: Station 8	50*		3	
	55° 29.96' N 4° 10.00' E	Bremerhaven Transect: Station 9	50*		0	
405	52° 38.2' N 0° 22.15' E	Wash (Ouse, Stowe Bridge)		0		
415	52° 44.38' N 0° 23.38' E	Wash (Ouse, Freebridge)		0		
425	52° 47.04' N 0° 22.45' E	Wash (Ouse, The Point)		3		
335	53° 33.75' N 0° 05.66' E	Humber (Spurn Head)		13		
365	53° 41.57' N 0° 05.66' E	Humber (North Killingholme)		0		
505	50° 52.95' N 1° 23.30' W	Southampton Water (Dock Head)				27
515	50° 51.14' N 1° 12.77' W	Southampton Water (East Bramble buoy)				43
525	50° 49.59' N 1° 18.29' W	Southampton Water (Hook buoy)		23		3

sediment quality was apparently measured in sediments bioassayed from Wear anchor (53% M), Sandy Point (40% M) and Wearmouth Bridge (57% M), but none of the three results were statistically different from the control.

On the River Tees estuary fourteen sediment samples were collected and bioassayed from seven locations between 1992 and 1995. Very poor sediment quality (100% M) was measured in two sediment samples from Redcar Jetty in 1993 and 1994. A substantial deterioration was apparently measured in sediments from ICI No. 4 buoy (93% M) in 1993 and Bamlett's Bight (47% M) in 1994, but in the latter case the result was not statistically different from the control. Redcar Jetty was the only station sampled for four consecutive years, and although very poor sediment quality (100% M) was measured in 1993 and 1994, sediment quality was found to be good in 1992 and 1995. This may indicate that the sediment was not taken from an identical location on each of the sampling occasions. Previous studies (Matthiessen *et al.*, 1998), have shown that sediment toxicity can change over very small distances (< 15 m).

Seven sediment samples were collected for bioassay from the River Humber estuary, five in 1992 and two in 1993. Sediment quality was good at each location.

Sediment quality was also good at several other sites including - three stations on the River Ouse (Wash) in 1993, fourteen sediments from nine intermediate and offshore NMP stations in the North Sea (1992-1995), seven sediments from three sites in Poole Harbour (1993-1995), five sediments from four sites in the Tamar estuary (1994-1995), ten sediments from six sites on the Mersey estuary (1993-1995), one sediment from the Dee estuary in 1994.

Four sediments were collected from three locations in Southampton Water in 1994 and 1995. *C. volutator* survival was apparently reduced in one sediment sample, East Bramble buoy (43% M), but this result was not statistically different from the control.

A total of fourteen sediment samples were bioassayed from ten intermediate and offshore NMP stations in the Channel, Celtic Sea and Irish Sea, between 1993 and 1995. These included the Western Approaches offshore station in 1994. On only one occasion, Cardigan Bay offshore, was *C. volutator* survival apparently reduced (47% M) but this result was not significantly different from the control.

In 1992, 1994 and 1995 sediments were collected and bioassayed from stations along the Bremerhaven Transect; nine stations in 1992 and 1994 and the first six stations in 1995. A substantial deterioration in sediment quality was measured on two occasions in 1992, at Stations 8 (50% M) and 9 (50% M). Station 9 lies on the NE Dogger Bank where poor sediment quality had also been observed in previous studies (Williams, 1994).

Table 17 shows the combined sediment bioassay results for whole sediment and sediment elutriate bioassays. Only those stations where very poor sediment quality was measured are included in the Table. It is clear that these sediments are mainly to be found in estuaries. The sediments bioassayed from Jarrow Slake on the Tyne and Redcar Jetty on the Tees were repeatedly very poor and gave responses with more than one of the bioassay techniques.

11.4 Conclusion

A. marina and *C. volutator* are both regarded as whole sediment feeders although their mode of feeding is different. *A. marina* directly ingests whole sediment, whereas *C. volutator* feeds on organic matter in the sediment or on organic matter attached to sediment particles. Both organisms have been successfully used for the testing of whole sediments and can be used on a range of sediment types - from very fine sediments (e.g. Celtic Deep) to very coarse sediments (e.g. Dogger Bank) - and in anoxic sediments found in many estuaries. The tests have been developed for shipboard deployment and the above surveys have successfully demonstrated this application.

In all cases the sediments collected on these surveys were bioassayed simultaneously with both bioassays. In instances where there is no result for a particular station, this will have been caused by insufficient sediment collection (6 kg is required for an *A. marina* bioassay). Therefore, the results are directly comparable.

The mortality and feeding activity results for *A. marina* show that very poor sediment quality was measured in sediments bioassayed from estuaries which receive inputs from chemical industrial processes and/or the shipbuilding industry. For example, there were three locations on the Tyne estuary, two on the Wear estuary, two on the Tees estuary and one on Southampton Water. In addition, were three sites in the German Bight, but these were close to the entrance of the Elbe and Weser estuaries and contaminants are known to be high in sediments from this area. It should be borne in mind that sediments are a sink for most contaminants and the poor sediment quality measured in these surveys is possibly the result of historical as well as current contamination. In five sediment samples, mortality over the ten-day exposure period was 20% or less but reduction in casting activity was greater than 90%. This clearly demonstrates the use of feeding activity as a very important end-point in the bioassay. It is also easy to measure and quantify. Although it may be regarded as a sub-lethal response for the duration of the test, in the longer term, a severe reduction in feeding rate is likely to result in death.

The *C. volutator* bioassay has one end point - mortality. In a total of 152 sediments bioassayed, only two were toxic at the 100% level (Tees - Redcar Jetty in 1993 and 1994) and one at 93% (Tees - ICI No. 4 buoy). Mortalities of around 50% were measured in ten sediments but the results were not always significantly different from controls. This resulted from a high replicate variance. Experience in deploying this bioassay on a routine basis in the laboratory and in the field suggests that considerable care and attention should be given when collecting the animals in July - August. At many *C. volutator* collecting sites the animals have a life span of 12 to 18 months, with major die-offs in the summer. Consequently, animals collected in July and August are either very small individuals or moribund adults. If the latter are used in a bioassay this may result in high control mortalities and/or a high variance amongst replicates.

The results from the two whole sediment and sediment elutriate bioassays clearly show that the current techniques are robust and sufficiently sensitive to identify grossly contaminated sediments. There are three estuaries where further studies need to be carried out - the Tyne, Tees and Mersey - all of equal importance. The use of a sub-lethal end point in the *A. marina* test has been very successful and indicates the need for further development of sensitive and chronic end points for use offshore. Nevertheless, reductions in casting at a few offshore stations (Off Tees, NE Dogger, Smiths Knoll, Outer Gabbard and South Varne) suggest that contaminants are able to re-concentrate at certain points and exert a degree of toxicity. This requires further investigation. Overall, however, the results show that the only sediments to give serious concern originate from heavily industrialised estuaries. It is likely that these highly toxic estuarine sediments are exerting a significant impact on benthic communities, and it is therefore imperative that the causes of toxicity and ecological implications are studied in detail.

Table 17. Combined results of whole sediment and sediment elutriate bioassays for stations where a major response was measured

NMP	Actual Position	Location	1990 OEB	1991 OEB	1992 *A. marina*	1992 *C. volutator*	1992 OEB	1993 *A. marina*	1993 *C. volutator*	1994 *A. Marina*	1994 *C. volutator*	1994 OEB	1995 *A. marina*	1995 *C. volutator*
	55° 01.48' N 1° 23.24' W	Tyne (anchor)										100 PNR		
	54° 59.29' N 1° 28.28' W	Tyne (Howden Downstream)											0% M: 95% RC	
	54° 59.17' N 1° 27.86' W	Tyne (buoy off Jarrow Slake)	100 PNR		0% M: 96% RC							100 PNR		
225	54° 59.09' N 1° 31.49' W	Tyne (Hebburn)	81 PNR										13% M: 97% RC	
	54° 58.09' N 1° 36.25' W	Tyne (Tyne Bridge)	100 PNR									55 PNR		
275	54° 55.05' N 1° 21.43' W	Wear (Sandy Point)											93% M: 100% RC	
265	54° 54.80' N 1° 24.24' W	Wear (Queen Alexandra Bridge)						100% M: 95% RC						
325	54° 37.40' N 1° 09.34' W	Tees (Redcar jetty)	66 PNR	100 PNR	100% M: 100% RC		100 PNR	100% M: 100% RC	100 % M		100% M			
	54° 36.22' N 1° 09.90' W	Tees (ICI No. 4 buoy)						33% M: 100% RC	93 % M					
	54° 35.30' N 1° 11.40' W	Tees No. 25 buoy					85 PNR							
	51° 59.99' N 2° 19.90' E	Thames (Outer Gabbard)										100 PNR		
	54° 03.98' N 8° 07.51' E	Bremerhaven Transect: Station 1											20% M: 93% RC	
	54° 01.98' N 8° 02.85' E	Bremerhaven Transect: Station 2											47% M: 99% RC	
	54° 00.86' N 7° 48.85' E	Bremerhaven Transect: Station 4											67% M: 35% RC	
	50° 51.14' N 1° 12.77' W	Southampton Water (East Bramble buoy)						0% M: 100% RC						
	53° 19.40' N 2° 56.85' W	Mersey (Eastham Lock)										100 PNR		

12. CONTAMINANTS IN DAB (*LIMANDA LIMANDA*)

12.1 Introduction

Sampling for dab was attempted at all intermediate and offshore NMP stations around England and Wales on a number of occasions. Where possible, analysis was undertaken on dab collected in 1994; these were augmented by samples collected in earlier years where necessary. Alternative sites had to be selected in the Humber, English Channel, Severn and offshore in the Irish Sea. Even after repeated attempts, only limited numbers of dab were obtained from stations in the English Channel (similar to results obtained in earlier surveys for the North Sea Monitoring Master Plan, (NSTF, 1990)) with none available at or in the vicinity of the offshore reference Station 595.

12.2 Methods

Analytical methods have been described elsewhere. Where possible, NMP guidelines were followed and the dab analysed in groups of five. Analysis was carried out for Hg and As in dab muscle and Cd, Pb, dieldrin, DDT and CBs in dab liver.

12.3 Results and discussion

Results for metals are summarised in Table 18(a) and for organics in Table 18(b).

Mercury in dab muscle

Concentrations were generally low (at or near the JMG 'lower' level category (<0.1 mg kg^{-1} wet weight) in most areas) (see Annex 2). As would be anticipated from previous studies, the highest levels were found in Liverpool and Morecambe Bays (Figure 37), both of which receive inputs of Hg from a number of sources, including the chloralkali industry. Even here however, no samples contained Hg in the 'upper' JMP category (>0.3 mg kg^{-1} wet weight). The Hg concentration in the fairly small dab taken from the intermediate Cardigan Bay station was relatively high and attempts will be made to obtain further samples from this area.

Arsenic in dab muscle

Highest concentrations were found off the north-east coast of England, with a maximum of over 20 mg kg^{-1} wet weight in the Tees area. Elsewhere, levels were generally well below 10 mg kg^{-1}.

Cadmium in dab liver

Concentrations were generally below 0.2 mg kg^{-1} wet weight, except in the area offshore of the Tyne-Humber (Figure 38) previously identified as a hot-spot in surveys carried out for the North Sea Task Force. As in this earlier study, the variation in concentrations found in the sub-samples analysed indicated that at least in some cases, mean high levels were the result of extreme contamination of a few individuals.

Lead in dab liver

Concentrations above 0.2 mg kg^{-1} were found only off the Tees and Humber and in Liverpool Bay where maximum values of ~0.4 mg kg^{-1} were recorded (Figure 39).

Dieldrin in dab liver

Concentrations above 0.02 mg kg^{-1} wet weight were only found in the Thames Estuary, Liverpool Bay and in the Lune Deep area.

DDT in dab liver

By far the highest concentrations of total DDT (>0.10 mg kg^{-1} wet weight) were found in Liverpool Bay and Morecambe Bay. In these samples, as in virtually all others collected around the coast of England and Wales, *p, p'*DDT itself made up only a fraction of the 'total' DDT concentration (*p, p'*DDE + *p, p'*TDE + *p, p'*DDT), indicating that inputs were mainly not of recent origin.

CBs in dab liver

The sum of the seven individual congeners (Σ7CBs) on the ICES primary list are given in Table 18(b). Twenty-five* individual CBs are now in fact routinely analysed for at the Burnham Laboratory and the sum of these (Σ25CBs) has also been included in the Table.

Maximum concentrations were found in Liverpool Bay (Figure 40), with values for Σ7CBs recorded up to 0.6 mg kg^{-1} (1.0 mg kg^{-1} for Σ25CBs). These were roughly twice that found in Morecambe Bay, the second most contaminated region. The Thames estuary and Severn were the only other areas where levels of Σ7CBs were recorded above 0.1 mg kg^{-1}.

[CBs 18, 28, 31, 44, 47, 49, 52, 66, 101, 105, 110, 118, 128, 138, 141, 149, 151, 153, 156, 158, 170, 180, 183, 187 and 194].*

13. BENTHOS STUDIES

13.1 Summary

The macrobenthic infauna was sampled by Day grab at several stations around the coastline of England and Wales as part of a wider interdisciplinary assessment of environmental quality by the regulatory authorities. Similar animal assemblages were encountered on both the eastern and western UK coasts in comparable environmental conditions. Tidal current velocity and sediment characteristics accounted for a significant amount of the observed variability in species richness and densities. There was no evidence of any adverse effects arising from trace metal contamination of sediments.

Table 18(a). Contaminants in dab - metals

NMP Station	Location	Site	Type	Position	Date collected	No.of fish	Length	Mercury (mg kg^{-1} w/w muscle)	Arsenic	Cadmium (mg kg^{-1} w/w liver)	Lead
245	Off Tyne	NSTF14	I	55° 0.5'N 1° 8'W	Feb-94	25	24	0.05	10.2	0.21	0.18
285	Tyne/Tees	NSTF43	O	54° 50'N 1°20'E	Jul-94	25	23.7	0.1	8.6	0.53	0.09
295	Off Tees	NSTF15	I	54° 44'N 0° 53'W	Jul-94	25	19.1	0.04	20.4	0.12	0.41
345	Humber/Wash	NSTF53	O	54° 0'N 2° 0'E	Jul-94	25	23.6	0.08	14	0.16	0.32
376	Humber	ALT	I B	53° 20'N 0° 35'E	Jul-94	20	24.8	0.09	10.1	0.2	0.05
385	Wash	NSTF17	I	53° 3.5'N 0° 28.5'E	Aug-94	25	22.7	0.11	13.2	0.13	0.05
395	S.Bight	S.Knoll	O	52° 50'N 2° 50'E	Jul-94	25	24.5	0.07	6.2	0.13	0.04
465	Thames	Warp	I	51° 30.8'N 0° 58'E	Nov-93	24	25.3	0.06	9.5	0.12	0.05
475	Thames	Gabbard	O	52° 0'N 2° 20'E	Jul-94	25	23.6	0.03	6.2	0.11	<0.03
486	Varne Alt	ALT	O F	50° 51'N 0° 48'E	Jul-94	25	23.4	0.07	4.4	0.06	0.03
496	S.Bill Alt.	ALT	I F	50°44'N 0°18'W	Oct-93	10	19.5	0.05	4.5	0.09	0.05
535	C.Channel	NSTF72	O	50°5'N 3° 0'W	Jul-94	25	24.1	0.07	4.7	<0.02	0.09
576	Tamar Alt.	ALT	I F	50° 12'N 4° 3'W	Oct-92	9	22	0.02	NR	0.06	0.14
585	Plymouth Sound	NSTF73	O	50° 2'N 4° 22'W	Jul-94	11	21.8	0.04	5.5	<0.04	0.09
605	C. Deep		O	51° 15'N 6° 0'W	Jul-94	25	21	0.04	6.7	0.1	NR
616	Severn Alt	ALT	I F	51° 31.5'N 4° 41.7'W	Jul-94	25	22.2	0.03	3.5	0.08	0.16
655	Cardigan Bay		I	52° 21.5'N 4° 10.5'W	Jul-94	25	19.6	0.1	7.4	NR	NR
665	Off Cardigan Bay		O	52° 30'N 5° 0'W	Jul-94	25	21.5	0.03	8.1	0.11	0.13
705	Liverpool Bay	B. Bight	I	53° 28.29'N 3° 15.6'W	Jul-94	25	21.7	0.25	8.9	0.2	0.37
715	Liverpool Bay	D. Site	O	53° 30'N 3° 41.5'W	Jul-94	25	23.3	0.17	8	0.13	0.26
776	Irish Sea Alt	ALT	O	53° 22'N 4° 9'W	Jul-94	25	22.4	0.08	7	0.09	0.16
785	Lune Deep		I	53° 57.7'N 3° 2.5'W	Jul-94	25	26.1	0.15	6.5	0.13	0.20
795	Morecambe Bay		O	53° 58'N 3° 20'W	Jul-94	25	25.2	0.14	7.1	0.08	0.18
805	SE Isle of Man		O	54° 0'N 3° 50'W	Jul-94	25	22.9	0.16	6.1	0.1	0.16

Note: NR = No result

Table 18(b). Contaminants in dab - organics

NMP Station	Location	Site	Type	Position	Date collected	No. of fish	Dieldrin	pp DDE (mg kg^{-1} w/w liver)	pp TDE	pp DDT	Σ DDT	Σ 25CBs	Σ 7CBs	Lipid (%)
245	Off Tyne	NSTF14	I	55° 0.5'N 1° 8'W	Feb-94	25	0.011	0.012	0.003	<0.001	<0.016	0.028	0.019	13
285	Tyne/Tees	NSTF43	O	54° 50'N 1° 20'E	Jul-94	25	0.009	0.024	0.014	0.01	0.048	0.11	0.066	15
295	Off Tees	NSTF15	I	54° 44'N 0° 53'W	Jul-94	25	0.007	0.012	0.009	0.007	0.028	0.059	0.040	11
345	Humber/Wash	NSTF53	O	54° 0'N 2° 0'E	Jul-94	25	0.008	0.023	0.018	0.014	0.055	0.070	0.053	16
376	Humber	ALT	I B	53° 20'N 0° 35'E	Jul-94	20	0.018	0.023	0.036	0.027	0.086	0.12	0.062	24
385	Wash	NSTF17	I	53° 3.5'N 0° 28.5'E	Aug-94	25	0.018	0.032	0.028	0.021	0.081	0.13	0.083	24
395	S.Bight	S.Knoll	O	52° 50'N 2° 50'E	Jul-94	25	0.012	0.026	<0.002	<0.001	<0.029	0.26	0.14	25
465	Thames	Warp	I	51° 30.8'N 0° 58'E	Nov-93	24	0.049	0.045	0.013	0.005	0.063	0.28	0.19	35
475	Thames	Gabbard	O	52° 0'N 2° 20'E	Jul-94	25	0.017	0.017	0.031	<0.001	<0.049	0.13	0.074	25
486	Varne Alt	ALT	O F	50° 51'N 0° 48'E	Jul-94	25	0.009	0.018	0.007	0.004	0.029	0.14	0.077	27
496	S.Bill Alt.	ALT	I F	50° 44'N 0° 18'W	Oct-93	10	0.011	0.013	0.034	<0.001	<0.048	0.12	0.060	30
535	C.Channel	NSTF72	O	50° 5'N 3° 0'W	Jul-94	25	0.013	0.01	0.005	<0.001	<0.016	0.16	0.10	37
576	Tamar Alt.	ALT	I F	50° 12'N 4° 3'W	Oct-92	9	0.013	0.007	0.005	<0.001	<0.041	0.094	0.052	32
585	Pl. Sound	NSTF73	O	50° 2'N 4° 22'W	Jul-94	11	0.006	0.007	0.041	<0.001	<0.049	0.15	0.079	32
605	C. Deep		O	51° 15'N 6° 0'W	Jul-94	25	0.014	0.006	0.004	<0.001	<0.011	0.095	0.055	19
616	Severn Alt	ALT	I F	51° 31.5'N 4° 41.7'W	Jul-94	25	0.008	0.007	<0.005	<0.001	<0.013	0.26	0.13	26
655	Cardardigan Bay		I	52° 21.5'N 4° 10.5'W	Jul-94	25	0.004	0.005	0.007	<0.001	<0.013	0.077	0.043	15
665	Off Cardigan Bay		O	52° 30'N 5° 0'W	Jul-94	25	0.004	0.005	0.006	<0.001	<0.012	0.079	0.046	20
705	Liverpool Bay	B. Bight	I	53° 28.29'N 3° 15.6'W	Jul-94	25	0.027	0.096	0.099	0.012	0.21	1.0	0.59	30
715	Liv. Bay	D. Site	O	53° 30'N 3° 41.5'W	Jul-94	25	0.032	0.081	0.11	0.026	0.22	0.96	0.54	37
776	Irish Sea Alt	ALT	O	53° 22'N 4° 9'W	Jul-94	25	0.009	0.015	0.024	<0.001	<0.040	0.19	0.10	24
785	Lune Deep		I	53° 57.7'N 3° 2.5'W	Jul-94	25	0.023	0.040	0.045	0.028	0.11	0.36	0.20	22
795	Morecambe Bay		O	53° 58'N 3° 20'W	Jul-94	25	0.014	0.054	0.071	0.017	0.14	0.47	0.27	32
805	SE Isle of Man		O	54° 0'N 3° 50'W	Jul-94	25	0.009	0.028	0.029	0.01	0.067	0.25	0.14	27

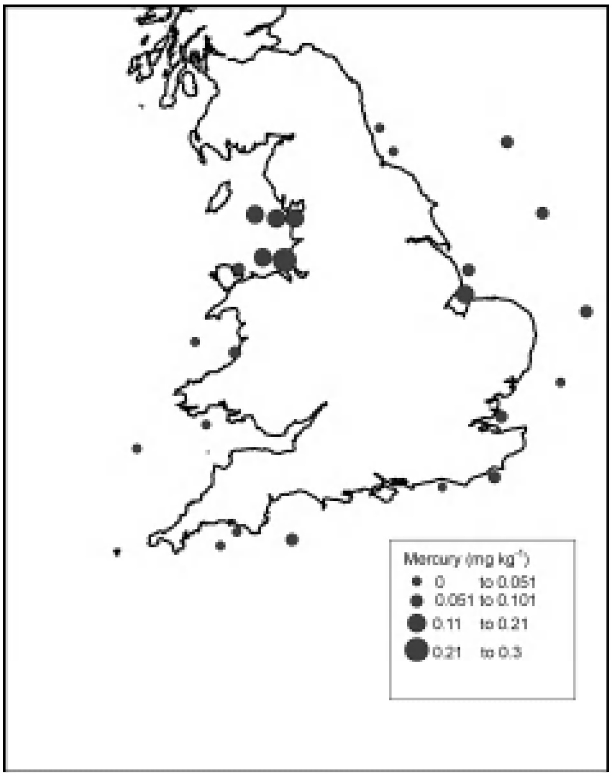


***Figure 37.** Concentrations of mercury (mg kg^{-1} wet weight) in dab muscle*

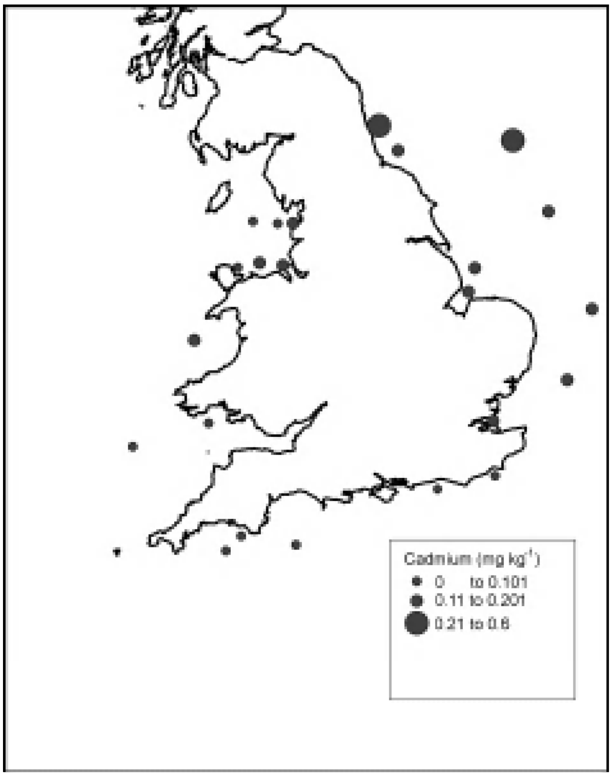


***Figure 38.** Concentrations of cadmium (mg kg^{-1} wet weight) in dab liver*

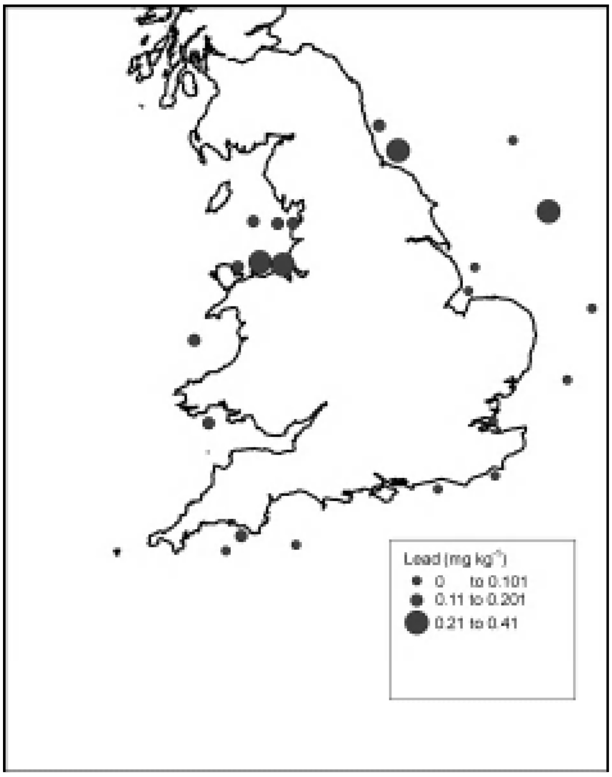


***Figure 39.** Concentrations of lead (mg kg^{-1} wet weight) in dab liver*

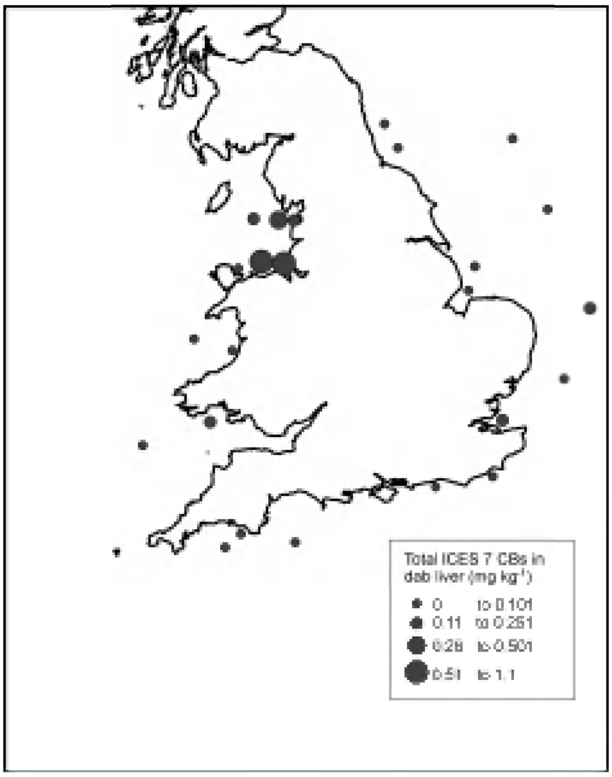


***Figure 40.** Concentrations of total ICES7 CBs (mg kg^{-1} wet weight) in dab liver*

13.2 Introduction

In the North Sea, recent examples of large-scale surveys of the benthic infauna include the work of Eleftheriou and Basford (1989) and Kunitzer *et al.* (1992). The fauna of large sectors of the English Channel have been described by Holme (1961, 1966) and, on the French side, by Cabioch and co-workers (e.g. Cabioch, 1968). A more recent evaluation of diversity across the easternmost part of the English Channel, based upon data collected in the 1970s, is given by Sanvicente-Anove *et al.* (1996).

Compared with the North Sea, coverage of western sea areas is more limited. Hartley (1979) described mollusc distributions in the central and northern Celtic Sea, while a more extensive dredge survey in this region, conducted jointly by French and Irish scientists between 1977 and 1983, unfortunately remains largely unreported (B. Ball and L. Cabioch, pers. comm.). Warwick and Davies (1977) described the benthic communities of the Bristol Channel and, more recently, Mackie *et al.* (1995) reported on infaunal and epifaunal surveys of a proportion of the southern Irish Sea. Rees, E. I. S. (1987) and Mackie *et al.* (1995) provide maps of the infaunal communities of the Irish Sea as a whole, although these contain a predictive element as they were not derived from systematic sampling. Rees and Walker (1991) and Hensley (1996) have conducted surveys of the benthic fauna over extensive areas of the NE and NW Irish Sea, respectively.

The United Kingdom National Monitoring Programme (NMP) has, to date, involved the co-ordinated sampling of over 80 'estuarine', 'intermediate' and 'offshore' stations by the regulatory agencies (MPMMG, 1994). The Ministry of Agriculture, Fisheries and Food (MAFF) undertook sampling at 'intermediate' and 'offshore' NMP stations around the coastline of England and Wales. The following account deals with the outcome of sampling for the benthic infauna at these stations, which collectively cover a wider geographical area than has hitherto been attempted, and hence allow a more coherent evaluation of spatial trends in the fauna in relation to environmental variability.

13.3 Methods

Field sampling

During April and May, 1993, and in February and May, 1994, samples of the benthic macrofauna were collected from MAFF research vessels at each of 25 'intermediate' and 'offshore' stations around the England and Wales coastline, following the guidelines of the National Monitoring Plan (MPMMG, 1994; see also Figure 1). One station in the SW Approaches (NMP 595) was sampled in December, 1992, i.e. outside the recommended February-May sampling window, but was included on grounds that this offshore, deep-water environment is of special interest as a clean-water 'reference' point. (A further attempt to sample the location in February, 1994 had to be abandoned due to bad weather). An additional station was sampled off the Tees estuary, to provide information on the shallow coastal environment in this area.

At each location, five sediment samples for later macrofauna analysis were collected using a 0.1 m^2 Day grab from the central point of a 500 m grid of 9 stations, the latter being sampled for contaminant analyses only. The five replicates were collected from within a 100 m range ring, using SEXTANT software and DGPS position-fixing.

On retrieval, the depth of sediment in the closed jaws of the grab was determined, as an indication of sample volume. Very small samples (i.e. less than about 5 cm depth) were discarded. A visual description of the sediment type was logged, along with information on the location and times at which the sample was collected, and the prevailing sea state, wind strength and water depth. A small sub-sample for later sediment particle size analysis was then removed using a 2 cm diameter perspex corer inserted to a depth of about 5 cm. The contents of the grab were transferred to a hopper, and gently washed over a brass 1 mm mesh sieve. The retained material was preserved in 5% formaldehyde in sea water with added Rose Bengal for later analysis.

Laboratory analysis

The macrofauna was extracted by eye from residual sediment, and then identified to species level, as far as possible, with the use of a range of standard taxonomic keys. In the preparation of fauna lists, nomenclature followed that of Howson (1987). The biomass of each taxon was determined as wet blotted weight, and then expressed as ash-free dry weight using conversion factors mainly from Rumohr *et al.* (1987).

For particle size analyses, sediment sub-samples were first wet-sieved at 500 microns. The >500 micron fraction was then dry-sieved at half-phi intervals, and the <500 fraction analysed using a Coulter LS130 laser sizer.

Percent organic carbon and nitrogen were determined using a CHN analyser, following exposure of sediment samples to concentrated hydrochloric acid in order to dissolve carbonates.

Concentrations of a range of trace metals were determined using an inductively-coupled plasma mass spectrometer or (for mercury) a cold-vapour atomic fluorescence spectrometer, following digestion of whole-sediment extracts (<2 mm) using hydroflouric acid/nitric acid.

As well as following 'in-house' quality control procedures, staff responsible for the processing of NMP macrofauna and sediment samples also actively participated in the UK National Marine Biological and Chemical Analytical Quality Control Schemes, which were established to ensure a measure of consistency in the generation of NMP data from all sources.

Data treatment

Inter-relationships between the following variables were examined using Pearson product moment correlation coefficients:

> maximum spring tidal current strength (kt) from Admiralty data, depth (m), average winter surface-water temperature and salinity from Lee and Ramster (eds, 1981); latitude, longitude, median diameter (mm), sorting coefficient, % silt/clay, numbers of taxa 0.1 m^{-2}, numbers of individuals 0.1 m^{-2}, g AFDW biomass 0.1 m^{-2}, $H'log_2$ (Shannon and Weaver, 1949), evenness (Pielou, 1966), % organic carbon and nitrogen, and concentrations in mg kg^{-1} of a range of trace metals in sediments (As, Cd, Cr, Cu, Hg, Ni, Pb and Zn).

Biological and sediment variables were averaged across the five samples (or 9 in the case of trace metal determinations) taken at each station. No data were available on trace metal concentrations and organic content at two stations, and on organic content at a further four stations.

Average surface-water temperature and salinity in winter (February) were selected on account of the more limited available data at the seabed, especially for the western UK coast (Lee and Ramster, eds, 1981). The authors note that differences in temperature between surface and bottom over most of the North and Irish Seas are minimal at this time of year. They also note the more conservative nature of salinity relative to temperature, with only very small differences in values between winter and summer both at the surface and at the seabed, and the similarity in distributional trends between surface and bottom, for the area covered by the present study.

Multivariate classification analysis was conducted on log-transformed quantitative infaunal data using the Bray-Curtis similarity measure (Bray and Curtis, 1957) and group-average sorting (Lance and Williams, 1967). Relationships between the ranked dissimilarity matrices for the infaunal data and different combinations of environmental variables were examined using the method described by Clarke and Ainsworth (1993).

13.4 Results

430 taxa were identified from field samples, consisting of 186 polychaetes, 112 crustaceans, 76 molluscs, 19 echinoderms and 37 belonging to the category of 'other groups'. Figure 41 provides an indication of spatial

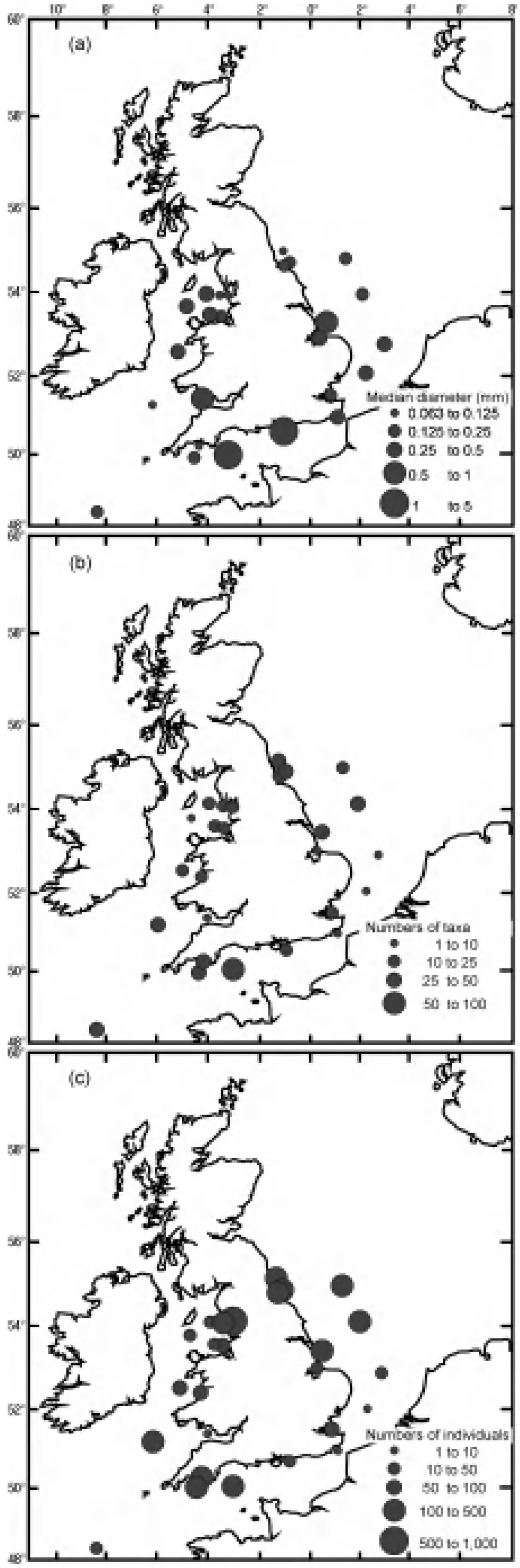


Figure 41. Median particle size of sediments (a), numbers of infaunal taxa (b) and densities (c) 0.1 m^{-2} at NMP stations

variability in the range and densities of taxa encountered at NMP stations, and in the prevailing sediment type. Stations in the easternmost part of the English Channel and southern North Sea off the Thames, and also within the Bristol Channel, supported a very sparse fauna in association with medium sandy sediments. Highest diversities were generally encountered off the north-east and south-west English coasts, across a range of median particle sizes. Densities were also relatively high at most of these stations, and in coastal waters off Morecambe Bay, north-west England.

A correlation matrix for a range of biological and environmental variables is given in Table 19. Concentrations of trace metals are all relatively low at the coastal and offshore stations examined here (Rowlatt and Lovell, 1994(a),(b)). With the exception of As and Cd, these metals are strongly positively correlated with each other, with % organic carbon and nitrogen and, in turn, with measures of particle size (sorting coefficient and % silt/clay). Correlations between a number of metals, notably Cr and Pb, and biological measures (numbers of individuals and taxa 0.1 m^{-2}) are also positive. Trends in metal concentrations are therefore best explained by variation in sediment characteristics, or some other factors associated with this variation. Furthermore, the positive links between these concentrations and biological measures provide no indication of any adverse effects of pollution. There were no significant relationships between As, Cd and biological measures.

Measures of particle size are significantly correlated with the primary biological measures, especially so in the case of sorting coefficient *versus* numbers and densities of taxa (Table 19). Power curves provided a better fit to these data (Figure 42(a),(b)) largely on account of three very sparsely populated stations near the origin of each plot. The characteristics of this group of stations are further described below, in relation to the outcome of cluster analysis. There are also relatively strong negative correlations between biological measures, particularly numbers of taxa, and current speed (Table 19 and Figure 42(c)). The latter is also correlated with the median diameter of sediments. Measures of diversity (H'$\log_2$ and evenness) were negatively correlated with longitude, i.e. diversity tends to increase in a westerly direction. This may be explained by coincident trends in depth, rather than suggesting any biogeographical influence (see Table 19). There were no significant relationships between biological variables and % organic carbon, winter temperature or salinity.

Relationships between physical measures and biological variation were also explored using the method of Clarke and Ainsworth (1993). The highest correlation (p_w = 0.64) arose from a combination of four variables:

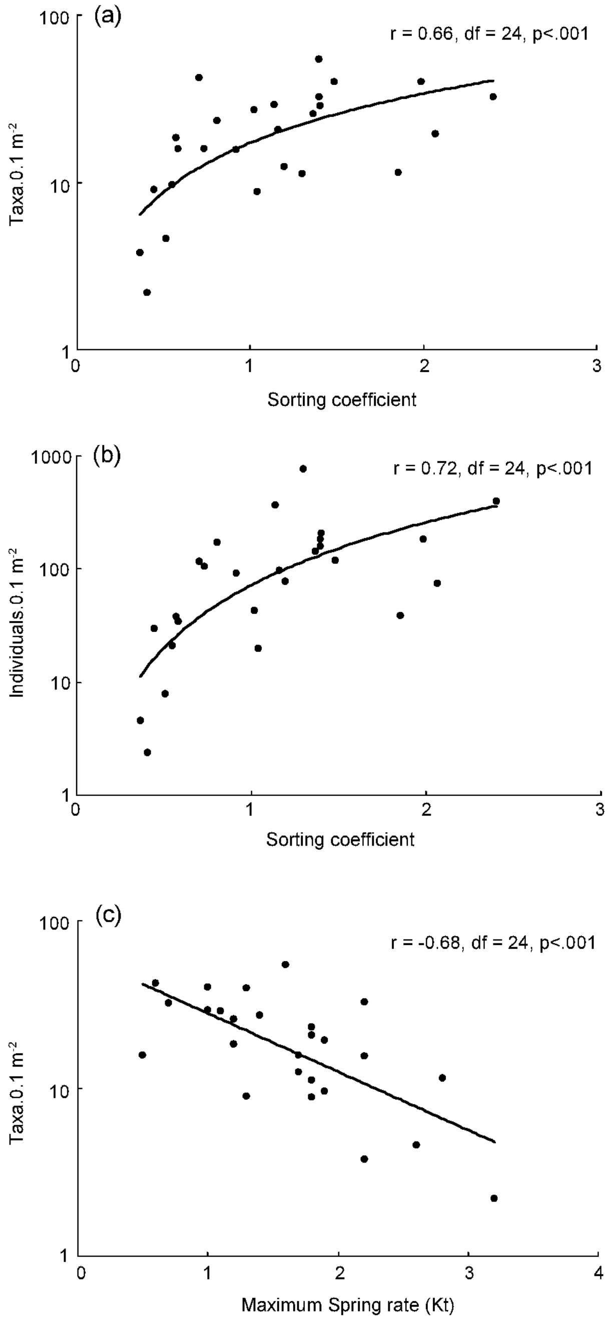


Figure 42. Plots of average numbers (a) and densities (b) of macrobenthic taxa 0.1 m^{-2} at NMP stations against sediment sorting coefficients, and the maximum spring rates at nearby locations, derived from Admiralty data (c)

maximum spring tidal current strength (0.41), median diameter (0.40), longitude (0.18) and sorting coefficient (0.23). These are listed in rank order of their contributions to ascending best-variable combinations, and the figures in parentheses are correlation coefficients for each variable when tested singly against the biological data.

*Table 19. Correlation matrix for biological and environmental variables determined from Day grab samples at NMP stations (n = 26 except for trace metals where n = 24, and % organic carbon and nitrogen, where n = 20) Significance levels: * .05 - .01; ** .01 - .001; *** <.001*

	Current speed	Log depth	Temperature	Salinity	Latitude	Longitude	Log median	Sorting	% silt/clay	Log taxa	Log counts	Log biomass	$H'log_2$	Eveness	% carbon	% nitrogen	Log As	Log Cd	Log Cr	Log Cu	Log Hg	Log Ni	Log Pb	Log Zn
Current speed																								
Log depth	ns																							
Temperature	ns	ns																						
Salinity	ns	ns	0.6 **																					
Latitude	ns	ns	ns	ns																				
Longitude	ns	-0.45 *	ns	ns	0.41 *																			
Log median	0.54 **	ns	-0.55 **	ns	-0.4 *	ns																		
Sorting	ns	ns	ns	ns	ns	ns	ns																	
% silt/clay	ns	ns	0.54 **	ns	ns	ns	-0.77 ***	0.64 ***																
Log taxa	-0.68 ***	ns	ns	ns	ns	ns	ns	0.57 **	0.41 *															
Log counts	-0.55 **	ns	ns	ns	ns	ns	-0.39 *	0.62 ***	0.51 **	0.81 ***														
Log biomass	ns	ns	ns	ns	ns	ns	-0.43 *	ns	0.44 *	0.47 *	0.64 ***													
$H'log_2$	-0.56 **	0.45 *	ns	ns	ns	-0.54 **	ns	ns	ns	0.84 **	ns	ns												
Evenness	ns	ns	ns	ns	ns	-0.43 *	ns	ns	ns	ns	-0.73 ***	-0.5 **	ns											
% carbon	ns	ns	0.54 *	ns	ns	ns	-0.58 **	0.58 **	0.82 ***	ns	ns	ns	ns	ns										
% nitrogen	ns	ns	0.62 *	ns	ns	ns	-0.63 **	0.63 **	0.85 ***	0.55 *	0.47 *	ns	0.47 *	ns	0.93 ***									
Log As	0.61 **	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns								
Log Cd	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns							
Log Cr	ns	ns	ns	ns	ns	ns	-0.71 ***	0.55 **	0.79 ***	0.49 *	0.6 **	0.52 **	ns	ns	0.76 ***	0.8 ***	ns	ns						
Log Cu	ns	ns	ns	ns	ns	ns	-0.56 **	0.58 **	0.71 ***	ns	0.43 *	ns	ns	ns	0.68 **	0.76 ***	ns	ns	0.79 ***					
Log Hg	ns	ns	ns	ns	ns	ns	-0.48 *	0.47 *	0.54 **	ns	0.51 *	0.45 *	ns	ns	0.61 **	0.68 **	ns	ns	0.77 ***	0.78 ***				
Log Ni	ns	ns	ns	ns	ns	ns	ns	0.48 *	0.57 **	ns	ns	ns	ns	ns	0.81 ***	0.87 ***	ns	ns	0.45 *	0.68 ***	0.55 **			
Log Pb	ns	ns	ns	ns	ns	ns	-0.64 ***	0.61 **	0.73 ***	0.42 *	0.5 *	0.46 *	ns	ns	0.83 ***	0.86 ***	ns	ns	0.86 ***	0.82 ***	0.77 ***	ns		
Log Zn	ns	ns	ns	ns	ns	ns	-0.53 **	0.62 **	0.68 ***	ns	0.46 *	ns	ns	ns	0.73 ***	0.79 ***	ns	ns	0.87 ***	0.82 ***	0.77 ***	ns	0.92 ***	

The outcome of correlation analyses therefore suggests that the predominant influence on benthic populations is that of tidal current strength (expressed in terms of maximum spring rate), mediated to a lesser degree through variation in particle size characteristics of sediments.

Six assemblages were identified from cluster analysis of log-transformed quantitative data (Figures 43 and 44). It is evident from Figure 44 that, where environmental conditions are comparable, a similar benthic fauna can develop irrespective of geographical location. Thus there is little evidence from this analysis of biogeographical constraints on the disposition of assemblage types A and C-E, or of a pronounced inshore/offshore dichotomy, although this is not to imply that all component species are cosmopolitan in their distribution within the survey area. Assemblage B, associated with coarser deposits, is confined to the English Channel and western approaches, while assemblage F comprises a discrete group of offshore medium sandy stations in the eastern Irish Sea (Figure 44).

The main characteristics of these assemblages are summarised in Table 20. The groups have little in common in terms of the dominant taxa, reflecting the relatively low levels of similarity at which they are linked. Previously identified trends in relation to environmental variables are exemplified by the contrast between clusters A and D. Stations within the former, located in areas of relatively high tidal current velocity, support a very impoverished fauna characterised by the presence of the polychaete *Ophelia borealis*, a typical inhabitant of mobile sandy sediments (e.g. Vanosmael *et al.*, 1982). Stations within the latter group, under conditions of lower tidal current velocity and generally deeper water, support a much higher diversity of species as well as enhanced densities and biomass, indicative of more stable substrata.

For other cluster groups in Table 20, it is clear that faunal affinities between stations can occur despite the fact that environmental conditions at a number of these are very different. For example, the coarse sand assemblage within the English Channel, typified by the dominant taxa of group B, occurs at widely varying depths and under substantially different tidal current regimes which, in turn, is reflected in the range in total numbers of taxa encountered. Similar observations apply especially to group E, and help to explain why the relationships established between univariate measures of biological and environmental status at individual stations are not so readily identified from the output of cluster analysis.

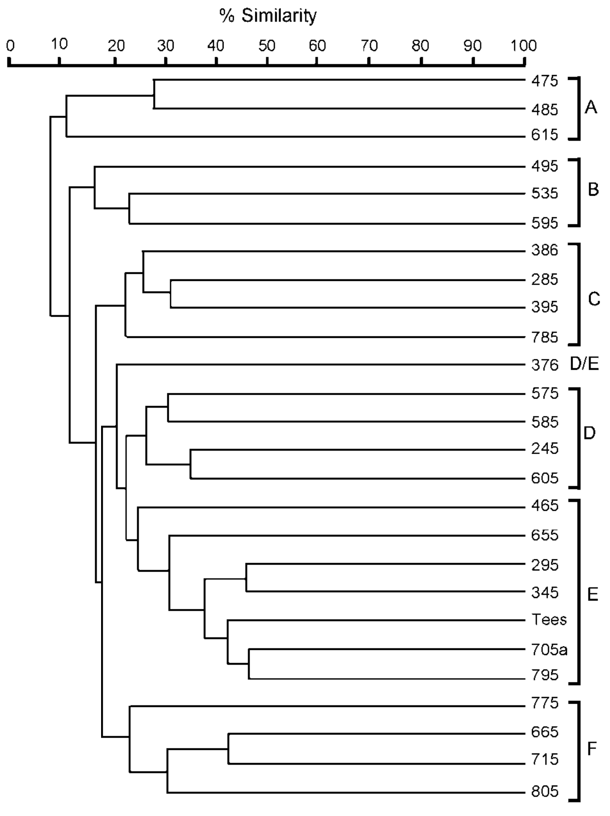


Figure 43. Dendrogram output from cluster analysis of the log-transformed macrofauna data at NMP stations. Six assemblage types have been identified at various levels of similarity

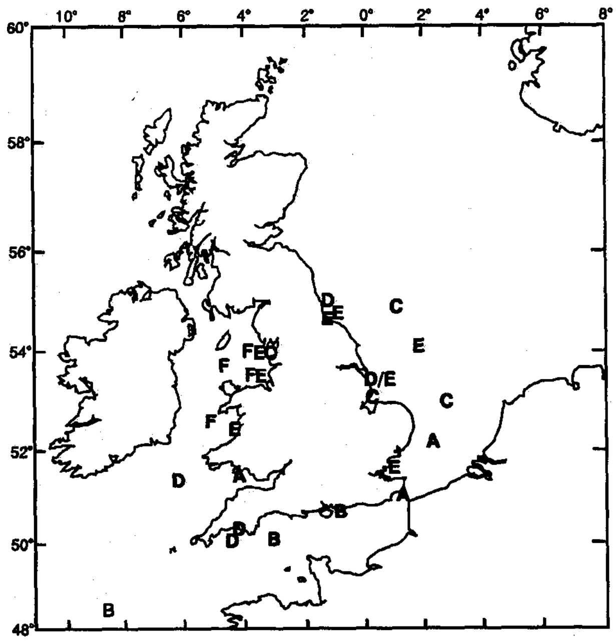


Figure 44. Grouping of NMP stations around the England and Wales coastline according to the outcome of cluster analysis of macrofauna data (see Figure 43)

Table 20. Top five ranked taxa in terms of derived mean densities.0.1 m^{-2} across station groups identified from cluster analysis. Numbers of taxa (means and ranges.0.1 m^{-2}), densities and biomass (derived means and ranges.0.1 m^{-2}) across stations together with particle size statistics, current strengths, depths and habitat descriptions, are listed below

	A	y	B	y	C	y	D/E	y
	Ophelia borealis	5.7	*Typosyllis* spp	37.3	*Lagis koreni*	868.3	*Nucula hanleyi*	128
	Nephtys spp	4.3	*Sphaerosyllis hystrix*	28.3	*Bathyporeia guilliamsoniana*	63.8	*Sabellaria spinulosa*	123
	Spisula elliptica	2	*Echinocyamus pusillus*	17	*Nephtys* spp	42.8	*Pholoe* sp	38
	Oligochaete sp	1.3	*Polycirrus medusa*	15	*Fabulina fabula*	37.5	*Ophiura* spp	20
	Bathyporeia elegans	1.3	*Glycera lapidum*	15	*Mysella bidentata*	22.5	*Ampelisca typica*	8
	Spio filicornis	1	Anthozoa sp	12.3				
Numbers of taxa	3.5 (2.2 - 4.6)		31.1 (11.4 - 54.6)		11.2 (8.8 - 15.8)		32.4	
Numbers of individuals	5 (2 - 8)		67 (38 - 181)		83 (20 - 768)		394	
Biomass (g AFDW)	0.042 (0.001 - 0.425)		0.120 (0.061 - 0.326)		0.188 (0.053 - 2.580)		0.523	
Median (mm)	0.44 (0.35 - 0.56)		1.56 (0.45 - 2.87)		0.23 (0.12 - 0.32)		0.63	
Sorting	0.43 (0.36 - 0.51)		1.42 (1.02 - 1.85)		0.88 (0.44 - 1.30)		2.4	
Maximum spring rate (kt)	2.7 (2.2 - 3.2)		1.9 (1.4 - 2.8)		1.4 (0.5 - 1.8)		2.2	
Depth (m)	34 (26 - 49)		84 (20 - 167)		30 (28 - 35)		20	
Habitat type	Mobile medium sand		Coarse sand		Fine sand		Muddy gravelly sand	
Location	S North Sea/ Bristol Channel		English Channel		North Sea		Wash, E England	

	D	y	E	y	F	y
	Maldanidae	57.5	*Chamelea gallina*	116.1	*Abra alba*	76
	Melinna palmata	46.3	*Amphiura filiformis*	96.1	*Scoloplos armiger*	16.3
	Abra alba	39.8	*Nucula nitidosa*	61.9	*Nephtys* spp	13.8
	Echinocyamus pusillus	37.5	*Spiophanes bombyx*	57.9	*Spatangus purpureus*	11
	Abra nitida	30.3	*Abra alba*	47.4	*Spisula elliptica*	10.3
Numbers of taxa	35.1 (25.8 - 42.2)		24.7 (12.4 - 39.6)		14.9 (9.6 - 18.4)	
Numbers of individuals	147 (116 - 181)		136 (75 - 360)		40 (21- 91)	
Biomass (g AFDW)	0.272 (0.096 - 0.564)		0.713 (0.220 - 3.068)		0.180 (0.095 - 0.303)	
Median (mm)	0.12 (0.06 - 0.24)		0.14 (0.04 - 0.24)		0.40 (0.25 - 0.47)	
Sorting	1.36 (0.70 - 1.99)		1.32 (0.81 - 2.06)		0.65 (0.55 - 0.92)	
Maximum spring rate (kt)	0.9 (0.6 - 1.2)		1.5 (1.0 - 1.9)		1.8 (1.2 - 2.2)	
Depth (m)	69 (39 - 95)		33 (16 - 74)		57 (39 - 79)	
Habitat type	Stable muddy v. fine sand		Predominantly inshore muddy fine sand		Offshore medium sand	
Location	NE and SW coasts		E and W coasts		W coast	

A single station representative of coarser deposits off the Humber estuary (D/E in Table 20, since it has closest affinity with these groups: see Figure 44), supported a rich and distinctive fauna characterised by the presence of the reef-building polychaete *Sabellaria spinulosa*. The development of such reefs, typically on gravelly substrata with strong tidal flow, provides a stable platform for colonisation by a wide variety of species (see, e.g. George and Warwick, 1985). Strictly, such an assemblage could be defined as epifaunal, even though the habitat presented is clearly suitable for both 'infaunal' and epifaunal colonisers (see Table 20).

13.5 Discussion

The National Monitoring Programme has involved the deployment of standard methods for the sampling of the subtidal infauna over a much wider geographical scale around the United Kingdom coastline than hitherto, and the data should therefore provide a valuable 'baseline' for future work directed at these groups.

Multivariate analysis showed that groups of similar stations associated with softer substrata were common to both the eastern and western UK coasts. Both sediment sorting and tidal current strengths are useful expressions of the dynamic nature of the local physical environment, and significant relationships with numbers and densities of taxa were evident (see Figure 42). Thus the degree of *physical disturbance* of sediments expressed in these terms, as well as particle size alone as a 'static' descriptor of habitat type, provided a convincing explanation of broad trends in the data. This finding is comparable with that of Warwick and Uncles (1980) who linked variability in the fauna of the Bristol Channel to bed shear stresses arising from tidal current action. Cabioch (1968) also identified the critical importance of tidal influences on the distribution of benthic species in the English Channel, mediated through their effects on substratum characteristics, particulate transport and water mixing.

Too few stations were occupied in the North Sea to delineate any patterns in the distribution of infaunal assemblage types comparable with that achieved for the ICES North Sea benthos survey conducted in 1986 (Kunitzer *et al.,* 1992), which also incorporated earlier data for the northern part, reported by Eleftheriou and Basford (1989). The survey design comprised a grid of stations across the whole North Sea, but the near-shore environment along the English east coast, where the majority of NMP stations were located, was not adequately covered. Nevertheless, some parallels are evident, for example, the two southern stations within group A of Figure 44 appear to represent extreme manifestations of the relatively species-poor assemblage Ia in this area (Figure 4 in Kunitzer *et al.,* 1992), characterised by coarser sediments in depths generally less than 30 m. The northernmost station within group D of Figure 44 has affinities with the finer-sediment assemblage IIIa of Kunitzer *et al.* (1992), occupying deeper water of 70–100 m adjacent to this coastline, which has also been described by Buchanan *et al.* (1978).

Parallels with groups C and E are less easy to draw, especially as stations within the latter group cross the latitudinal and depth boundaries for assemblage types identified by Kunitzer *et al.* (1992). Counterparts of North Sea assemblage types C and E are associated with inshore sediments of the Irish Sea, where they share attributes of the 'shallow *Venus*' and *Abra* communities, described in these areas by Mackie *et al.* (1995). The description of an '*Abra alba-Pectinaria koreni*' community for the eastern Bay of Seine (Thiebaut *et al*., 1997) also matches the fauna frequently associated with inshore muddy sands of the Irish Sea. Offshore medium sandy stations in the Irish Sea (comprising Group F in Figure 44) fall within the zone of a 'deep *Venus*' community interspersed among areas of hard ground, according to Mackie *et al.* (1995), and the species complement is broadly consistent with this definition. Elements of the fauna of group B stations in the English Channel and western approaches are also indicative of coarser deposits, for example, the presence of the green sea urchin *Echinocyamus pusillus*, but there are few similarities with the work of Holme (1961, 1966), in which he employed an Anchor dredge for seabed sampling, and concentrated only on the larger mollusc and echinoderm species.

Concentrations of trace metals in sediments from the present study were relatively low, and there was no evidence of any adverse effects on the benthic fauna. Future work will include an evaluation of temporal trends in benthic populations at representative stations, which should facilitate the detection of more subtle effects, if any, arising from anthropogenic activities. However, at present, it is evident that any contaminant effects are subsidiary to natural influences in accounting for the overall spatial distribution of assemblage types at intermediate and offshore NMP stations.

14. MEASUREMENTS OF ETHOXYRESORUFIN-O-DEETHYLASE (EROD) ACTIVITY IN FLATFISH

14.1 Introduction

Probably some of the most biologically significant groups of contaminants in the benthic marine environment are the polycyclic aromatic hydrocarbons (PAH), the planar polychlorinated biphenyls (PCB), the dibenzo-*p*-furans and the dioxins. The PCBs are exclusively anthropogenic, while the others arise from a range of natural and anthropogenic processes. As they are all extremely hydrophobic, they tend to become associated with fine sediments, and benthic flatfish may therefore experience higher exposure than pelagic fish. When absorbed into fish, these substances all induce synthesis of the mono-oxygenase enzymes known as the cytochrome P450 group, which are found in large amounts in the microsomal fraction of liver cells. Cyt-P450 enzymes are responsible in part for catalysing the degradation of these exogenous substances (which can have a variety of harmful effects), as well as for metabolising endogenous sex steroids and vitamins, but some of the degradation products of the exogenous materials (e.g. epoxides) are harmful in their own right. In particular, they can bind with the genetic material (DNA) in the nucleus of cells and ultimately cause *inter alia* carcino- and teratogenicity. This probably explains, at least in part, the occurrence of liver tumours in some flatfish (Section 15).

It may be useful to obtain early warning of this sequence of events, or at least of the exposure of fish to the relevant contaminants, because this can potentially enable remedial action to be taken before serious effects occur at the population level. This can be done by measuring the induction of cytochrome P4501A, as detected by the activity of 7-ethoxyresorufin-O-deethylase (EROD) in fish liver (e.g. Eggens *et al.*, 1995).

14.2 Methods

Flatfish (dab - *Limanda limanda*, and plaice - *Pleuronectes platessa*) more than 10 cm in length were generally collected by means of Granton or 3 m beam trawls. Liver samples were taken immediately and stored in cryovials in liquid nitrogen to await measurement of EROD activity. This was accomplished for homogenates of 200 mg subsamples by methods similar to those of Stagg *et al.* (1995). In essence, EROD activity at 20°C was quantified by fluorometric spectrometry (535 nm excitation; 580 nm emission) using a 250 pM resorufin internal standard. Activity was normalised to protein (measured by a modification of the Bradford method) and expressed as pM resorufin/min/mg protein.

An initial set of dab liver samples was taken from the North Sea in April 1991, and in the North Sea, English Channel and Irish Sea in October 1991 in order to establish 'background' EROD activities over a wide area. In the knowledge that crude oil contains a number of PAHs, a further series of EROD activity measurements in plaice and dab was made in the Irish Sea subsequent to the *SEA EMPRESS* oil spill in Milford Haven in February 1996.

14.3 Results and discussion

1991 data for dab

Part of the 1991 data was published in the North Sea Quality Status Report (NSTF, 1993) and its sub-regional reports, and in MAFF (1993). Most of the 1996 data can be found in Kirby *et al.* (1996).

Many of the 1991 dab samples (all intermediate and offshore sites) contained rather small (<10) numbers of fish, a factor which contributed to the sometimes large standard deviations, although EROD is often inherently very variable between individuals in a sample. The April 1991 EROD activity values were generally rather high (up to 1247 pM/min/mg protein in females and 3607 pM/min/mg protein in males) (Table 21). This phenomenon is linked to the breeding cycle, and may be an entirely natural effect connected with temperature and steroid metabolism (Sleiderink *et al.*, 1995; Lange *et al.*, 1995). However, it has also been suggested (Cooreman *et al.*, 1993) that it may be due to the mobilisation of PCBs when fish start utilising their fat reserves in spring.

In contrast, EROD activity in October 1991 well after the breeding season was generally relatively low, the highest mean level being 856 pM/min/mg protein for females from north of Flamborough Head. All other sites were below 500 pM/min/mg protein in either sex. Although a gradient of decreasing EROD activity

Table 21. 1991 EROD activity data (pM/min/mg protein) for dab Limanda limanda (17-27 cm length)

Date	Station	Coordinates	EROD in females			EROD in males		
			Mean	n	s.d.	Mean	n	s.d.
North Sea								
4/91	North Dogger	55° 24'N 3° 10'E	313	11	347	3607	11	1576
10/91	North Dogger	55° 07'N 3° 15'E	90	8	63	188	4	90
10/91	West Dogger	54° 50'N 1° 15'E	-	-	-	278	6	165
4/91	Oyster Grounds	54° 06'N 4° 19'E	278	11	360	1333	10	1325
4/91	Silver Pit	54° 07'N 2° 27'E	131	13	223	783	11	788
4/91	Smiths Knoll	52° 45'N 2° 42'E	1247	16	1410	2047	3	1220
10/91	Smiths Knoll	52° 45'N 2° 42'E	105	10	82	-	-	-
4/91	North of Spurn Head	53° 57'/ 54° 17'N 0° 25' / 0° 48'E	48	10	83	623	12	448
10/91	North of Spurn Head	53° 54'N 0° 56'E	461	6	293	314	6	217
10/91	North of Flamborough Head	54° 30'N 0° 39'E	856	-	324 (std. error)	409	-	77 (std. error)
English Channel								
10/91	Rye Bay	50° 52.42'N 00° 48.91'E	161	-	64 (s.e.)	73	-	25 (s.e.)
10/91	Lyme Bay	50° 30'N 3° 07'W	1013	-	460 (s.e.)	225	-	73 (s.e.)
Irish Sea								
10/91	Cardigan Bay	52° 19'N 4° 14'W	133	8	64	205	5	117
10/91	Liverpool Bay (inner)	53° 27'N 3° 21'W	474	4	454	483	6	481
10/91	Liverpool Bay (middle)	53° 26'N 3° 32'W	427	8	391	472	8	332
10/91	Liverpool Bay (outer)	53° 29'N 3° 38'W	149	4	94	47	4	30
10/91	Morecambe Bay	53° 57'N 3° 20'W	347	5	372	322	6	306

appeared to be present in samples taken at increasing distances from the inner part of Liverpool Bay (which receives considerable contamination from the Mersey), this was not statistically significant, possibly due to the small sample sizes.

No contaminant data are available for the same samples of fish in which EROD was measured in 1991, although this is desirable to assist interpretation. Values of total PCB in livers of other dab caught in 1990-91 from north of Spurn Head, Silver Pit, offshore Tyne/Tees, Dogger Bank and Smiths Knoll were 7.8, 4.3, 8.3, 7.7 and 3.1 mg kg^{-1} fat weight, respectively, but none of these are thought to be sufficiently high to cause adverse biological effects.

1996 data for dab - Milford Haven area
No hydrocarbon residue data are available for the same fish in which EROD activity was assayed in the February-July period, but levels in coastal and offshore fish remained generally low (total hydrocarbons in flatfish liver near Milford Haven were 0.8 to 15 mg kg^{-1} between February and May, 1996). In addition, all offshore sediments sampled in May had low total hydrocarbon concentrations (<27 mg kg^{-1}) except for Tenby north beach (107 mg kg^{-1}). In general, there were few significant differences in EROD activity between the sexes and only weak indications of correlations between EROD activity and fish length, and the descriptions which follow are largely based on pooled data for all fish in each sample. Overall, following relatively low EROD activity in February some 2 weeks after the *SEA EMPRESS* spill (mean values ranged from 118 pM/min/mg protein at Rhossili Bay to 955 pM/min/mg protein at St. Brides Bay), activity increased sharply in May giving a range of 1496 pM/min/mg protein (St. Brides Bay) to 4909 pM/min/mg protein (Turbot Bank). This broad increase was in part probably related to seasonal effects referred to above. By July (after the breeding season), EROD activity had dropped down again (giving a range of 1035 pM/min/mg protein at St. Brides Bay to 1655 pM/min/mg protein at east Carmarthen Bay), although not right back to February levels.

These strong seasonal changes would tend to have masked oil-related EROD induction, especially as coastal and offshore fish were generally not significantly contaminated with *SEA EMPRESS* oil. Reference to data collected in October 1991 in the dab pre-spawning period shows that EROD activity in relatively uncontaminated areas is generally less than 500 pM/min/mg protein. EROD activity in fish caught in February from St. Brides, Tenby and central Carmarthen Bay all marginally exceeded this, but although this may have been oil-related, the February fish were already into their spawning period. Firm conclusions about the February data cannot therefore be reached.

Attempts to compare inshore EROD activity in May and July, to presumably uncontaminated reference areas offshore, (Milford offshore Stn C166, in May; SW Milford Stn 152, in July) were thwarted by the fact that EROD activities at these sites were among the highest seen (3888 and 2548 pM/min/mg protein, respectively). The offshore stations are unlikely to have received significant concentrations of oil because they do not accumulate fine sediments, but it is possible that these 'reference' results can be explained by the lower temperatures to be expected in 60 m deep bottom waters (Sleiderink *et al.*, 1995).

Despite the lack of reliable reference data, it is perhaps noteworthy that the highest EROD activities in May (4909 and 3918 pM/min/mg protein) were observed at Turbot Bank and Freshwater West, respectively, the two stations nearest the site of the *SEA EMPRESS* spill. These values were significantly higher ($p<0.05$) than those at most other stations, but it is not possible to conclude unequivovally that they were related to oil exposure because the fish were still in their post-spawning period. April 1991 data (also in the post-spawning period) from the central North Sea show EROD activities up to 3600 pM/min/mg protein, so the values seen at Turbot Bank and Freshwater West were not necessarily unusual.

The July inshore fish were in the resting phase of their reproductive cycle, so their EROD activity (1035-1655 pM/min/mg protein) was expected to have been minimal. Although activity was generally somewhat elevated with respect to fish caught in October 1991, comparisons with dab caught elsewhere in the Irish and North Seas in July 1996 (449-1828 pM/min/mg protein; Table 22) show that EROD activities in the Milford Haven area were not unusually elevated at this time. It therefore seems that, although seasonal changes may have been masking small effects of the oil in February and May 1996, these effects had entirely disappeared by July.

1996 data for dab - Irish Sea (general) and North Sea
The mean EROD activities in dab from the Irish Sea and North Sea (males and females pooled) in July 1996 (Table 22) lay in the ranges 601-1156 and 449-1828 pM/min/mg protein, respectively. No contaminant data are available for these fish, so firm conclusions about contaminant-related effects cannot be reached. EROD activity appears to have been mildly elevated off the Tyne, the Tees, on the Dogger Bank, in the Burbo Bight, and in Red Wharf Bay, but was probably within the normal range. Mean activity at the SE Isle of Man station (601 pM/min/mg protein) was significantly lower ($p<0.05$) than at all other stations except outer Cardigan Bay. EROD activity was negatively correlated ($r = -0.96$) with depth in female fish from the Irish Sea, and also negatively correlated ($r = -0.88$) with gonadosomatic index in females, so it seems possible that post-spawning seasonal factors may still have been affecting activity.

Table 22. EROD activity levels (pM/min/mg protein) in dab (Limanda limanda) sampled in 1996 (mean lengths 14.8-26.6 cm)

Date	Station	Coordinates	EROD in females			EROD in males		
			Mean	n	s.d.	Mean	n	s.d.
Milford Haven area								
2/96	St. Brides Bay	51° 47'N 5° 11'W	1180	10	1371	392	4	268
5/96	St. Brides Bay	51° 47'N 5° 11'W	1323	10		2075	3	
7/96	St. Brides Bay	51° 47'N 5° 11'W	1321	10	704	749	10	361
2/96	Tenby	51° 40'N 4° 42'W	171	1	-	879	10	390
5/96	Tenby	51° 40'N 4° 42'W	2101	18		2314	2	
2/96	Carmarthen Bay (central)	51° 40'N 4° 33'W	807	11	564	500	2	220
5/96	Carmarthen Bay (central)	51° 40'N 4° 33'W	2511	12	1091	3319	12	832
7/96	Carmarthen Bay (central)	51° 40'N 4° 33'W	1463	5	1055	1260	1	-
2/96	Carmarthen Bay (offshore)	51° 34'N 4° 33'W	125	3	66	233	1	-
5/96	Carmarthen Bay (offshore)	51° 34'N 4° 33'W	3203	9	1412	4368	5	959
5/96	Carmarthen Bay (C192)	51° 36'N 4° 33'W	3848	7	1462	3779	17	1521
7/96	Carmarthen Bay (163)	51° 40'N 4° 31'W	1462	13	872	1771	11	1244
7/96	Carmarthen Bay (east)	51° 35'N 4° 21'W	1364	11	1100	1946	11	1188
7/96	Carmarthen Bay (west)	51° 33'N 4° 52'W	1600	10	768	1584	10	750
2/96	Rhossili Bay	51° 35'N 4° 19'W	171	3	271	39	2	26
5/96	Rhossili Bay	51° 35'N 4° 19'W	2881	18	818	3527	7	1698
5/96	Skomer	51° 45'N 5° 14'W	1624	4	585	-	-	-
5/96	Manorbier	51° 37'N 4° 45'W	1863	8	1176	4456	5	1787
5/96	Caldey Island	51° 31'N 4° 40'W	2132	2	619	3137	2	771
5/96	Pembrey	51° 41'N 4° 24'W	3560	10	1199	3532	5	1163
5/96	Turbot Bank	51° 37'N 5° 08'W	4489	3	1387	5329	3	1873
5/96	Freshwater West	51° 40'N 5° 06'W	3430	7	477	4772	4	850
5/96	Milford offshore (C166)	51° 23'N 5° 35'W	4105	5	1223	3789	11	1273
7/96	Milford offshore (152)	51° 29'N 5° 33'W	2603	10	1224	2164	10	2164
Irish Sea (general)								
7/96	Cardigan Bay (outer)	52° 23'N 4° 53'W	680	5	451	996	7	487
7/96	Red Wharf Bay	53° 22'N 4° 09'W	1319	9	1057	1022	11	791
7/96	Liverpool Bay	53° 29'N 3° 47'W	765	10	571	1200	10	790
7/96	Burbo Bight	53° 28'N 3° 22'W	1556	10	1002	737	10	754
7/96	Morecambe Bay	53° 54'N 3° 25'W	1223	10	707	857	10	447
7/96	S.E. Isle of Man	54° 00'N 3° 50'W	665	10	370	522	10	378
North Sea								
7/96	Tyne (offshore)	55° 18'N 1° 15'W	1608	10	1204	2047	10	1147
7/96	Dogger Bank	54° 48'N 1° 16'E	799	10	479	1886	10	912
7/96	Tees (offshore)	54° 46'N 1° 02'W	1321	10	978	1527	10	662
7/96	Humber (offshore)	53° 20'N 0° 25'E	456	17	249	404	3	146
7/96	The Wash	53° 09'N 0° 34'E	830	10	653	-	-	-

1996 data for plaice - Milford Haven area

Broadly speaking, the picture in plaice (Table 23) was similar to that in dab, and no specific contaminant data are available. Any slight effects of oil from the *SEA EMPRESS* were probably masked by seasonal factors which led to low mean (sexes pooled) EROD activities in February (102-260 pM/min/mg protein), a peak in May (404-1032 pM/min/mg protein), and levels which were still elevated in July (185-981 pM/min/mg protein). The EROD activities observed near Milford Haven in July were similar to those seen in other Irish Sea areas at that time. Furthermore, EROD activity was generally several-fold lower in plaice than in dab, so they appear to have a less well-developed EROD response. Note, however, that plaice spawn earlier than dab (January-February), and many of the sampled plaice were immature, so confounding factors connected with the breeding cycle were probably not as strong as in dab.

1996 data for plaice - Irish Sea (general)

Mean EROD activities (sexes pooled) in plaice caught in July 1996 in Irish Sea areas remote from Milford Haven (Table 23) were generally low (147-524 pM/min/mg protein). Activity at Burbo Bight (524 pM/min/mg protein) was significantly greater than elsewhere ($p<0.05$), and there was a weak negative correlation ($r = -0.59$) with depth, but there is no evidence to suggest the influence of contaminants. As with dab, plaice from SE Isle of Man showed low levels of EROD activity (160 pM/min/mg protein).

Table 23. EROD activity levels (pM/min/mg protein) in plaice (Pleuronectes platessa) sampled in 1996 (mean lengths 13.6-28.1 cm)

Date	Station	Coordinates	EROD in females			EROD in males		
			Mean	n	s.d.	Mean	n	s.d.
Milford Haven area								
2/96	St. Brides Bay	51° 47'N 5° 11'W	156	11	91	464	1	-
5/96	St. Brides Bay	51° 47'N 5° 11'W	399	3		409	3	
7/96	St. Brides Bay	51° 47'N 5° 11'W	246	2	61	124	3	82
2/96	Tenby	51° 40'N 4° 42'W	-	-	-	260	6	111
5/96	Tenby	51° 40'N 4° 42'W	824	7		729	1	
2/96	Carmarthen Bay (central)	51° 40'N 4° 33'W	438	1	-	107	2	1
5/96	Carmarthen Bay (central)	51° 40'N 4° 33'W	869	14		1377	4	
7/96	Carmarthen Bay (central)	51° 40'N 4° 33'W	593	1	-	1059	5	481
2/96	Carmarthen Bay (offshore)	51° 34'N 4° 33'W	180	3	57	86	1	-
5/96	Carmarthen Bay (offshore)	51° 34'N 4° 33'W	949	11		1213	5	
5/96	Carmarthen Bay (C192)	51° 36'N 4° 33'W	859	19		797	9	
7/96	Carmarthen Bay (163)	51° 40'N 4° 31'W	307	4	82	279	8	91
7/96	Carmarthen Bay (east)	51° 35'N 4° 21'W	327	6	210	154	5	96
7/96	Carmarthen Bay (west)	51° 33'N 4° 52'W	316	6	193	148	6	62
2/96	Rhossili Bay	51° 35'N 4° 19'W	101	4	45	-	-	-
5/96	Rhossili Bay	51° 35'N 4° 19'W	646	12		717	7	
5/96	Skomer	51°45'N 5° 14'W	603	3		141	2	
5/96	Manorbier	51° 37'N 4° 45'W	776	19		752	10	
5/96	Caldey Island	51° 31'N 4° 40'W	827	3		605	2	
5/96	Pembrey	51° 41'N 4° 24'W	707	12		567	14	
5/96	Turbot Bank	51° 37'N 5° 08'W	789	19		752	2	
5/96	Freshwater West	51° 40'N 5° 06'W	831	12		850	11	
5/96	Milford offshore (C166)	51° 23'N 5° 35'W	-	-	-	-	-	-
7/96	Milford offshore (152)	51° 29'N 5° 33'W	542	3	270	596	9	94
7/96	Swansea Bay	51° 31'N 3° 52'W	175	7	93	171	5	146
Irish Sea (general)								
7/96	Cardigan Bay (outer)	52° 23'N 4° 53'W	311	6	120	184	2	54
7/96	Red Wharf Bay	53° 22'N 4° 09'W	232	8	51	180	4	38
7/96	Liverpool Bay	53° 29'N 3° 47'W	178	6	70	117	6	40
7/96	Burbo Bight	53° 28'N 3° 22'W	467	3	138	543	9	275
7/96	Morecambe Bay	53° 54'N 3° 25'W	282	5	195	266	7	107
7/96	S.E. Isle of Man	54° 00'N 3° 50'W	125	5	64	186	7	158

14.4 Conclusions

Taken as a whole, the EROD activity data for dab and plaice reveal a strong seasonal influence that is probably linked to the breeding cycle of these fish. There are hints that EROD activity may have been slightly elevated by exposure to oil from the *SEA EMPRESS* spill at a few stations near Milford Haven in February and May 1996, but the absence of oil residue data for the specific fish samples in question prevents firm conclusions. It is therefore strongly recommended that future measurements of EROD activity should always be accompanied by analysis of suspect contaminants in the same individual fish.

It is clear that flatfish in coastal waters of England and Wales are being exposed to substances which induce the P4501A enzyme system, although levels of EROD activity in the inactive part of the breeding cycle (when confounding influences should be at a minimum) are fairly low. The exceptions to this were the stations 'North of Flamborough' and 'Lyme Bay' where dab had relatively high EROD activity in October 1991. Reference to the section on fish disease (Section 15) shows that the prevalence of liver tumours in dab, which could be a consequence of P4501A induction by contaminants, is generally about 2-7% in English and Welsh waters. This rate is not considered to be negligible, so it is possible that even the generally low levels of EROD activity may be a marker for tumour formation. Interestingly, one of the areas with a high prevalence (about 15%) of liver tumours in dab is Flamborough, but insufficient tumour data are yet available for Lyme Bay. It is clear that more information is needed on the long-term consequences for fish of P4501A induction by contaminants before confident predictions can be made about the significance of particular levels of EROD activity.

15. MONITORING AND SURVEILLANCE FOR DISEASES IN MARINE FISH 1993 TO 1996

15.1 Introduction

As a result of concerns that the incidence of disease in marine fish can be correlated to the presence of anthropogenic pollutants, MAFF (CEFAS) has maintained a disease monitoring programme to investigate temporal and spatial changes in disease prevalence in the dab (*Limanda limanda*), flounder (*Platichthys flesus*) and other commercial species. This is in support of obligations under various Government Acts, e.g. Great Britain - Parliament, 1985(a), 1990. Since 1989, protocols for sampling and recording have followed international guidelines as recommended by the International Council for the Exploration of the Sea (ICES, 1989, 1996).

In conjunction with the monitoring programme CEFAS continues to investigate disease trends in non-target species, especially where these are commercially important. The programme is also used to monitor for the presence of new fish diseases and the possible significance of these. Results are published in the scientific literature (Bucke, 1989; Bucke and Feist, 1990; Bucke and Feist, 1993).

15.2 Materials and methods

Between 1993 and 1996, four cruises were conducted for monitoring fish diseases (*RV CORYSTES* Cruise 2b/93, 7-18 February, 1993; *RV CIROLANA* Cruise 2a/94, 25 January-7 February, 1994, *RV CORYSTES* Cruise 2b/95, 10-20 February, 1995 and *RV CORYSTES* Cruise 2b/96, 18 January-2 February, 1996.). A total of twenty areas were investigated including stations off the North-East Coast (Amble), Humber and Flamborough Off Grounds, the Dogger Bank and Rye Bay in the eastern Channel and stations in the Irish Sea (Figure 45). Three areas (ICES rectangles 33F2, 30E7 and 34 E4) did not provide a viable catch of dab for disease monitoring purposes. Standard 1 hour tows were made using a Granton trawl.

Sampling and disease reporting protocols followed those recommended in the ICES guidelines (ICES, 1989, 1996). These were applied to dab (*Limanda limanda*) and cod (*Gadus morhua*) for offshore stations, and flounder (*Platichthys flesus*) for inshore or estuarine stations. For dab, gross examination for the presence of liver nodules was routinely undertaken on the two larger size categories only, i.e. those greater than 20 cm in length. In addition, samples of all predominant species caught were examined for

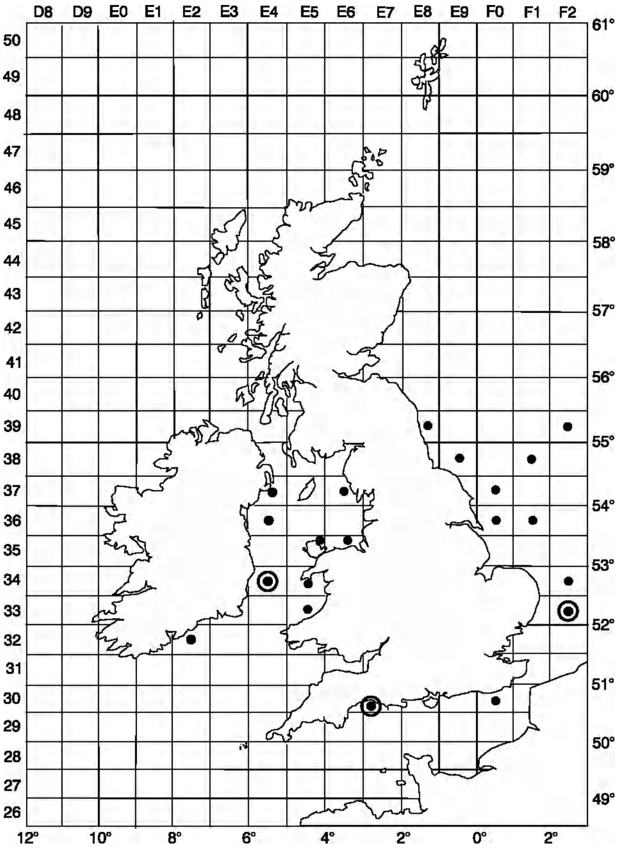


Figure 45. Areas sampled for fish disease monitoring (by ICES rectangle)

significant diseases or parasites. Herring (*Clupea harengus*) and sprat (*Sprattus sprattus*) in particular were examined macroscopically for the presence of the fungal pathogen *Ichthyophonus*, wherever sufficient numbers were caught. In continuation of previous studies, samples of dab liver were preserved for confirmation of macroscopic lesions recorded on board ship and also to obtain data on the prevalence of histological and cellular changes in this organ from fish sampled from different sea areas. For this, random samples from female dab 20 cm or greater in length, from West Dogger (ICES rectangle 38F1) and Humber Off Ground (ICES rectangle 36F0) (1993 cruise); from the Irish Sea areas, Dundrum Bay, Morecambe Bay, Red Wharf Bay, Liverpool Bay and Cardigan Bay (ICES rectangles. 37E4, 37E6, 35E5, 35E6 and 33E5 respectively) and Sole Pit, Flamborough Off Ground and Rye Bay (ICES rectangles. 36F1, 37F0 and 30F0 respectively) from the 1995 and 1996 cruises. Samples were prepared for microscopical examination using standard histological techniques (Bucke, 1994). The extent of liver pathology was determined and placed in four categories: 1 = no abnormalities detected; 2 = non-neoplastic changes including hepatocyte necrosis, parasitic cysts, peliosis and increase in number of melanomacrophage cells; 3 = pre-neoplastic lesions, including foci of cellular alteration; and 4 = hepatocellular adenoma or other liver neoplasias.

15.3 Results

Dab diseases

Summary findings for 1993 to 1996 are shown in Table 24. External diseases recorded included lymphocystis, ulceration, hyperplasia/papilloma and epidermal hyperpigmentation. Prevalence data for these diseases is presented in Figures 46, 47, 48 and 49. Prevalence of epidermal ulceration is calculated for open ulcers only (Grades 1 and 2 (ICES, 1996)). The prevalence of hepatic changes found in dab from the larger size groups, i.e. 20 to 24 cm and >25 cm in length together with the histological diagnoses are given in Table 25.

Cod diseases

A total of 332 male and 741 female fish were examined for the presence of external and internal diseases and parasites. Results are summarised in Table 26. The general disease prevalence in cod stocks was low with only four fish exhibiting ulceration and fourteen with skeletal deformities, consisting of scoliosis and/or lordosis. Pseudobranchial tumour was recorded in one fish from ICES rectangle 39E8 off Amble. Forty one fish were infected with the pathogenic copepod parasite *Lernaeocera branchialis*, although few of these appeared emaciated, pale coloration of the gills was indicative of anaemia, a typical finding with this infection. Visceral granulomatosis was only recorded in three fish from ICES rectangle 39F2 (western Dogger Bank).

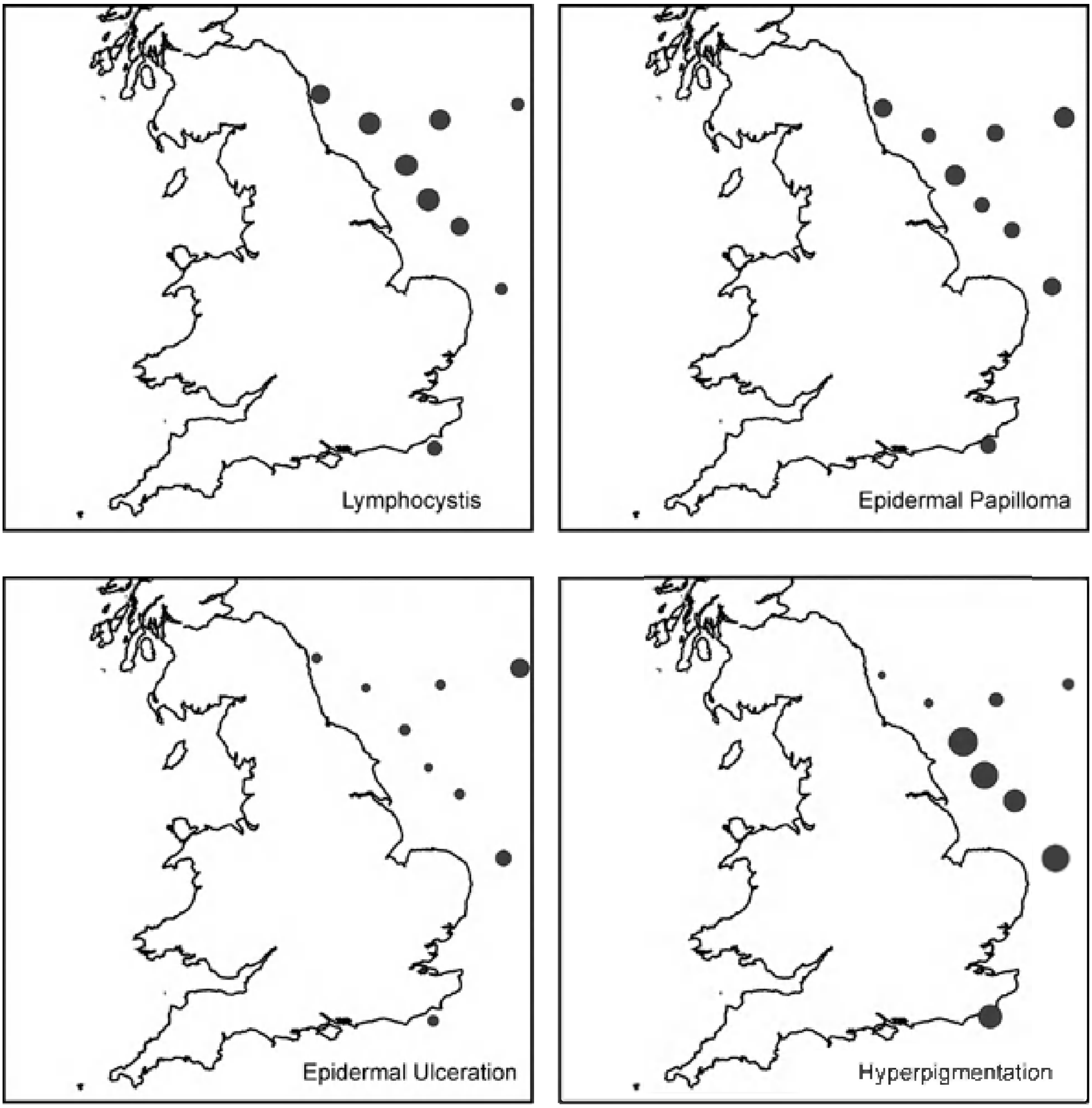
Histological examination of dab livers from selected areas in the North Sea and Irish Sea

Table 27 presents data on the histological characterisation of randomly selected livers from >20 cm dab sampled from several areas in the North Sea and Irish Sea. Only two areas were sampled in 1993 (off Humber and west Dogger). More comprehensive samples were obtained from the 1995 and 1996 cruises. Neoplastic lesions were detected in several North Sea samples but also at low levels in the Irish Sea areas of Liverpool Bay and Cardigan Bay.

Table 24. Catch data and disease prevelance in dab (Limanda limanda) by size categories on stations sampled in the North Sea and Irish Sea for fish disease monitoring (1 hour tows using Granton trawl), 1993-1996

Area	Year	ICES Rectangle	Total no. dab examined	% total disease prevalence LY	E/P	U	HYP	LN
Rye Bay	1993	30F0	225	3.6	3.6	2.2	8.9	2.7
	1994		626	3.0	3.4	2.1	2.4	2.4
	1996		241	1.2	4.6	1.7	1.7	5.2
Waterford Bay	1994	32E2	387	2.1	1.6	4.1	0.0	1.3
South Cardigan Bay	1996	33E5	913	0.7	1.8	2.6	2.3	5.4
North Cardigan Bay	1995	34E5	159	5.0	5.0	3.1	3.1	1.6
Smiths Knoll	1993	34F2	381	2.1	4.5	3.4	10.8	1.8
Red Wharf Bay	1995	35E5	124	0.8	0.0	0.0	0.0	0.0
Central Liverpool Bay	1994	35E6	311	4.2	4.7	1.5	0.0	2.3
	1995		552	7.1	9.1	2.2	0.0	0.0
	1996		443	2.5	7.7	3.2	0.2	0.9
Rockabill	1994	36E4	307	2.3	1.6	1.3	0.0	3.7
Off Humber	1993	36F0	816	6.6	4.3	1.1	10.4	5.9
Sole Pit	1993	36F1	445	4.5	4.3	1.6	7.4	4.1
	1996		470	2.1	5.1	0.4	10.0	4.4
S.Sole Pit	1995	36F1	888	4.1	3.8	3.2	9.0	7.4
Dundrum Bay	1995	37E4	402	7.2	2.7	1.5	0.0	0.0
	1996		284	4.2	6.0	3.9	0.0	1.5
Morecambe Bay	1994	37E6	212	2.8	1.9	0.9	0.0	1.4
	1995		323	1.9	2.5	0.3	0.0	1.4
	1996		266	0.4	3.4	0.8	0.0	0.0
Off Flamborough	1993	37F0	579	7.1	6.2	2.1	11.7	9.8
	1994		697	5.9	3.7	1.1	8.5	5.1
	1995		1201	5.1	2.9	2.0	12.3	7.0
	1996		449	5.1	6.2	3.1	21.8	3.6
Silver Pit	1993	39F2	478	2.7	5.4	5.6	2.1	4.0
Off Hartlepool	1993	38E9	479	8.1	3.5	1.0	1.3	3.6
West Dogger	1993	38F1	1113	6.3	4.5	1.4	2.9	3.9
Amble	1993	39E8	288	6.3	5.6	1.4	0.7	3.8

Key: LY = Lymphocystis
E/P = Epidermal papilloma
U =Epidermal ulceration
HYP = Hyperpigmentation
LN = Liver nodules



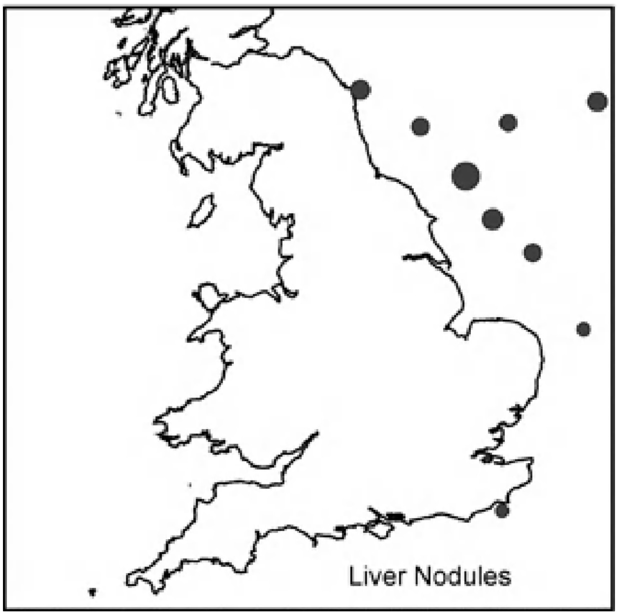
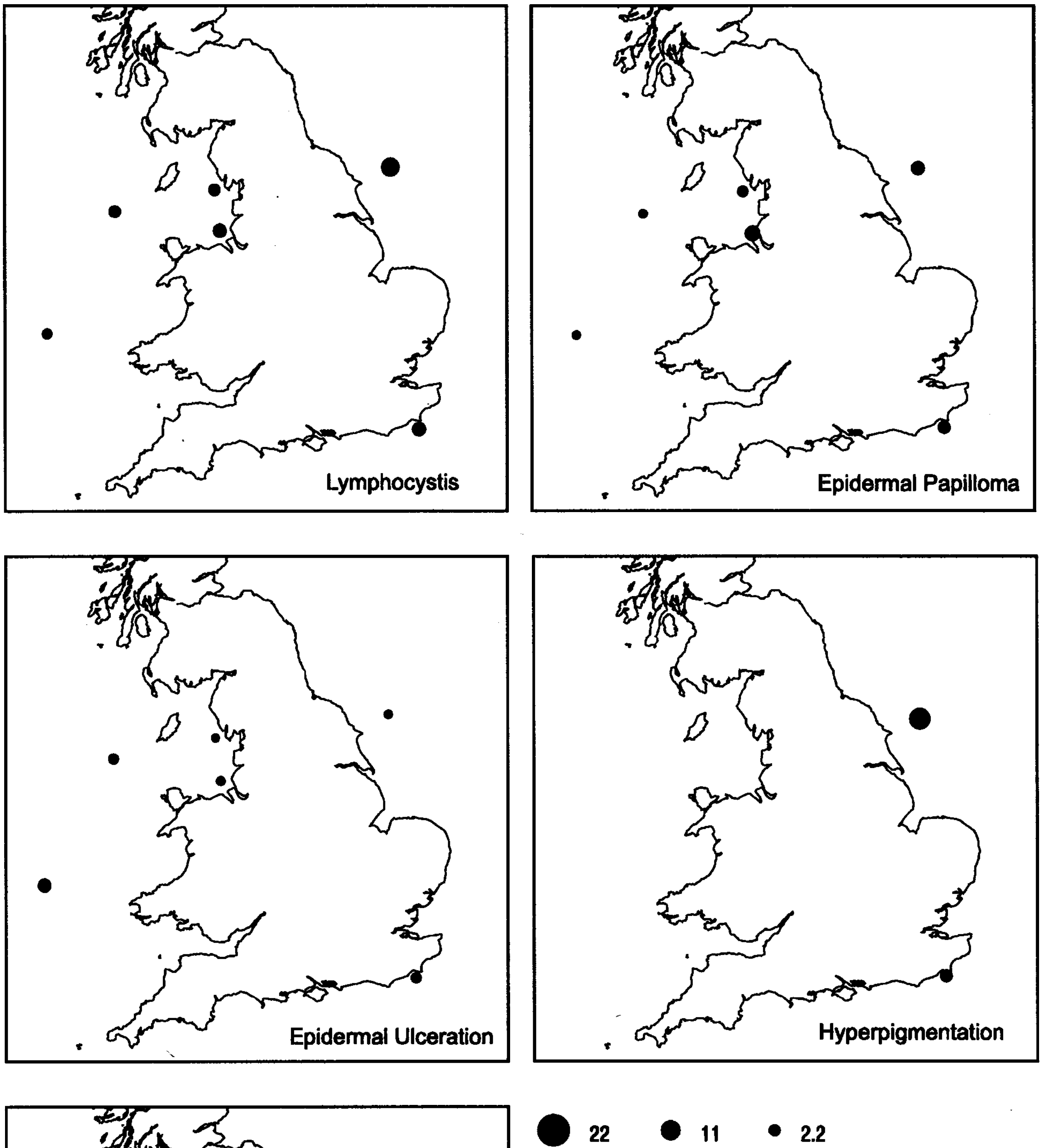


Figure 46. ***Percentage prevalence levels of lymphocystis, epidermal hyperplasia/ papilloma, ulcerations, epidermal hyperpigmentation and gross liver nodules in dab, RV CORYSTES Cruise 2b/93. Concentrations are presented as area proportional symbols; scale symbols are shown above***



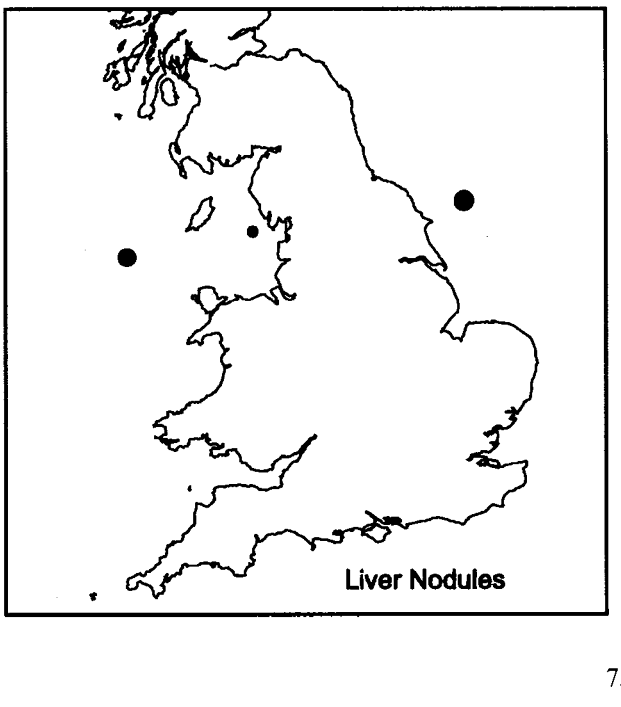
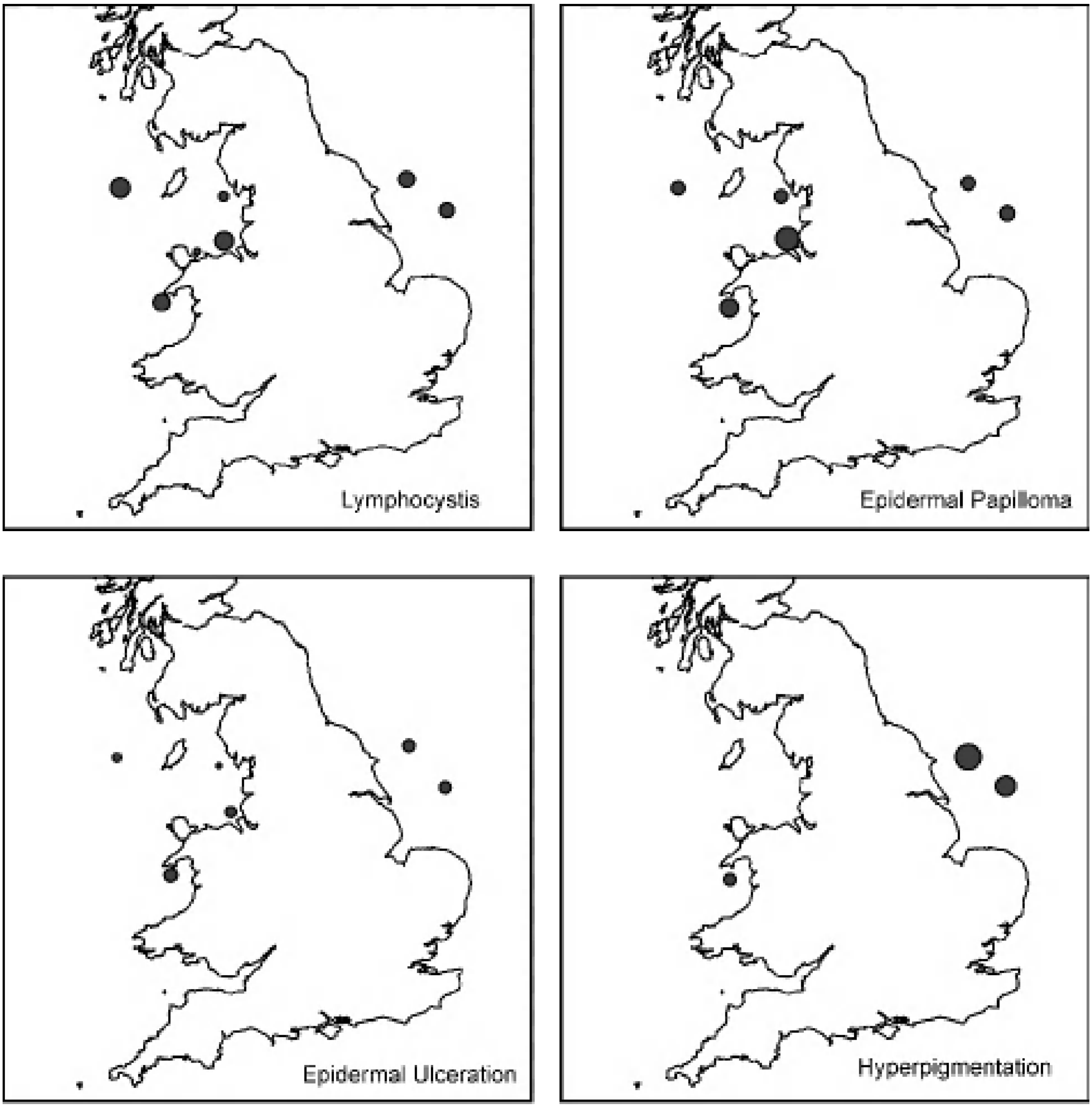


Figure 47. Percentage prevalence levels of lymphocystis, epidermal hyperplasia/ papilloma, ulcerations, epidermal hyperpigmentation and gross liver nodules in dab, RV CIROLANA Cruise 2a/ 94. Concentrations are presented as area proportional symbols; scale symbols are shown above



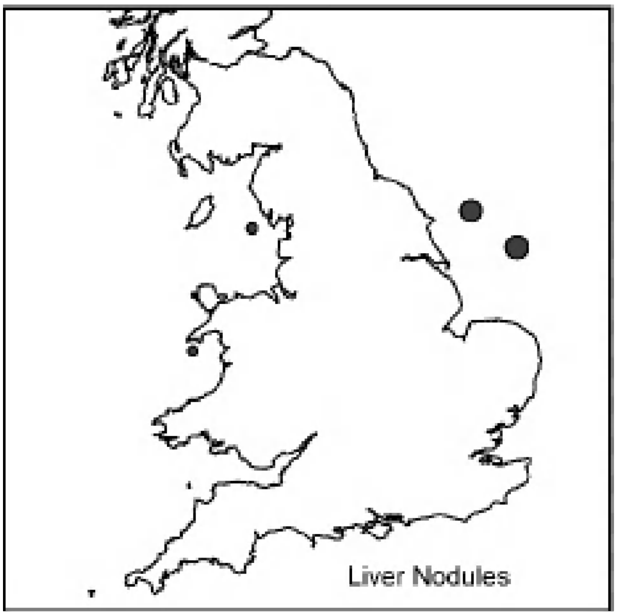
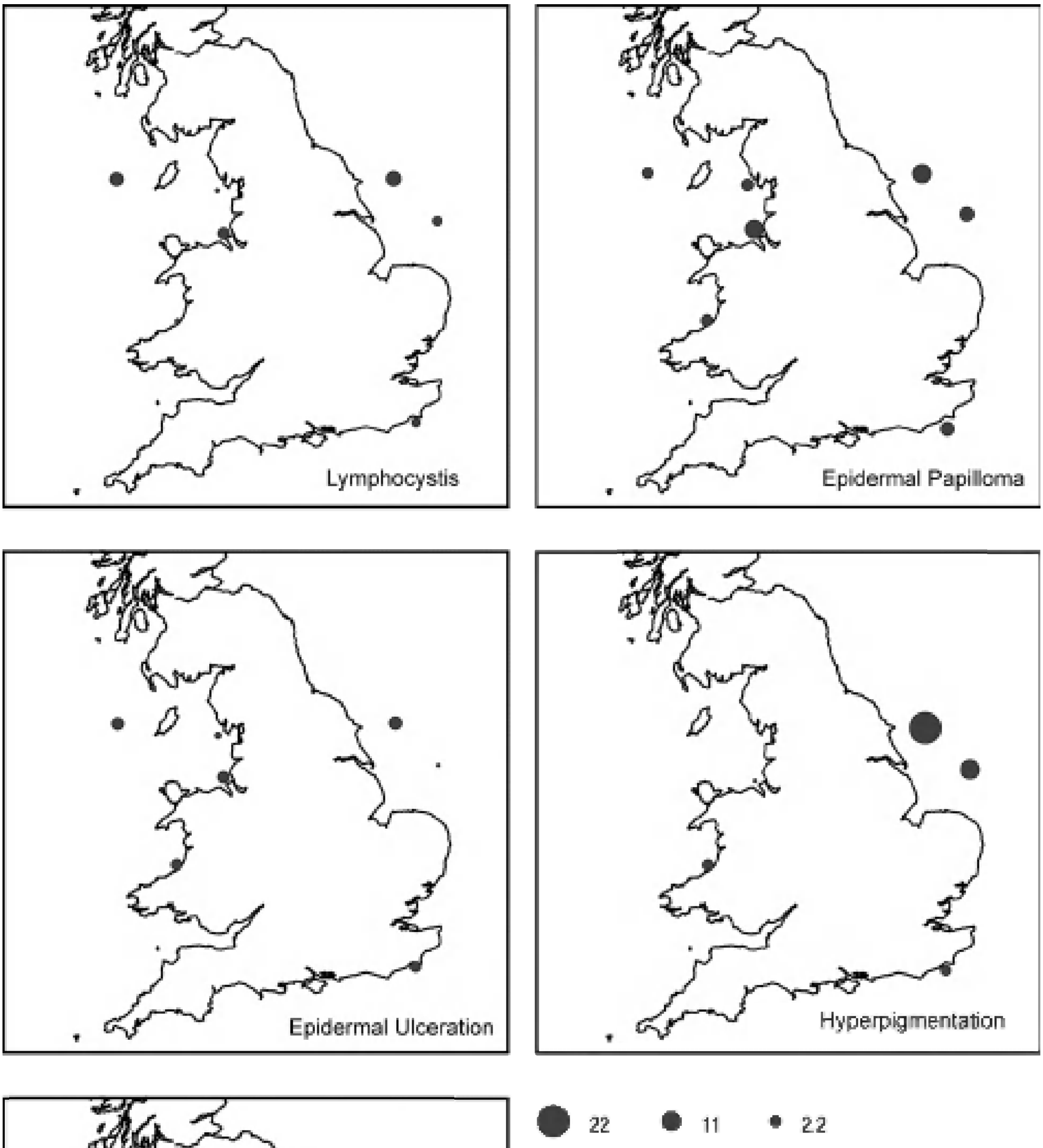


Figure 48. ***Percentage prevalence levels of lymphocystis, epidermal hyperplasia/ papilloma, ulcerations, epidermal hyperpigmentation and gross liver nodules in dab, RV CORYSTES Cruise 2b/95. Concentrations are presented as area proportional symbols; scale symbols are shown above***



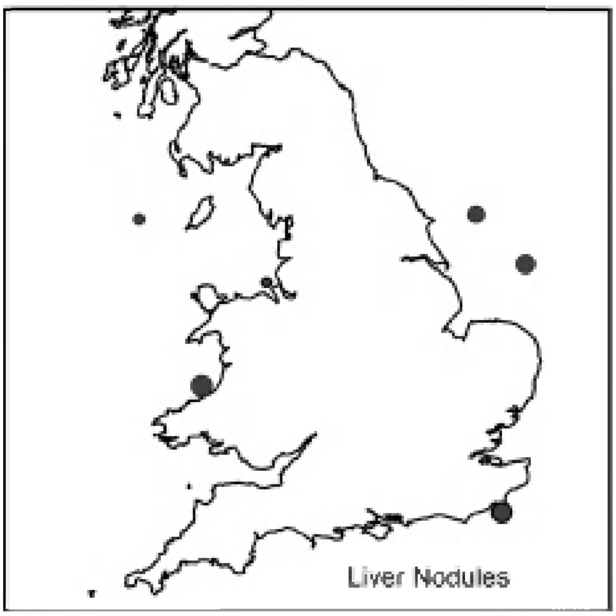


Figure 49. ***Percentage prevalence levels of lymphocystis, epidermal hyperplasia/ papilloma, ulcerations, epidermal hyperpigmentation and gross liver nodules in dab, RV CORYSTES Cruise 2b/96. Concentrations are presented as area proportional symbols; scale symbols are shown above***

Table 25. Histological characterisation of liver pathology in the two larger size categories of dab sampled on stations in the North Sea and Irish Sea, 1993-1996 (1 hour tows using a Granton trawl)

Area	Year	ICES Rectangle	Total no. dabs examined	Macroscopic Liver lesions		Lesion classification							Confirmed neoplastic lesions	
				no.	%	AD	CH	HE	PF	NEC	OT	NAD	no.	%
Rye Bay	1993	30F0	73	2	2.7	1						1	1	1.4
	1994		245	5	2.0				1		2	2	0	0.0
	1996		115	6	5.2	4			2				4	3.5
Waterford Bay	1994	32E2	153	0	0.0								NE	NE
South Cardigan Bay	1996	33E5	514	28	5.4	20			2		2	4	20	3.9
North Cardigan Bay	1995	34E5	62	1	1.6	1							1	1.6
Smiths Knoll	1993	34F2	228	6	2.6				4		2		0	0.0
Red Wharf Bay	1995	35E5	24	0	0.0								0	0.0
Liverpool Bay	1994	35E6	247	0	0.0								NE	NE
	1995		230	0	0.0								0	0.0
	1996		227	5	2.2	2					1	2	2	0.9
Rockabill	1994	36E4	162	0	0.0								NE	NE
Off Humber	1993	36F0	424	26	6.1	6			8	2	1	9	6	1.4
S. Sole Pit	1993	36F1	245	10	4.1	3			3			4	3	1.2
Sole Pit	1995	36F1	394	29	7.4	7		1	4	1	2	14	8	2.0
	1996		270	12	4.4	8				1	1	2	8	3.0
Dundrum Bay	1995	37E4	46	0	0.0								0	0.0
	1996		133	2	1.5	1						1	1	0.8
Morecambe Bay	1994	37E6	142	2	1.4	1						1	1	0.7
	1995		143	0	0.0								0	0.0
	1996		187	0	0.0	0							0	0.0
Off Flamborough	1993	37F0	379	36	9.5	8			9	1	2	16	8	2.1
	1994		297	15	5.1	13					1	1	13	4.4
	1995		701	39	5.6	12	1		2	1	6	17	13	1.9
	1996		338	11	3.3	7			1		1	2	7	2.1
Off Hartlepool	1993	38E9	139	5	3.6				1		2	2	0	0.0
West Dogger	1993	38F1	613	24	3.9	4	1		1			18	5	0.8
Amble	1993	39E8	157	6	3.8	3				1		2	3	1.9
Silver Pit	1993	39F2	278	12	4.3	4			5	1		2	4	1.4

Key: *AD = Adenoma*
CH = cholangioma
HE = hemangioma
PF = preneoplastic foci (basophillic, foci of cellular alteration, clear cell focus)
NEC = necrosis
OT = other (granuloma, cyst, storage change)
NAD = no abnormalities detected

Table 26. Disease prevelance in cod (Gadus morhua) sampled in the North Sea and Irish Sea (1 hour tows using a Granton trawl 1993-1996)

ICES Rectangle	Year	No. Examined		Number and severity of disease cases according to ICES (1996)						Notes
		Male	Female	ULC			SKD	PBT	CR	
				1	2	3				
30F0	1996	6	10	0	0	0	1	0	0	2LE
32E2	1994	0	110	0	0	0	0	0	3	
33F0	1996	20	29	1	0	0	4	0	0	4LE
33F2	1993	5	9	0	0	0	0	0	0	
34F2	1993	9	14	0	0	0	0	0	0	
35E5	1995/96	26	222	1	0	0	1	0	6	25 LE
35E6	1994/95/96	50	42	1	0	0	1	0	1	7 LE
36E4	1994	23	17	0	0	0	0	0	9	
36E6	1994	2	84	0	0	0	0	0	0	
37E4	1996	21	13	1	0	0	1	0	5	1LE
37E6	1996	5	4	0	0	0	0	0	0	2LE
36F1	1996	4	2	0	0	0	0	0	0	
37F0	1996	3	2	0	0	0	1	0	0	
37F4	1995	6	6	0	0	0	0	0	4	1 LE
37F6	1995	10	8	0	0	0	1	0	0	1 ulcerated eye
38F1	1993	7	3	0	0	0	0	0	0	
38E9	1993	25	30	0	0	0	1	0	0	
39E8	1993	58	88	1	0	0	2	1	0	1 LE, 1 cataract
39F2	1993	42	58	0	0	0	1	0	0	5 LE, 3 VG

Key: ULC = Ulcers (1=acute, 2= healing, 3= healed)
SKD = Skeletal deformity
PBT = Pseudobranchial 'tumour'
CR = Cryptocotyle
LE = Lernaeocera branchialis
VG = Visceral granulomatosis

Table 27. Summary of histological results for samples of >20 cm female dab livers sampled from areas in the North Sea and Irish Sea, 1993-1996

Area	Year	ICES Rectangle	No. fish examined	No. lesions/category of liver histology			
				Grade1	Grade2	Grade3	Grade4
Rye Bay	1995	30F0	15	7	2	6	0
	1996		20	11	0	9	0
Cardigan Bay	1996	33E5	20	15	2	2	1
Red Wharf	1995	35E5	10	6	1	3	0
Central Liverpool Bay	1995	35E6	45	29	3	12	1
	1996		20	10	2	7	1
Off Humber	1993	36F0	25	13	6	2	4
Sole Pit	1995	36F1	19	18	1	0	0
	1996		20	7	2	11	0
Dundrum Bay	1995	37E4	20	17	3	0	0
	1996		10	5	5	0	0
Morecambe Bay	1995	37E6	14	13	0	1	0
	1996		14	10	1	3	0
Off Flamborough	1995	37F0	40	27	2	9	2
	1996		17	7	2	4	4
West Dogger	1993	38F1	25	11	10	1	3

Key: Grade1 = no abnormalities detected
Grade 2 = hepatocyte necrosis, peliosis, parasite cysts, melanomacrophage cell increase
Grade 3 = foci of cellular alteration
Grade 4 = hepatocellular adenoma or other liver neoplasis

Examination of total catch for fish diseases

Examination of other species including haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*), herring, gurnard (*Eutrigla gurnardus*), plaice (*Pleuronectes platessa)* and flounder (*Platichthys flesus*) revealed generally low levels of disease. Skeletal deformity in haddock was noted in several areas in the North Sea with a similar condition rarely observed in gurnard from stations off the North-East Coast. Heavy parasite infections with *L. branchialis* in whiting were widespread but at low prevalence. From this and stock assessment surveys, the incidence of *Ichthyophonus* infections in herring had declined significantly during the study period and the epizootic has practically disappeared from the mid- and southern North Sea.

Disease reports from MAFF Sea Fisheries Inspectorate Offices (SFIs) and from other bodies

During the period of this report relatively few reports of diseased fish were received at the CEFAS Weymouth Laboratory. The majority of those that were received were of flounder or plaice, originally submitted by anglers to the Sea Fisheries Inspectorate. Despite the sometimes poor preservation of these specimens, positive diagnosis of lymphocystis disease was made in most instances, with abnormal pigmentation also being found in one case. A suspect bacterial septicaemia in a wild caught eel (*Anguilla anguilla*) was also recorded. As in previous years, at ports on the North-East Coast, landings of cod exhibiting dermal necrosis remained at low levels throughout the reporting period with an increase in numbers landed during 1995. Small numbers of diseased cod continued to be reported by anglers from various parts of the country. The majority of these were either emaciated, ulcerated or affected by scoliosis and other skeletal deformities. A single case of *Kudoa* (a potentially serious protistan parasite affecting the muscle) was recorded in a fish caught off the South Coast. This was the first record of cod being infected with this pathogen.

From July 1993, cases of pigment anomalies and blindness in commercial catches of angler fish (*Lophius piscatorius* and *L. budegassa*) were reported from areas in the vicinity of the Celtic Deep (Figure 50). Most cases were initially recorded by Fisheries Inspectors examining fish landed at Newlyn.

Affected fish were generally pale with light-brown to grey mottling and consistently possessed rudimentary or deformed eyes; however, one specimen with normal eyes, was bright orange in colour. This latter specimen was caught in ICES rectangle 28E3. Almost every specimen examined, including normally pigmented fish, was heavily infected with the microsporean parasite *Spraguea lophii*, in the brain and ganglion cells of the peripheral nerves close to the spinal cord. Histological examination of the skin and muscle of abnormally pigmented fish revealed a complete loss of epidermis, leaving a thin 'surface-layer' of cells containing diffuse melanin granules. There was also some deposition of iridophore-like pigments in the dermis and occasionally the presence of foreign bodies (grains of sand, detritus etc). These changes were usually associated with the breakdown of muscle fibres.

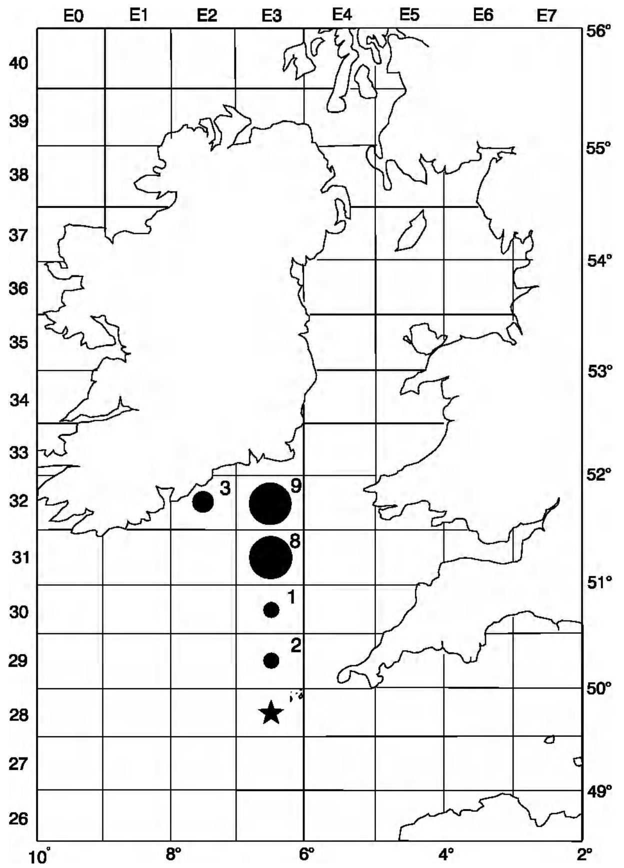


Figure 50.* *Distribution by ICES rectangles of abnormally pigmented and blind angler fish (Lophius piscatorius). Numbers of specimens per rectangle are also indicated. The ICES rectangle where the single orange specimen was captured is indicated (*)

Since the submitted specimens were poorly preserved the presence of significant post-mortem artefact did not allow a clear diagnosis to be made. The infections with *Spraguea lophii* were not thought to be a significant factor.

15.4 Conclusions

The results of the disease monitoring surveys indicate that epidermal disease prevalence in dab remain at generally low levels and are broadly consistent with findings from previous surveys. However, higher levels of disease were consistently recorded off Flamborough (ICES rectangle 37F0) and at Sole Pit (ICES rectangle 36F1), this also being consistent with previous findings. The presence of high levels of epidermal hyperpigmentation at these and other locations in the North Sea appears significant, since the condition was absent from Irish Sea stations visited during 1994 and 1995 and only present at a low prevalence in 1996. Disease levels at the reference area Rye Bay (ICES rectangle 30F0) remained low with the exception of epidermal hyperpigmentation which was recorded at approximately 9% prevalence in 1993. This finding was not repeated subsequently and contrasts with earlier data showing levels in Rye Bay to be much lower. Overall, the prevalence of dab exhibiting hyperpigmentation appears to be increasing. Histological evaluation of specimens affected by epidermal hyperpigmentation has revealed marked proliferation of pigmented cells (melanophores in the dermal layers of the upper surface and iridophore cells in the same location on the underside) but has not thus far revealed the presence of infectious agents. The aetiology of the hyperpigmentation remains unknown. The possibility that this condition represents a pre-neoplastic pathology cannot yet be ruled out.

It is essential to use histology for diagnostic confirmation of liver neoplasia in specimens showing macroscopic changes. The results of the histological examination of liver nodules recorded during gross examination revealed that not all nodules were hepatocellular adenomas or pre-neoplastic foci. Several other pathological changes, such as parasitic cysts and necrosis, were found to have been initially recorded as 'liver nodules'. As in previous surveys, confirmed hepatocellular adenomas were more prevalent in North Sea dab from Flamborough Off Ground and the Dogger Bank.

The use of toxicopathic hepatic lesions in biological effects of contaminants monitoring has been adopted by the Oslo and Paris Commissions (OSPARCOM) as part of the Joint Assessment and Monitoring Programme (JAMP). The application of histopathology in this context was utilised for material collected during 1993, 1995 and 1996. The results of these investigations support the data collected from gross disease recording but have also revealed that several putative pre-neoplastic lesion types were present in livers collected from several of the areas visited.

Disease monitoring in other species revealed a very low prevalence of disease, with only few specimens from the areas visited exhibiting a significant disease condition or parasitism. Fish from each of the other areas appearing in good condition.

16. TRIBUTYLTIN (TBT)

16.1 Introduction

Tributyltin compounds have been used extensively as the active component of antifouling paints for ships and marine structures since the 1960s. The use of TBT-based antifouling on small craft <25 m in length has been restricted in many countries since the late 1980s as it caused shell thickening and spat failure in oysters, and imposex in gastropods, in estuarine and coastal waters (Alzieu, 1991; Bryan *et al.,* 1987; Waite *et al.,* 1991). At that time, the open sea was not considered to be at risk, and the use of TBT antifouling has continued on large vessels. However, one recent study in the southern North Sea has now demonstrated the presence of imposex in whelks (*Buccinum undatum*) as a result of TBT contamination from shipping (Ten Hallers-Tjabbes *et al.,* 1994) causing its local extinction within the Dutch Wadden Sea (Cadee *et al.,* 1995).

Many studies of organotin contamination have been conducted, but to date few have included determinations in tissues of marine mammals. As top predators, cetaceans and pinnipeds can accumulate high concentrations of lipophilic and persistent organic compounds through their diet due to a low metabolic capacity for degradation both in the mammals themselves and components of their food-chain (Suzuki *et al.,* 1992; Tanabe and Tatsukawa, 1992). TBT is bioaccumulative, with an octanol-water partition coefficient in the range 10^3 - 10^4 (Laughlin and Lindén, 1987) and the ability of cetaceans to metabolise TBT is thought to be low as a result of the limited activity of some cytochrome P450 enzymes within these animals (Kannan *et al.,* 1996; Tanabe *et al.,* 1988). This suggests that butyltin compounds may accumulate in marine mammals, and this has been demonstrated in bottlenose dolphins from the Italian coast (Kannan *et al.,* 1996) and the USA (Kannan *et al.,* 1997), porpoises from the Baltic Sea (Kannan and Falandysz, 1997), and seals, Steller sea lions, and a range of cetacean species from Japan and the north Pacific Ocean (Iwata *et al.,* 1994 and 1995; Kim *et al.,* 1996). No information has been presented for the UK, and in this study concentrations of monobutyltin (MBT), dibutyltin (DBT) and TBT have been determined in the livers of porpoises and grey seals from the coast around England and Wales in order to establish the current levels of contamination by these compounds, and to assess the need for further work.

16.2 Methods and results

Organotin analyses were conducted on samples of liver tissue from 29 porpoises and 5 seals bycaught or stranded around England and Wales from 1992-96. The full details of the methods used are given elsewhere (Law *et al.,* in press (a)); the distribution of sampling sites around England and Wales is shown in Figure 51. The results of the analyses are given in Table 28. Concentrations of total butyltins (ΣBTs) in porpoise liver from this study were within the range 22 to 640 µg kg^{-1} wet weight, lower than those reported in finless porpoise from Japan (1120 to 10200 µg kg^{-1} wet weight; Table 29) and bottlenose dolphins from the Adriatic Sea (1200 and 2200 µg kg^{-1} wet weight) and the USA (110 to 11340 µg kg^{-1} wet weight). On average, only about 20% of the butyltin tin was present as TBT with DBT the major component. Concentrations of total butyltins in grey seals were lower than those seen in the porpoises (Table 28; 3 to 22 µg kg^{-1} wet weight), similar to that reported for a Largha seal from Hokkaido, Japan (4.4 µg kg^{-1}) and lower than concentrations in Steller sea lions from the same area (170 to 460 µg kg^{-1}). This suggests that the seals have either a lower intake of organotins from their diet or a higher metabolic capacity for these compounds than sea lions or small cetaceans.

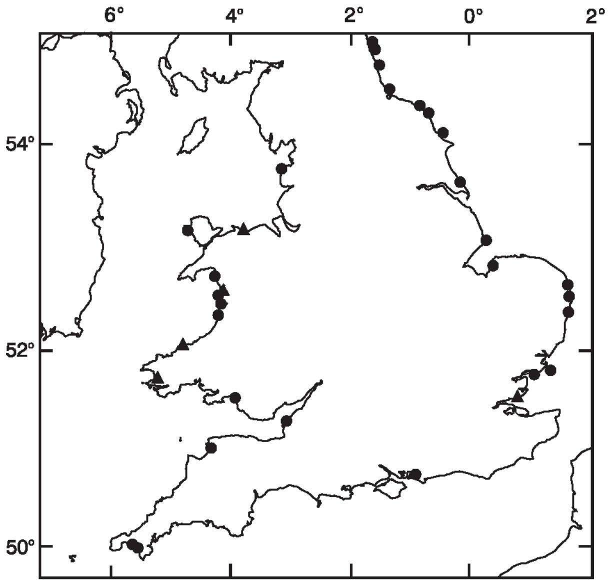


Figure 51. Map of England and Wales showing the stranding locations of porpoises (circles) and grey seals (triangles)

Table 28. Concentrations of organotin compounds (µg kg⁻¹ in livers of porpoises and grey seals. TBT (tributyltin); DBT (dibutyltin); MBT (monobutyltin); ΣBTs (sum of MBT, DBT and TBT)

Species	Ref No.	Location	Date found	Sex	Age	Length (cm)	TBT	DBT	MBT	ΣBTs
Harbour porpoise	SW1992/202	Sunderland, Tyne and Wear	13/10/92	F	nd	133	180	350	110	640
Harbour porpoise	SW1993/12	Cambois, Northumberland	27/01/93	M	nd	144	39	150	63	252
Harbour porpoise	SW1994/32	Westward Ho!, Devon	04/03/94	M	2	127	21	99	< 10	120
Harbour porpoise	SW1994/45A	Rossall Point, Lancashire	02/04/94	M	8	151	9	25	19	53
Harbour porpoise	SW1994/53	Morfa Dyffryn, Gwynedd	10/04/94	F	3	167	19	46	9	74
Harbour porpoise	SW1994/68	6 miles off Walton pier, Essex	29/04/94	F	nd	112	53	150	50	253
Harbour porpoise	SW1994/80	Port Talbot, West Glamorgan	06/05/94	M	4	122	23	82	16	121
Harbour porpoise	SW1994/99	Tywyn, Gwynedd	02/06/94	M	1	120	< 10	14	8	22
Harbour porpoise	SW1994/108	Weston-super-mare, Avon	25/06/94	M	0	75	< 10	13	100	113
Harbour porpoise	SW1994/148	Sandsend, Whitby, North Yorkshire	01/09/94	M	nd	130	40	160	94	294
Harbour porpoise	SW1994/153	Ynyslas, Dyfed	07/09/94	M	nd	153	21	97	26	144
Harbour porpoise	SW1994/171	Martello Bay, Clacton, Essex	22/11/94	M	nd	146	57	210	< 10	267
Harbour porpoise	SW1994/175	Marazion, Cornwall	04/12/94	F	nd	NR	8	71	49	128
Harbour porpoise	SW1994/185	Bosham Harbour, West Sussex	30/12/94	F	5	145	36	460	130	626
Harbour porpoise	SW1995/52	Seaton sluice, Teesside	20/04/95	M	3	NR	41	140	< 9	181
Harbour porpoise	SW1995/55	Seaton Sands, Teesside	01/05/95	M	8	153	47	190	14	251
Harbour porpoise	SW1995/76	Newport, Norfolk	1995*	M	0	NR	47	58	< 7	105
Harbour porpoise	SW1995/78	Filey Brigg, North Yorkshire	07/07/95	M	nd	NR	120	440	18	578
Harbour porpoise	SW1995/85	Gorleston, Norfolk	05/07/95	F	0	86	19	71	7	97
Harbour porpoise	SW1995/86	Trearddur Bay, Anglesey, Gwynedd	07/07/95	F	5	172	46	210	9	265
Harbour porpoise	SW1995/94	St. Mary's Island, Whitley Bay, Tyne and Wear	31/07/95	F	nd	112	33	79	8	120
Harbour porpoise	SW1995/102	Aberystwyth, Dyfed	01/10/95	F	nd	167	14	150	16	180
Harbour porpoise	SW1995/120A	Snettisham, Norfolk	05/10/95	F	nd	107	16	120	< 10	136
Harbour porpoise	SW1995/126	Withernsea, East Yorkshire	13/10/95	F	0	95	64	150	< 390	214
Harbour porpoise	SW1996/2	Robin Hood's Bay, North Yorkshire	03/01/96	M	5	140	41	21	< 7	62
Harbour porpoise	SW1996/27(1)	Praa Sands, Cornwall	22/01/96	M	nd	153	39	240	12	291
Harbour porpoise	SW1996/29	Skegness, Lincolnshire	25/01/96	M	> 1	126	42	91	< 6	133
Harbour porpoise	SW1996/30	Blyth, Northumberland	26/01/96	M	2	117	32	65	< 6	97
Harbour porpoise	SW1996/37	Kessingland, Suffolk	07/02/96	M	nd	137	76	300	15	391
Grey seal	SS1993/243	Colwyn Bay, Clwyd	25/12/93	F	nd	176	6	5	< 10	11
Grey seal	SS1994/63	Poppitt Sands, Cardigan	24/05/94	F	nd	141	< 4	< 5	< 3	nd
Grey seal	SS1994/277	Tywyn, Gwynedd	07/10/94	F	nd	179	< 4	6	14	20
Grey seal	SS1995/80	Broad Haven, Pembrokeshire	13/07/95	M	nd	224	< 4	< 4	11	11
Grey seal	SS1995/143	River Thames	11/09/95	M	nd	226	< 4	11	11	22

*Note: * date not known*
nd = not determined

16.3 Discussion

The data demonstrate that low-level organotin contamination in marine mammal top predators extends to the UK in addition to those areas previously reported, and tends to suggest that these compounds may be ubiquitous in coastal areas frequented by shipping. Their significance is, however, harder to assess. Their presence at relatively high concentrations in exposed animals suggests a limited metabolic capacity for organotin compounds in both the mammals themselves and their prey, although biomagnification seems to be relatively modest. The occurrence of DBT as the major component in liver, whereas TBT dominates in blubber, indicates that some active metabolism does occur in all the marine mammal species studied to date. The reported effects of butyltins in mammals include immunosuppression (Snoeij *et al.*, 1989; Vos *et al.*, 1984), and it has been suggested that a number of mass mortalities in marine mammal populations in European and North American waters in recent years resulting from morbillivirus infections, may have been rendered more severe in animals whose immune function has been impaired by environmental pollutants (Dietz *et al.*, 1989; Heide-Jørgensen *et al.*, 1992; Ross *et al.*, 1995). Interest in this area has mainly centred on organochlorine contaminants (including PCB, dieldrin and DDT and its metabolites) which are accumulated to high concentrations in the blubber of many marine mammals (Hall *et al.*, 1992), but high concentrations of organotins could have an additive action in effect (Kannan *et al.*, 1997). Whilst levels of organotin contamination in porpoises and seals stranded around England and Wales are lower than those reported for small cetaceans from other areas, further study is needed of the possible toxic effects of these compounds and the risk that their accumulation poses to these animals. Some data are also needed for other UK coastal mammals, such as the common seal (*Phoca vitulina*) and the bottlenose dolphin (*Tursiops truncatus*).

Table 29. Concentrations of organotin compounds in blubber and liver tissues of marine mammals reported in the literature (μg kg^{-1} wet weight). NR: not reported. Where a range of years is indicated the date of sampling of individual animals was not given in the original paper

Species	Location	Year	Sex	Tissue	TBT	DBT	MBT	SBTs	Ref.
Atlantic spotted dolphin	Southeastern USA	1991-94	M	Liver	76	380	170	630	A
Finless porpoise	Pacific coast of Chiba, Japan	1981	M	Liver	200	790	130	1120	B
Finless porpoise	Seto-inland Sea, Japan	1985	M	Liver	1100	6100	3000	10200	B
Finless porpoise	Ise Bay, Japan	1994	F	Liver	810	1800	680	3290	B
Harbour porpoise	Baltic Sea, coast of Poland	1991	F	Liver	NR	NR	NR	18 ‡	C
Harbour porpoise	Baltic Sea, coast of Poland	1991	F	Liver	NR	NR	NR	27 ‡	C
Bottlenose dolphin	NW Adriatic Sea, coast of Italy	1992	M	Liver	250	800	150	1200	D
Bottlenose dolphin	NW Adriatic Sea, coast of Italy	1992	M	Liver	400	1600	200	2200	D
Bottlenose dolphin	Southeastern USA	1989-94	M$	Liver	5.8-770	450-8300	120-2260	570-11340	A
Bottlenose dolphin	Southeastern USA	1989-94	F$	Liver	26-170	290-1570	100-760	420-2500	A
Bottlenose dolphin	Southeastern USA	1989-94	M#	Liver	22	230	68	320	A
Bottlenose dolphin	Southeastern USA	1989-94	F#	Liver	94-130	67-720	310-360	1120-1160	A
Bottlenose dolphin	Southeastern USA	1989-94	M*	Liver	40-50	54-370	44-290	140-710	A
Bottlenose dolphin	Southeastern USA	1989-94	F*	Liver	10-110	70-880	32-350	110-1260	A
Pygmy sperm whale	Southeastern USA	1991-94	M	Liver	5-12	240-290	86-160	350-410	A
Steller sea lion	Coast of Hokkaido, Japan	1994	M	Liver	20	89	63	170	E
Steller sea lion	Coast of Hokkaido, Japan	1995	M	Liver	16	130	100	250	E
Steller sea lion	Coast of Hokkaido, Japan	1995	F	Liver	22	120	52	190	E
Steller sea lion	Coast of Hokkaido, Japan	1995	F	Liver	19	98	67	180	E
Steller sea lion	Coast of Hokkaido, Japan	1995	F	Liver	26	110	100	240	E
Steller sea lion	Coast of Hokkaido, Japan	1995	F	Liver	16	51	110	180	E
Steller sea lion	Coast of Hokkaido, Japan	1995	F	Liver	85	370	< 6.6	460	E

Note: Atlantic spotted dolphin *Stenella frontalis*; Finless porpoise *Neophocoena phocaenoides*; Harbour porpoise *Phocoena phocoena*; Bottlenose dolphin *Tursiops truncatus*; Pygmy sperm whale *Kogia breviceps*; Steller sea lion *Eumetopias jubatus*

$ adults
# juveniles
* calves
‡ neonates

A=Kannan *et al.* (1997)
B=Iwata *et al.* (1995)
C=Kannan & Falandysz (1997)
D=Kannan *et al.* (1996)
E=Kim *et al.* (1996)

17. CONTAMINANT CONCENTRATIONS IN TWO SPECIES OF WHALES

17.1 Introduction

Blainville's beaked whales (*Mesoplodon densirostris*) occur in warm temperate to tropical waters of all oceans. Their distribution is known almost entirely from records of stranded individuals, due to the rarity of sightings at sea (Mead, 1989). These whales grow to a maximum length of *ca.* 4.7 m, and a weight of around 1 tonne. They are thought to live in small family units of 3 to 6 animals and, in the Atlantic Ocean, their northward distribution (generally to about 45°N) is related to the presence of the warm waters of the Gulf Stream. The limited information available suggests that squid and possibly some fish are the main prey, the whales generally feeding at the seabed in deep waters (Evans, 1987; Martin, 1990). The whale which stranded in Aberaeron in 1993, was the first of this species found on the coasts of the British Isles since detailed stranding records began in 1913 and, only the sixth to strand on the eastern shores of the North Atlantic Ocean. Further information may be found in Herman *et al.* (1994).

The killer whale (*Orcinus orca*) is very widely distributed, occurring in all oceans and most seas, from the equator to polar regions, and from the coast to the very deepest seas. Males average 6.7 to 8 m in length (*ca.* 5 tonnes body weight) and females 5.7 to 6.6 m (*ca.* 3 tonnes; see Martin, 1990). They probably have the most diverse diet of all cetaceans, being able to take prey of all sizes from fish and squid to blue and sperm whales, and including seals and other cetacean species (Hamilton, 1835; Villiers, 1925; Tarpy, 1979; Ellis, 1982; Dufault and Whitehead, 1995). Killer whales are intensely social, living in stable pods consisting of up to 50 individuals. Around Britain and Ireland, most sightings occur along the Atlantic seaboard and in the northern North Sea (Evans, 1992), and killer whales are scarce in the English Channel and virtually absent from the southern North Sea. The stranding of a killer whale on the coast of Kent is therefore an unusual occurrence. Stranded killer whales occur infrequently around the UK, with eighteen records between 1967 and 1990. Fifteen of these strandings were in Scotland, mostly on the Western Isles, Shetland and Orkney to the north and west of the UK (Sheldrick *et al.,* 1991). Details of the dates and locations of strandings and biological information for each of the two cetaceans studied here are given in Table 30. Information derived from post-mortem studies conducted on these two animals has been reported elsewhere (Law *et al.,* 1997(c)).

Table 30. Locations, dates of stranding and biological data for the two cetaceans studied here

	Killer whale	Blainville's beaked whale
Reference Number	SW1995/54	SW1993/78
Location	Sandwich, Kent	Aberaeron, Dyfed
Date of stranding	26 April 1995	18 July 1993
Position	51° 19'N 1° 22'E	52° 14'N 4° 15'W
Sex	mature female	mature female
Age	16 - 18	21 +
Length (m)	5.25	4.11
Dorsal blubber thickness (mm)	28	40

17.2 Results

The results of analyses for trace metals, As and Se are given in Table 31, and for organochlorines in Tables 32 to 34. Comparative data for both species are sparse. Concentrations of Cu and Zn were within previously established ranges (Law, 1996), and the levels of Pb were low in both animals. Concentrations of Cd were 6.2 and 3.7 mg kg^{-1} wet weight in the beaked whale and the killer whale respectively, and those of Hg were 248 and 88 mg kg^{-1} wet weight respectively. Elevated concentrations of Cd are usually ascribed to a diet in which cephalopods predominate (Law, 1996), whereas higher concentrations of Hg would be expected to result from a fish-based diet. The beaked whale exhibited higher concentrations of both elements than the killer whale.

17.3 Discussion

The diet of beaked whales is not well characterised, but squid and various deep-water fish are thought to be taken (Law *et al.,* in press (b)). It is perhaps surprising that such a high Hg concentration was found in the beaked whale as they feed in deep waters presumably little affected by coastal anthropogenic discharges. Mercury is also mobilised by natural means, however, and elevated concentrations of both dimethyl- and monomethylmercury have been reported from waters below the thermocline (>200 m depth) in the equatorial Pacific Ocean (Mason and Fitzgerald, 1990). Although the mechanisms for *in situ* formation of alkylmercury species in the deep waters of the open ocean have not been elucidated, this finding does suggest that mercury could then accumulate through the food chain into pelagic fish as organic mercury is bioaccumulated to a greater extent than inorganic mercury. That this enhanced mercury bioaccumulation in sub-thermocline, low oxygen, waters can occur has been confirmed by a study of mercury levels in fish from the deep waters of the sub-tropical mid-North Atlantic Ocean, where mean mercury concentrations were found to be significantly and positively correlated with median daytime depth (Monteiro *et al.*, 1996), and this may provide an explanation for the high Hg concentration seen in the beaked whale. The concentrations of As (0.62 and 2.5 mg kg^{-1}; see Table 31) were within the range of concentrations reported for common dolphins (*Delphinus delphis*; primarily an offshore species) stranded in southwest England in 1992 (Kuiken *et al.,* 1994), and indeed within the range reported for marine mammals in general (Law, 1996). The concentrations of Ag (0.74 and 0.89 mg kg^{-1}; Table 31) were intermediate between the ranges reported for two other cetacean species by Becker *et al.* (1995). The significance of elevated concentrations of this element in cetaceans is presently unknown.

Concentrations of γ-HCH were low in both animals, whilst concentrations of α-HCH, HCB, pp'DDT and its metabolites, and all but one of the 25 CB congeners were higher in the killer whale than the beaked whale. Both dietary and metabolic differences between species could contribute to these variations (Aguilar *et al.,* in press). Amongst the Blainville's beaked whales, the lowest CB concentrations seem to be found in the southern hemisphere, off the coast of Africa. The ΣICES7 concentrations reported previously for three mature killer whales from Japan (Ono *et al.*, 1987) were almost an order of magnitude higher than that found in this specimen.

Table 31. Concentrations of trace metals in the liver tissue of a Blainville's beaked whale (BBW) and a killer whale (KIW) (All data as mg kg^{-1} wet weight; TS%: percentage of dry matter in the samples)

	TS%	Cr	Ni	Cu	Zn	As	Se	Ag	Cd	Hg	Pb
BBW	33.8	0.63	0.75	5.6	41	2.5	98	0.74	6.2	248	0.05
KIW	23.9	0.81	<0.07	8.3	48	0.62	31	0.89	3.7	88	<0.02

Table 32. Concentrations of organochlorines in the blubber of a Blainville's beaked whale (BBW) and a killer whale (KIW) (All data as mg kg^{-1} wet weight). %HEL : percentage of hexane-extractable lipid

	% HEL	α-HCH	γ-HCH	HCB	*p, p*'-DDE	*p, p*'-TDE	*p, p*'-DDT	Dieldrin
BBW	83	< 0.001	0.056	0.066	2.9	0.65	2.6	0.074
KIW	49	0.066	0.053	0.74	18	2.9	3.6	2.4

Table 33. Concentrations of 25 individual CB congeners in the blubber of a Blainville's beaked whale (BBW) and a killer whale (KIW) in order of elution on an HP-5 column (All data as mg kg^{-1} wet weight). %HEL : percentage of hexane-extractable lipid. CB congeners numbered according to IUPAC nomenclature

	%HEL	CB18	CB31	CB28	CB52	CB49	CB47	CB44	CB66
BBW	83	0.015	0.003	0.015	0.08	0.055	0.017	0.021	0.12
KIW	49	0.035	0.01	0.058	0.67	0.097	0.14	0.067	0.82

	CB101	CB110	CB151	CB149	CB118	CB153	CB105	CB141	CB138
BBW	0.22	0.09	0.097	0.26	0.31	0.76	0.083	0.068	0.66
KIW	0.82	0.31	0.6	1.4	0.89	2.9	0.33	0.096	2.9

	CB158	CB187	CB183	CB128	CB156	CB180	CB170	CB194
BBW	0.034	0.48	0.17	0.12	0.082	0.64	0.24	0.15
KIW	0.14	1.2	0.39	0.51	< 0.001	1.3	0.57	0.12

Table 34. Concentrations of summed CB congeners, DDT and its metabolites (ΣDDT), and the ratio DDE/ ΣDDT in the blubber of a Blainville's beaked whale (BBW) and a killer whale (KIW) (All data as mg kg^{-1} wet weight). ΣICES7: sum of the seven CB congeners of the ICES primary list. Σ25CBs: sum of the 25 CB congeners determined

	%HEL	ΣICES7	Σ25CBs	ΣDDT	DDE/ΣDDT
BBW	83	2.69	4.78	6.15	0.47
KIW	49	9.54	16.4	24.5	0.73

ENVIRONMENTAL ASSESSMENT STUDIES

18. HASTINGS SHINGLE BANK

18.1 Introduction

Sand and gravel has been extracted from the Hastings Shingle Bank for more than eleven years, with an average of approximately 1.5 million tonnes per annum being removed. The original licence, issued by the Crown Estates Commission, identified an overall boundary, within which two sub-areas, X and Y, were subsequently defined (see Figure 52). Most of the dredging effort has been confined to these sub-areas.

MAFF has undertaken studies at this site, assessing the impact of this activity periodically (Rees, H. L., 1987; Lees *et al.,* 1990; Kenny *et al.,* 1991). In June 1995, as part of an ongoing field assessment programme, eight sites were sampled, four within and four outside of the dredged sub-area Y, as shown in Figure 52. Although geographically close, the two sets of stations were separated across the tidal axis, which is sharply defined along a line running WSW to ENE (Rees, H. L., 1987). The purpose of this design was to further examine the nature of impacts arising from intensive dredging, and the scope for any wider consequences on the benthic

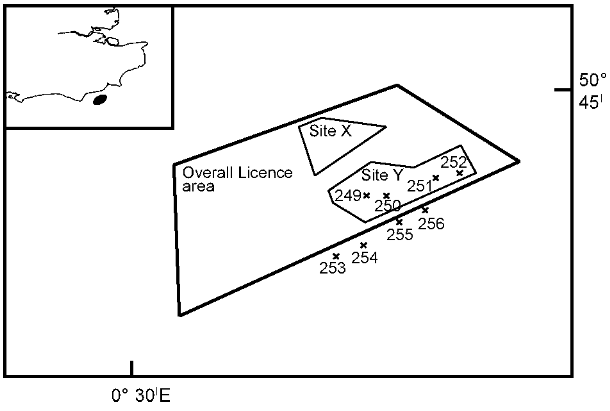


Figure 52. The location of sampling sites in relation to the licensed sand and gravel extraction area off Hastings

fauna towards the southern edge of the bank. A more comprehensive investigation of impacts along the tidal axis will be the subject of a later report.

18.2 Methods

Field work

A single sample was collected at each site, using a Hamon Grab, deployed from *RV CORYSTES*. The Hamon Grab is a suitable device for quantitative sampling of coarse sediments, removing a surface area of approximately 0.2 m^2 (Holme and McIntyre, 1984). The collected sediment was released from the grab into a 60 l container and the volume recorded. A 500 ml sample was then removed for particle-size analysis, and the remainder was sieved over 5 mm and 1 mm meshes, to extract the macrofauna. The residue over 5 mm was sorted visually and the organisms present extracted, allowing the bulk of gravel to be discarded. All material retained by the finer (1 mm mesh) sieve was kept. The two fractions were then preserved in buffered formalin, diluted in sea water to a concentration of approximately 5%.

Laboratory procedures

The preserved samples were released onto a 1 mm mesh in a fume cupboard and flushed with fresh water to remove residual formalin. The smaller fraction was sorted to remove the organisms from the sediment, with the use of an illuminated bench magnifier. Both fractions were then identified, to species level where possible, using low- and high-power microscopes and standard taxonomic keys and the results pooled. The organisms were then blotted, to remove extraneous liquid, and wet weights recorded for each species. The ash-free dry weights were calculated using conversion factors from Rumohr *et al.* (1987). Particle size distributions of sediments were obtained by wet sieving at 0.5 ϕ intervals down to 4 ϕ (63 μm) using British Standard stainless steel sieves.

18.3 Results

The sites chosen for the present investigation in this survey corresponded with a number of those that were sampled by Lees *et al.* (1993), although a different sampling technique (an Anchor dredge) was employed. The faunal analysis revealed that the species assemblage was similar to that reported during previous surveys (Rees, H. L., 1987, Lees *et al.,* 1993), containing one dominant species, the barnacle *Balanus crenatus,* which accounted for 76% of the total number of individuals found in this study and was present throughout the study area. However, despite the species composition being similar, the abundance distributions contrasted with those of Lees *et al.* (1993) (see Table 35).

A total of 95 taxa were recorded in the present survey, of which 48 were found within the impacted area and 85 outside (see Figure 53). Twenty seven of these species were singletons, 7 from the sites in the extraction area and 20 from those outside. One species, *Echinocyamus pusillus* (the Green Sea Urchin) was found in moderate numbers at the undisturbed sites, but

Table 35. Numerically dominant taxa

Dredged area		Undredged area	
Taxon	Total numbers	Taxon	Total numbers
Balanus crenatus	1118	*Balanus crenatus*	540
Pisidia longicornis	16	*Megalopae*	46
Harmothoe impar	15	*Lumberineris gracilis*	23
Notomastus laterieus	13	*Levinsenia gracilis*	21
Lumberineris gracilis	11	*Echinocyamus pusillus*	21
Galathea intermedia	11	*Harmothoe impar*	11
Caulleriella alata	8	*Corophium bonellii*	10
Cheirocratus sundevallii	8	*Protodorvillea kefersteini*	9
Ensis ensis (juv)	8	*Poecilochaetus serpens*	9
Scalibregma inflatum	7	*Pholoe minuta*	8
Lanice conchelega	7	*Ophelia neglecta*	7
Ampelisca spinipes	7	*Urothoe elegans*	7

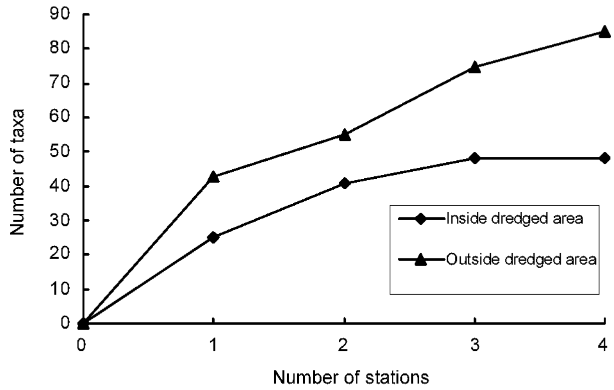


Figure 53. Cumulative numbers of taxa found

was absent from the extraction area, which paralleled the findings of Lees *et al.* (1993), who also showed a reduction in numbers at the dredged sites. Otherwise, the abundances of individual species were generally too low and variable to identify clear differences between dredged and non-dredged sites. More crab larvae, in their megalopa stage, were found outside the dredged area than within. One site from within the dredged area contained only one individual (*Balanus crenatus).*

Total mean biomass was higher in the dredged area than outside (20.1 g and 7.7 g ash-free dry weight, respectively), but because of variability between replicates, the difference was not statistically significant (df=3, t=1.712, p=0.09). Results at both the sites were influenced by the numbers of *Balanus crenatus* present; when biomass values of this species were excluded the mean was still higher at the dredged area (4.9 g versus 0.9 g), but this difference was again not statistically significant (df=3, t=0.801, p=0.24). The overall percentage of biomass accounted for by the barnacles was 60%, but the percentages ranged from 0 to 100. Generally, it could be inferred that the animals that contribute to the higher species count outside the dredged area are smaller species that are easily removed by the physical disturbance that dredging produces, whilst occasional large individuals remaining after dredging activity within the licenced area are more resistant to disturbance.

The particle size analysis revealed little difference in the general substrate type; all the sites had sediments classified as sandy gravel. However, the sites located outside were somewhat more variable than those inside (see Figure 54) which might be expected to enhance the scope for colonisation by a wider array of species.

Cluster analysis of the quantitative benthos data was performed using the Bray-Curtis similarity measure (Bray and Curtis, 1957) and group-average sorting (Lance and Williams, 1967). Undredged sites were grouped into one cluster which was distinct from a group of three sites within the dredged area and an additional, dissimilar, site characterised by the presence of a single specimen of *Balanus* (see Figure 55). Overall, the dendrogram suggests distinctive differences between dredged and undredged locations.

18.4 Discussion

During June 1995, when these sites were sampled, sand and gravel extraction had ceased temporarily and previous dredging effort during 1995 had been much reduced. Also, in contrast to the average of 1.5 million tonnes in the preceding years, the total material extracted for 1994 was 800 thousand tonnes, due to the licensed tonnage limit having been reached by two of

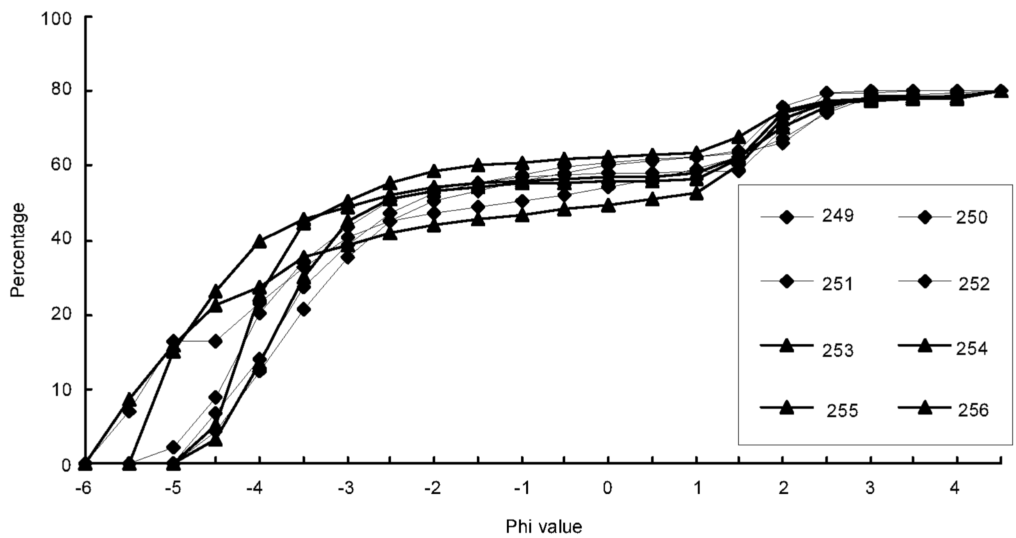


Figure 54. Particle size analyses: cumulative percentage curves

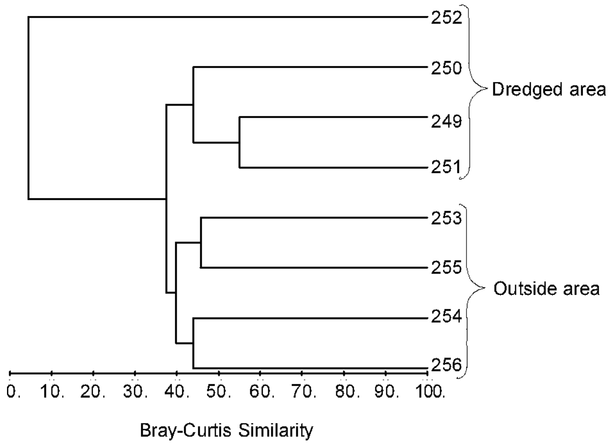


Figure 55. Dendrogram of output from cluster analysis, using 4th root-transformed data

the five companies that had been granted extraction rights. No dredging took place during June or August 1995, and limited tonnages were dredged during July, September and October in the period following sampling. A new licence subsequently allowed the dredging to recommence at levels comparable with previous years, after November 1995. The differences observed between the areas sampled were therefore expected to be less than would have been the case during more active dredging, and also suggest that recolonisation takes place relatively rapidly. The sampling carried out by Lees *et al.* during 1991 was during a period of more intensive dredging and hence the observed differences were more marked.

Differences in particle size distributions are considered to be insufficient to fully explain contrasts in the fauna between dredged and undredged sites, suggesting that the physical disturbance engendered by the extraction of gravel is the major influence on the animals in the locality. The consequences of physical disturbances can include the removal of animals previously present, the exposure of hitherto uncolonised sediments, increased turbidity and redistribution of fine sediments. Of the total number of species encountered, some 40 occurred only outside the dredged area, but too few individuals were present to draw any conclusions about their susceptibility to disturbance during this study. However, many of these species are small infaunal taxa, supporting the suggestion in Rees, H. L. (1987) that the finer sediments in the gravel interstices are relatively stable and provide a suitable habitat, when dredging is not taking place. One species, *Echinocyamus pusillus,* was present in sufficient numbers outside the impacted area to suggest that its absence within the licensed area was due to dredging. During periods of reduced dredging intensity, some locations within the licensed site may experience only limited exposure to the direct effects of extraction, allowing survival by some species, and recolonisation by others. It is likely that some recolonisation occurs even during times of extraction. The site that contained only one animal was clearly the result of a recent passage of the drag-head.

Lees *et al.* (1990) sampled the same stations as in the present study and, despite differences in sampling methodology, the conclusions from both are broadly similar. Thus most species are rare and, as might be expected, the numbers of taxa within the extraction site are consistently lower than those outside the dredged area. The entire area is characterised by the dominance of the barnacle, *Balanus crenatus* (Rees, H. L., 1987; Lees *et al.,* 1990; Kenny *et al.,* 1991). Studies in this area, aimed at better identifying the nature and geographical scale of biological effects arising from aggregate extraction, are continuing.

19. SIDESCAN SURVEY OF THE NAB TOWER DREDGED MATERIAL DISPOSAL SITE

The Nab Tower dredged material disposal site is situated approximately 8 nautical miles east of Sandown Bay at the eastern end of the Isle of Wight (Figure 56). It routinely receives around 1,000,000 tonnes per annum of both maintenance and capital dredgings. Between June 1996 and July 1997 a total of 10,600,000 tonnes of mainly capital material was deposited at the site as a result of construction operations in Southampton Water.

The purpose of this survey, carried out in June 1995, was to establish the physical nature of the substrates existing in and around the Nab Tower dredged material disposal site ahead of the large scale capital disposal operation, in order that any resultant changes in the sediments might be identified. Seven legs of sidescan with a one nautical mile spacing were completed,

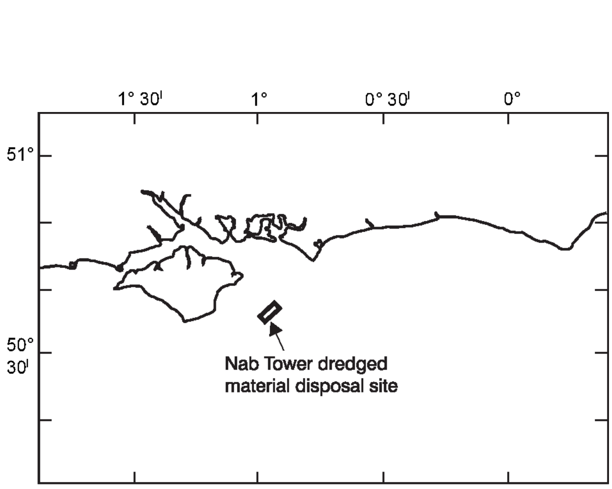


Figure 56. Position of Nab Tower dredged material disposal site

producing a total survey distance of 41 nautical miles. The sidescan swath distance was 300 m. Ground truth samples were collected at regular intervals over the survey area using a Shipek grab. *In situ* visual descriptions and subsequent particle size analysis of the samples provide additional substrate information which enhances the interpretation of the sidescan record (Table 36).

Table 36. Nab Tower dredged material disposal site - particle size distribution

Sample	% Gravel	% Sand	% Silt/Clay
160	8.52	91.46	0.02
161	70.88	28.49	0.63
162	16.77	83.05	0.18
164	64.27	34.85	0.88
165	53.69	45.48	0.83
166	61.67	38.15	0.18
167	61.21	38.51	0.28
168	75.38	21.04	3.58
170	50.25	49.45	0.30
171	8.32	24.37	67.31
172	43.94	54.04	2.02
173	55.46	44.33	0.21
174	65.11	30.41	4.48
175	59.84	36.73	3.43
176	95.25	4.57	0.18
177	74.91	24.00	1.09
178	44.84	53.01	2.15
179	12.61	85.92	1.47
180	75.56	21.19	3.25
181	45.65	51.66	2.69
182	66.07	33.77	0.17
183	23.64	75.25	1.11
184	9.31	90.48	0.22
185	74.39	24.90	0.72
186	47.10	50.13	2.77
187	55.20	43.40	1.40
188	89.23	10.70	0.07
189	60.19	38.27	1.54
190	0.03	99.36	0.60
191	6.22	92.79	0.99
192	91.57	7.86	0.57
193	39.66	56.69	3.65

Figure 57 describes the substrates and features observed over the survey area. Evidence from the grab samples suggests that substrates over the survey area are predominantly a mixture of sand, gravel and pebbles occurring in varying proportions. The sidescan image indicates the presence of discrete reefs of even coarser material, such as cobbles and boulders which are too large to be collected in a Shipek grab. The silt/clay component of the substrates is minimal. Only within the disposal site itself does the finer fraction constitute a significant proportion of the sediment. Sidescan images from within the site show patchy mottled features consistent with the presence of spoil. Occassionally the underlying bedrock is exposed either as platform features, or more commonly as narrow, low ribs of rock outcropping just above the surface of the sediment.

Predominantly sandy sediments occur in the north east and south east parts of the survey area. In the south east the sand is present as large wave features with a wavelength of approximately 750 m. The structure of the waves indicates an easterly bed transport regime. In the north east the sandier substrates extend into the survey area as a finger of soft rippled sand.

The sidescan sonar record shows areas impacted as a result of the activities of aggregate suction trailer dredgers. Dredge tracks appear to be restricted to licensed aggregate areas 213, 340 and 351. Anchor drag marks were observed within a deep-draught vessel anchorage immediately to the west of the dredged material disposal site.

Evidence of dredged material over the survey area seems to be restricted to the disposal site itself, and possibly to an area immediately adjacent to the northern corner of the site. It does not appear from the physical evidence generated from this survey that an extensive 'footprint' of fine material surrounds the site. Further analysis of the samples and data generated from this survey, along with the work reported here, will provide a baseline against which future surveys may be compared.

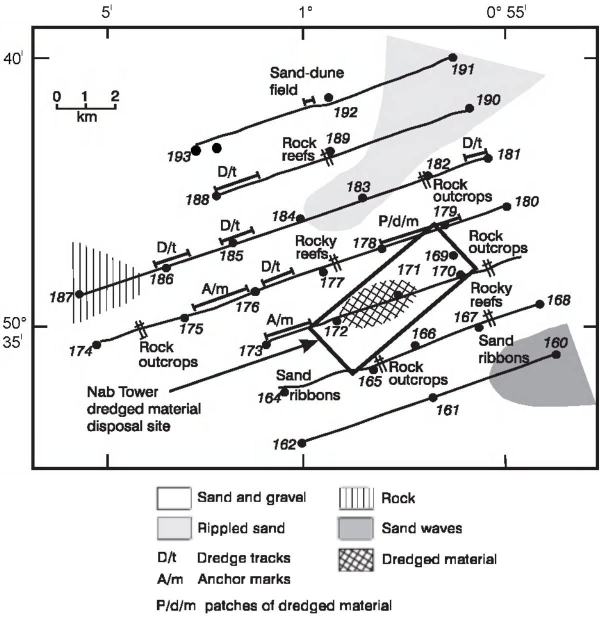


Figure 57. Distribution of sediments and seabed features over the survey area

20. COMPARATIVE STUDIES OF BENTHIC CHANGES AT DREDGED MATERIAL DISPOSAL SITES

20.1 Introduction

Biological assessment of the effects of disposal have historically consisted of an analysis of the macrofaunal component of the benthos (Pearson and Rosenberg, 1978; Gray, 1979). However, recently it has emerged that meiofaunal communities (animals passing through a 500 μm sieve and retained on a 63 μm sieve) appear to be more sensitive to the ongoing disposal of dredgings i.e. short-term events, in contrast to macrofaunal communities that may reflect longer-term changes in disposal practices (Somerfield *et al.*, 1995).

In order to fully evaluate the usefulness of meiofauna studies in comparison to more conventional approaches such as macrofaunal assessments, surveys have been conducted at four major dredged material disposal sites around the UK coast (Tees Bay, Swansea Bay, Liverpool Bay and Morecambe Bay). This will permit inter-regional comparisons of the responses of meiofaunal and macrofaunal communities to the disposal of dredged material varying both in sediment composition and contaminant burden. The objective is to establish common threads with a view to producing a generic model of responses suitable for wider application. The account below describes the findings at the Tees Bay dredged material disposal site.

20.2 Methods

Field sampling

The disposal site is located at approximately 30 m depth in the Tees Bay and currently receives 2-3 million tonnes of dredged material from the industrialised Tees estuary. Six stations were sampled in total, five of which (Stations 1, 2, 3, 5, 6) were located along an approximately north-south transect through the disposal site (Figure 58). A further station (Station 4) was positioned inshore of the transect within the licensed site. In May 1995, three Day grab samples were collected from each station, with the exception of Station 6, where only two could be obtained due to the deteriorating weather conditions. After removal of sub-samples of sediment using a 3-cm diameter perspex corer, for later particle size and meiofaunal analyses, macrofauna samples were washed over a 1-mm mesh sieve. Both macrofaunal and meiofaunal samples were then preserved separately in 4% formalin in sea water with added Rose Bengal (a vital stain). A sample of the surface of a further grab sample at each station was removed and frozen, for later analyses of metal concentrations.

The stations were revisited in May 1996 and 3 sediment cores of 55-mm internal diameter were collected for meiofaunal analyses at each station from separate deployments of a Bowers and Connelly Multiple Mini-Corer. The corer is specially designed to retrieve virtually undisturbed sediment cores. The sediment cores were immediately preserved in 4% formalin in sea water.

Laboratory analysis

After removal of the preservative, macrofauna samples were sorted and then identified to species level as far as possible using a standard range of taxonomic keys. Samples for meiofauna analysis were washed on to a 63 μm sieve to remove most of the fine sediment and the preservative. The meiofauna were then extracted from any residual sediment by a 2-stage process of elutriation and decantation with fresh water followed by flotation in the density medium Ludox TM (see Somerfield and Warwick, 1996). Core samples were then sub-sampled using a sample splitter (Jensen, 1982). Meiofaunal grab sub-samples were extracted and analysed whole. Sub-samples (both from grabs and cores) were then slowly evaporated to anhydrous glycerol and mounted on microscope slides. Nematode specimens from each sub-sample were counted and identified to species level using a compound microscope.

After thawing, sediment samples were wet sieved using a 63 μm sieve to separate the fine and coarse sediment fraction, dried for 12 hours at 95°C and weighed. The concentrations of cadmium, chromium, copper, silver, nickel, lead and zinc were determined following the procedures outlined in Harper *et al.* (1989).

Data analysis

The PRIMER software package (see Clarke and Warwick, 1994) was employed for analysis of species abundance data, and for exploring relationships between the fauna and environmental variables. Square-root transformations were used to reduce the influence of the numerically dominant species in the multivariate analyses. Both biotic and sediment data were then pooled between stations in order to identify any common trends attributable to the disposal of dredgings.

20.3 Results

Environmental variables

Concentrations of a range of trace metals (Table 37) show that the inshore disposal station (Station 4) has elevated levels of all the measured trace metals compared with the other stations. However, the offshore disposal station (Station 3) shows only slightly elevated levels of some metals (Table 37, see also Figure 59 for an example with Zn). This suggests that the bulk of the dredgings are being disposed of in the inshore margins of the licensed site. The substrate at Stations (3 and 4) within the disposal site is also coarser in nature than stations outside (Table 37). This is

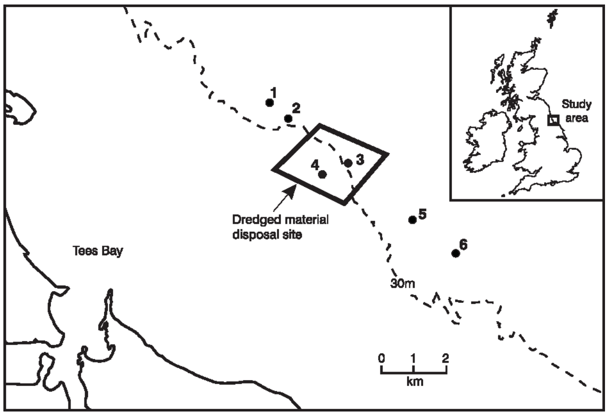


Figure 58. The location of sampling positions in relation to the Tees Bay dredged material disposal site

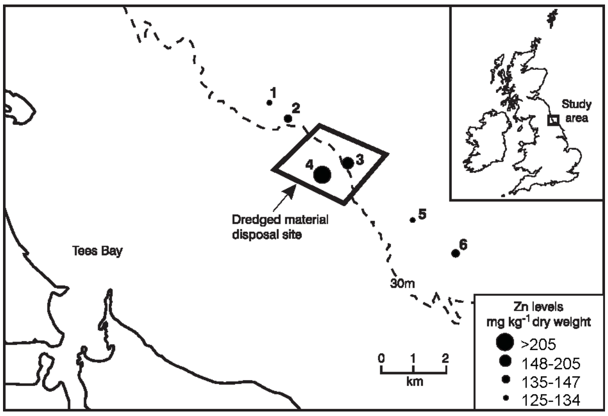


Figure 59. Concentrations of zinc (mg kg^{-1} dry weight) in sediments from stations 1-6 along the Tees Bay transect

probably due to the disposal of 'sandy' maintenance dredgings at the site. These data are further examined below, in relation to the faunal distributions.

Benthic fauna

Summary statistics derived from both meiofaunal and macrofaunal data are plotted in Figures 60, 61 and 62. Although measures derived from macrofaunal data appear reduced within the disposal site compared to outside they are not significant. The pattern of impact is more apparent when the meiofaunal data from both cores and grab sub-samples is considered. Overall, there is a reduction in the number and diversity of meiofaunal species within the zone of immediate impact at Station 4. There is also the suggestion of marginal enrichment in the fauna to either side of the disposal site, possibly as a result of the dispersion of organically rich fine particulates associated with disposal practices.

Cluster analysis of macrofaunal data generally separated into two major groups, those samples outside the licensed disposal site and those within (Figure 63(a)). An essentially similar pattern was obtained with the meiofauna grab sub-samples (Figure 63(b)). Three groupings were evident with meiofaunal core data, with samples from the offshore disposal station (Station 3) occupying an intermediate position between the inshore disposal station (Station 4) and stations outside the disposal site (Figure 63(c)).

The outcome of 'Multidimensional Scaling' (MDS) of square-root transformed macrofaunal data is presented in a 2-d plot which represents the 'distance' (or dissimilarity) between stations or groups of stations (Figure 64(a). Stations 3 and 4 are located inside the disposal site and are separated from stations outside. A similar result emerged from MDS analyses of meiofaunal data derived both from grab sub-samples and cores (Figures 64(b) and (c)). Also evident with the meiofaunal data is a clear separation between the two disposal stations (Stations 3 and 4). This is likely to be related to the frequency of disposal that occurs in different areas within the site. By inference, Station 4, the station most dissimilar from the stations outside the disposal site, is the most severely affected by dredgings disposal. The tight clustering of the meiofaunal data compared with that obtained with macrofaunal data reflects the better precision observed with meiofaunal data in this study.

When the output of MDS is examined using averaged data, common patterns emerge with the inshore disposal station (Station 4) most severely impacted from dredgings disposal and the offshore disposal station (Station 3) apparently less affected (Figures 65(a), (b), (c)). This pattern is also evident with the 'Principal Components Analysis' (PCA) of environmental data (Figure 65(d)).

Table 37. Concentrations (mg kg^{-1} dry weight) of a range of trace metals concentrations and sediment parameters at Stations 1 to 6 from Day Grabs. %sc : average % (silt+clay)

Station	Cd	Cr	Cu	Hg	Ni	Pb	Zn	% sc
1	<0.220	61	39	0.49	34	97	125	37.99
2	<0.210	38	43	0.35	25	47	147	21.74
3	<0.210	68	42	0.43	32	106	148	9.11
4	0.44	94	87	0.74	39	119	206	15.03
5	<0.240	53	36	0.26	29	75	131	34.75
6	<0.220	64	46	0.42	39	106	135	74.07

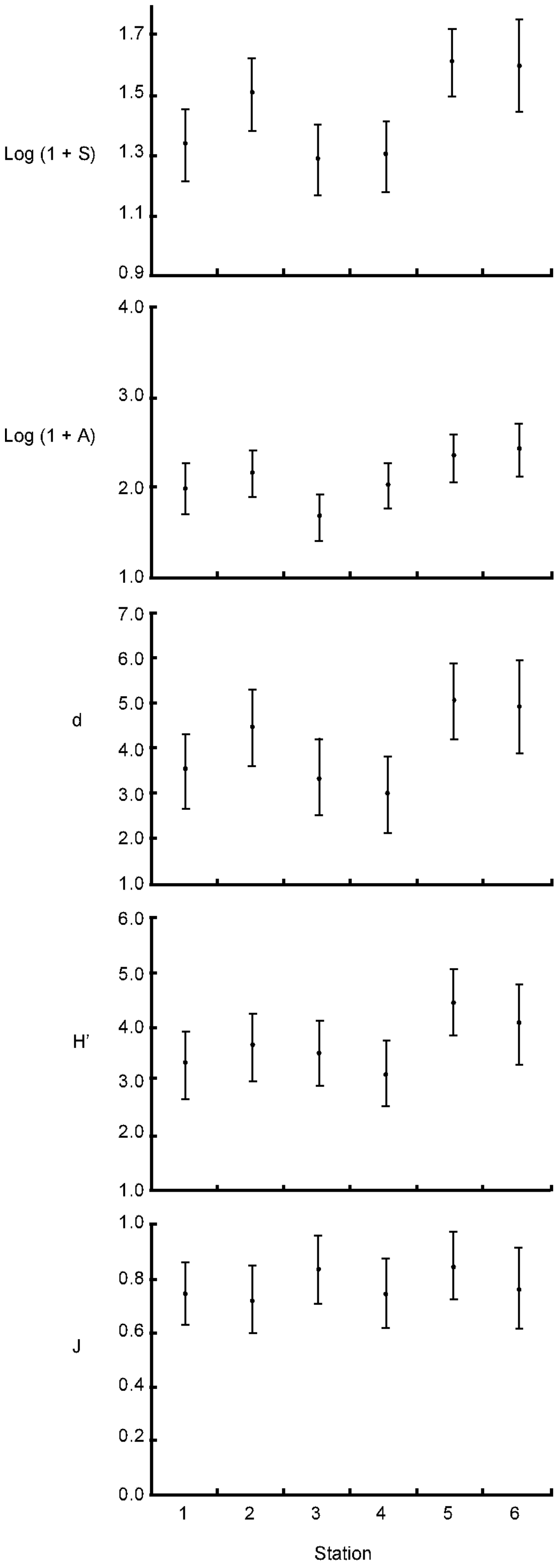


Figure 60. Means and 95% Least significant differences for univariate measures of macrofaunal community structure

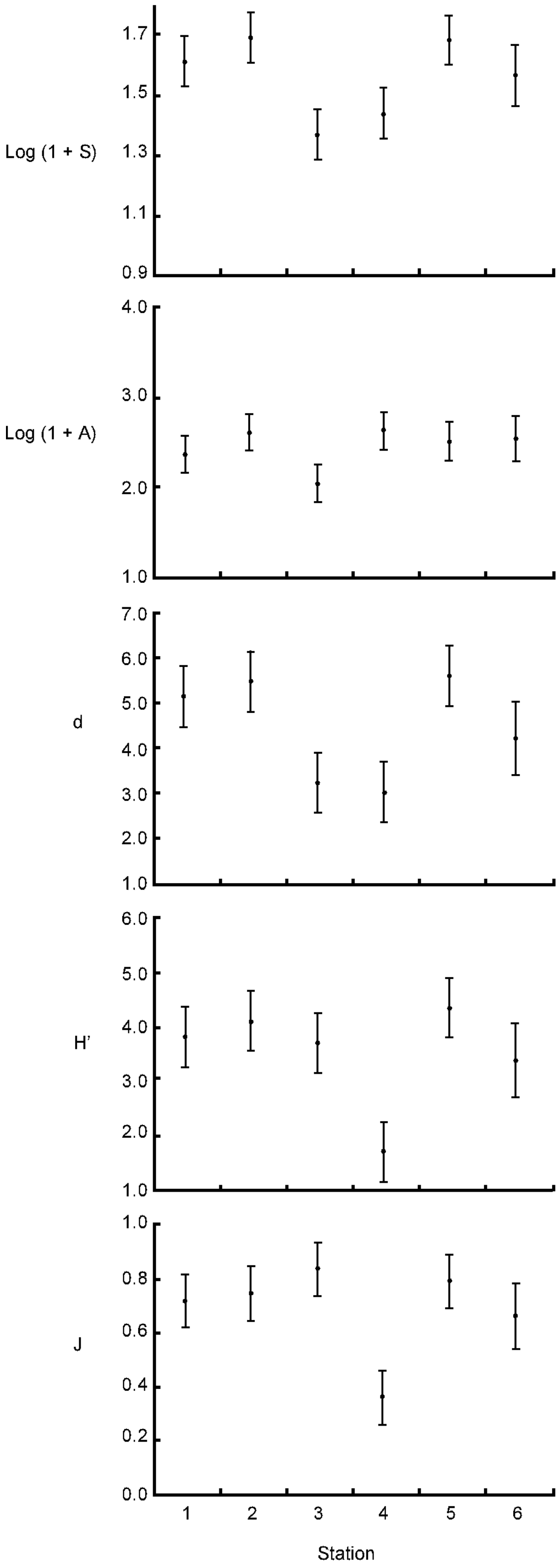


Figure 61. Means and 95% Least significant differences for univariate measures of macrofaunal community structure from grab sub-samples

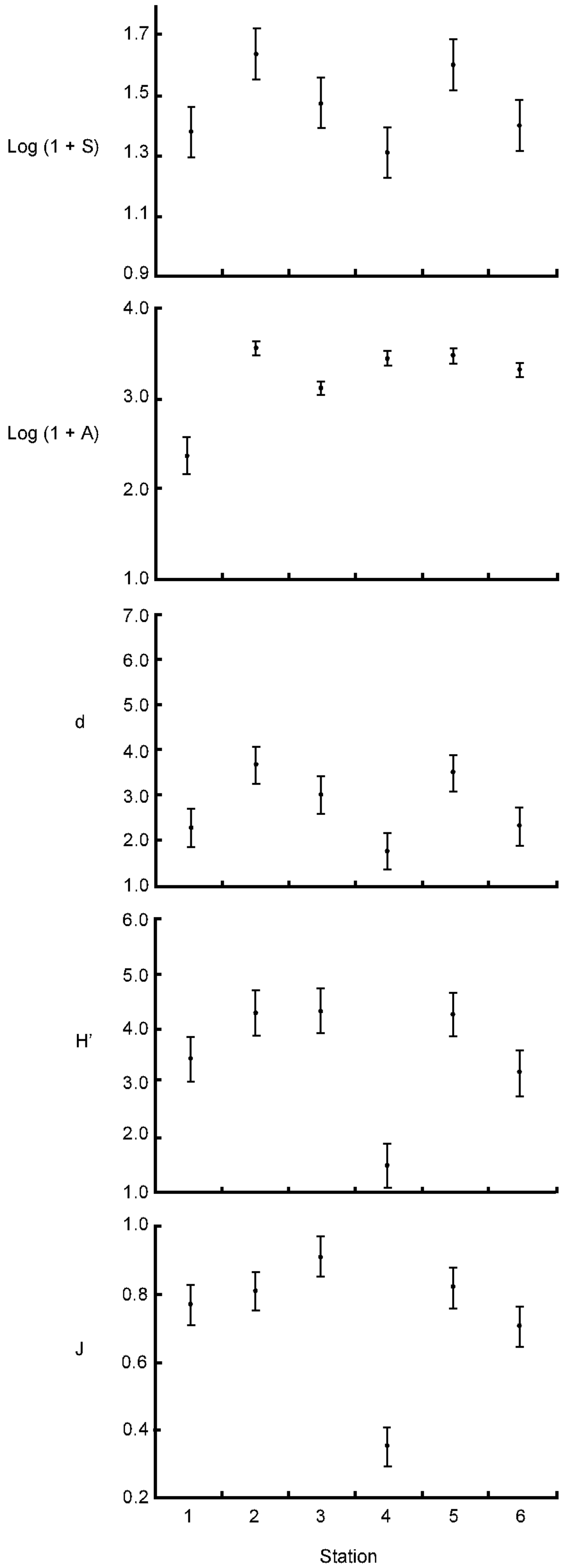


Figure 62. Means and 95% Least significant differences for univariate measures of macrofaunal community structure from multicores

The macrofaunal organisms important in characterising the inshore disposal station comprised *Polydora ciliata* (agg.), *Tubificoides benedeni*, *Capitella* sp., *Mytilus edulis*, *Nephtys hombergii*, *Ophryotrocha* sp. and *Tubificoides pseudogaster.* Whilst the bivalves *Nucula nitidosa*, *Nuculoma tenuis*, *Artica islandica* and *Chamelea gallina*, together with the polychaetes *Prionospio fallax* and *Chaetozone setosa* (agg.) were important in defining the stations outside the disposal site. Nematode species present in the inshore disposal station but occurring in lower numbers or absent to the north and south of it include *Sabatieria punctata*, *Chaetonema riemanni*, *Paracanthonchus heterodontus*, *Daptonema tenuispiculum* and *Eumorpholaimus* sp. Nematodes typical of muddy-sand habitats such as *Sabatieria ornata, Daptonema normandicum* and *Tripyloides marinus* characterise stations outside the disposal site.

20.4 Discussion

The macrofaunal community found within the disposal site is similar in composition to that reported from an intertidal sand community at Seal Sands at the mouth of the Tees estuary (Alexander *et al*., 1935; Gray, 1976; Kendall, 1979). Some macrofaunal organisms more typical of estuarine conditions such as the oligochaete *Tubificoides pseudogaster* were also observed within the disposal site suggesting that some organisms may have been transported to the site along with the dredgings. Among the species dominating the meiofaunal community were the nematodes *Sabatieria punctata* and *Daptonema tenuispiculum.* These particular species also characterise a dredged material disposal site in Liverpool Bay (Somerfield *et al*., 1995; Boyd unpublished data). This pattern of the proliferation of certain meiofaunal species at dredged material disposal sites will be particularly useful if it is found to occur at the disposal sites, as such consistent patterns have not so far been reported for macrofaunal species (MPMMG, 1996).

Analyses of the meiofaunal community clearly indicated marked changes both in terms of diversity and abundance in response to dredged material disposal. Such changes were also reflected by differences in the sediment and by contaminant levels. Station 4 which is located inside the disposal site was found to have the lowest diversity but the highest levels of metal concentrations compared to the other sampled stations. In general, species more typical of sandy sediments such as *Chaetonema riemanni* and *Eumorpholaimus* sp replace a muddy sediment assemblage at the disposal site. Their presence together with the coarser nature of the substrate may be attributed to the disposal of sandy dredgings. Within the disposal site itself differences were also apparent in meiofaunal community structure. It is likely that these differences are related to the frequency of disposal that occurs in different regions of the disposal site.

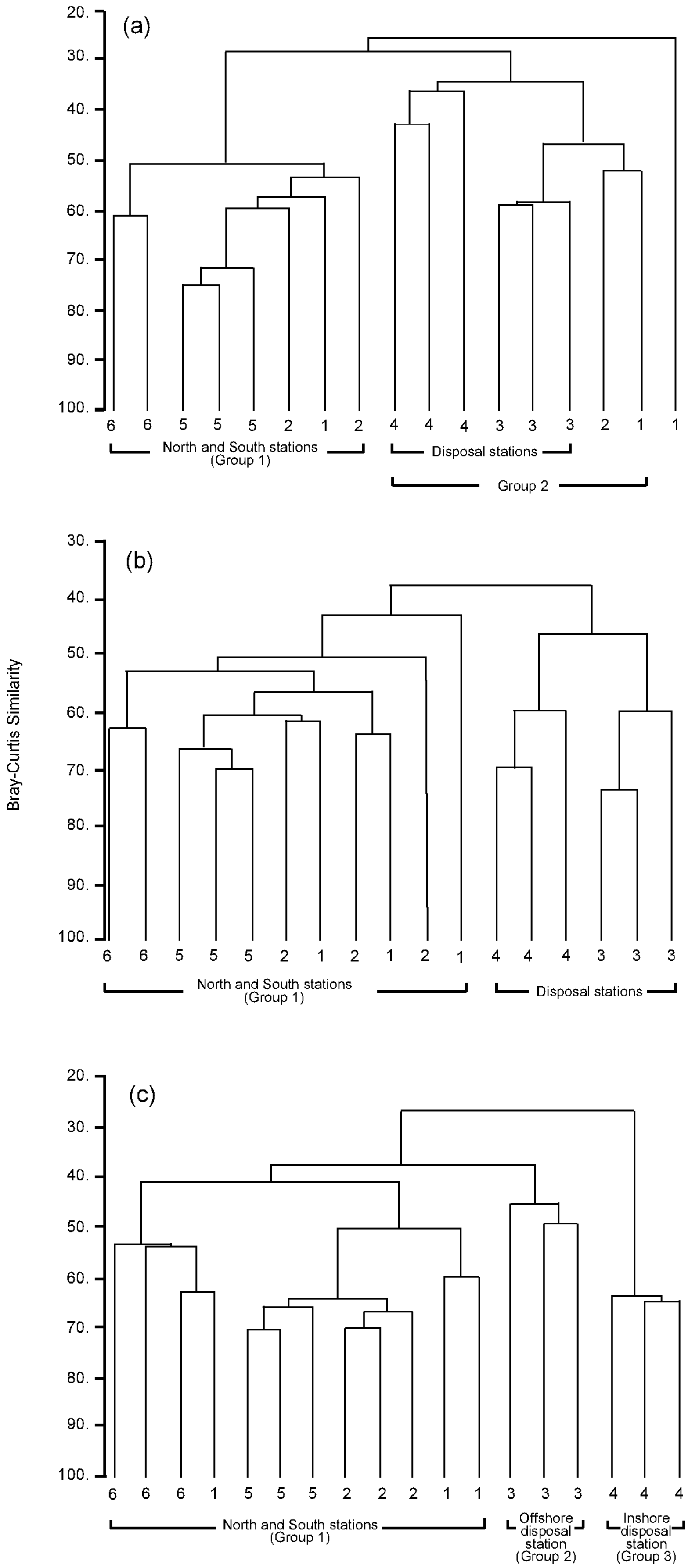


Figure 63. Dendrograms for group average clustering of Bray Curtis similarities based on square-root transformed data for stations 1-6 (a) macrofauna (b) meiofauna (grab sub-samples) (c) meiofauna (cores)

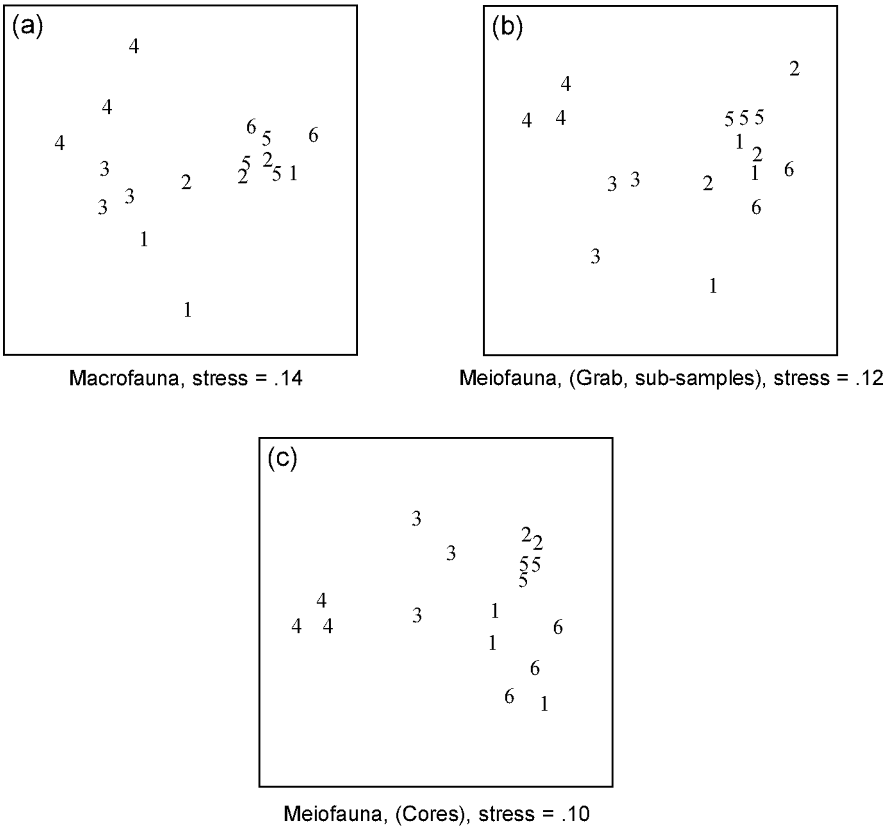


Figure 64. MDS ordination of square-root transformed biotic data (a) macrofauna (b) meiofauna (grab sub-samples) (c) meiofauna (cores)

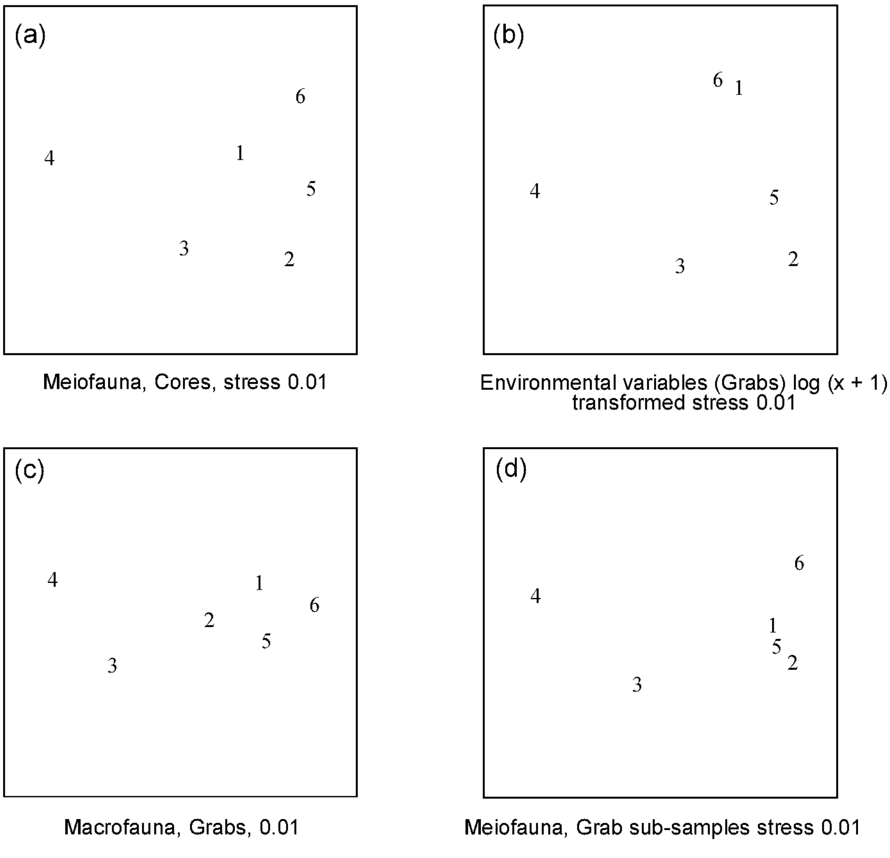


Figure 65. Ordination by PCA of environmental variables, and by MSD of average abundance from stations 1-6. Environmental variables log transformed, biotic data square-root transformed (a) meiofauna (cores) (b) environmental variables (grabs) (c) macrofauna (d) meiofauna grab sub-samples

There was close agreement between the meiofauna data obtained from grab sub-samples and cores. Grabs are robust and can be used in a wider range of sediment types and conditions than corers. Therefore, the use of grab sub-samples for evaluating changes in the meiofauna may be permissible in areas where core samples cannot be retrieved. However, further work is required before firm recommendations can be made regarding the utility of sub-samples from grabs for assessing changes in the meiofauna.

The overall pattern of impact observed with meiofaunal data was very similar to that with macrofauna data, although discrimination between stations within the disposal site is not so evident as with the meiofaunal data. There is also some evidence for a local enrichment effect immediately outside the disposal site that may be associated with dispersing dredged material (Zambriborsch *et al.*, 1982; Rees *et al.*, 1992) and this was most pronounced with meiofaunal data from cores. In fact, the pattern of change in the meiofauna between stations was generally less ambiguous than that of the macrofauna, primarily due to the higher precision of the meiofaunal data. Thus, this study lends further weight to the suggestion that meiofaunal studies can be effectively employed to evaluate the biological consequences of disposal activities. The results from studies at other dredged material disposal sites will help to further clarify in which circumstances meiofaunal investigations are best utilised.

LICENSING AND RELATED ACTIVITIES

21. LICENSING OF DEPOSITS IN THE SEA

21.1 Introduction

This section gives information about the licensing of deposits in the sea during 1995 and 1996 under Part II of the Food and Environment Protection Act (1985) (FEPA) (Great Britain Parliament, 1985(a)). For convenience, licensing statistics for Scotland and Northern Ireland are included in this Section to provide statistics for the UK as a whole.

This report also includes statistics of other deposits in the sea which are principally for construction purposes.

21.2 Legislation and licensing authorities

The disposal of waste at sea, as opposed to discharge into the sea via pipelines, is controlled by a system of licences issued under Part II of FEPA. Certain operations (e.g. deposit of scientific instruments, navigation aids), are exempt from licensing under the Deposits in the Sea (Exemptions) Order 1985 (Great Britain – Parliament 1985(b)). In England and Wales, the licensing function rests with MAFF and in Scotland with the Scottish Office Agriculture, Environment and Fisheries Department (SOAEFD). In Northern Ireland, the issuing of licences is the responsibility of the Environment and Heritage Service, an agency within the Department of the Environment for Northern Ireland.

Section 147 of the Environmental Protection Act (1990) (Great Britain – Parliament, 1990) provides for further additional material about sea disposal activities to be added to the public registers, established under FEPA. A Statutory Instrument relating to licences issued in England and Wales came into force on 1 July 1996, extending the information to be held on the public register about licence applications, breaches of the legislation and enforcement action. Similar Orders are in preparation in respect of licensing activity in Scotland and Northern Ireland.

21.3 Enforcement

Scientists from the CEFAS Burnham Laboratory have powers to enforce licence provisions. Visits are made to construction sites and treatment works, storage facilities and disposal vessels. Samples are taken and records, including logbooks, are checked. Scientific staff carried out 5 inspections in 1995 and 20 in 1996. The Sea Fisheries Inspectorate, with staff based on the coasts, detects unlicensed activities and enforces licence conditions relating to construction and the disposal of wastes in designated disposal areas. They made 549 inspections in 1995 and a further 610 in 1996.

In Scotland, similar enforcement powers are held by staff of the SOAEFD Marine Laboratory, Aberdeen and by the Scottish Fisheries Protection Agency (SFPA). The Marine Laboratory made 7 inspections in 1995 and 6 in 1996. SFPA also made 8 inspection visits in 1995 and 36 in 1996. In Northern Ireland, 6 inspections were made in 1995 and 4 in 1996.

In England and Wales, a number of incidents of apparent infringement of the Act were investigated during 1995 and 1996 involving activities for which no licence had been obtained (in most instances this was due to ignorance of the need for MAFF consent) or where the terms and conditions of a licence had not been complied with. Although only one incident during this period was considered serious enough to merit action being taken through the Courts, one licence, authorising the disposal at sea of dredgings arising from the construction work at Cardiff Bay Barrage, was formally revoked in October 1995 when the licensee, Bechtel Ltd, significantly exceeded the permitted tonnage for disposal.

In November 1995, a Danish company, Corral Line Aps, operating out of Brightlingsea was formally warned that they should not dispose overboard of straw and animal litter used as bedding for livestock being exported to the Continent on the vessel *CAROLINE*. The Company agreed to take the wastes ashore for disposal.

A similar incident involved Associated British Ports, Silloth, Cumbria, where effluent was being discharged from a facility used as a lairage for third world animal imports. Investigations established that there was no infringement of FEPA but the case was referred to the Department of Transport for consideration under MARPOL.

A visit by the local Fisheries Officer to Burnham-Overy-Staith established that an alleged illegal deposit of rubble on the foreshore had in fact been made above the level of Mean High Water Spring Tide mark and did not constitute an offence under FEPA.

There were, however, incidents where activities being undertaken by the licensee or his agents were not within the terms or conditions of the licence. Towards the end of 1994, Anglian Water was found to be disposing at sea of grout used in the construction of the new West Runton Outfall. An application to vary the licence accordingly was made and granted in the Summer of 1995.

During the year there was continued liaison with the Falmouth Docks and Engineering Company over the origin and nature of material being used as infill in part of the docks and enquiries were made about the construction of an associated slipway which was not within the terms of the licence. An application to vary the licence to include these works was agreed in April 1996.

Similarly, works additional to those covered by their licence were undertaken during 1994 by IMP Developments at Aberystwyth. A formal variation to the licence was subsequently requested and agreed in February 1995.

The National Rivers Authority (now the Environment Agency) were found to be pursuing a programme of restoration involving river bed 'stoning' in some 30 separate locations. They had originally understood that this activity was exempt from control but subsequently applied for retrospective licences where the work had not been completed. The Environment Agency also constructed a groyne on the River Crouch at Burnham; a retrospective licence subsequently being issued.

Unlicensed works were undertaken on Brighton Pier and by North East Water Plc at Lindisfarne, Holy Island for which retrospective applications were required.

Construction work by Clwyd County Council was underway on the Deeside road link river crossing when the site was visited in 1994 and subsequently an application was made and a licence issued in June 1995.

Investigations were pursued concerning material removed by two local residents from a mooring area and dumped without a licence in deeper water at Fodder Lake, Cornwall. Following a warning letter, a licence was subsequently applied for and issued in October 1995.

There was also correspondence with Castle Marine in North Wales concerning minor harbour improvements at Associated British Ports on the Tyne but it was decided that the works undertaken were not licensable.

In 1996, retrospective licences were issued to Torbay Borough Council for unlicensed deposits in Brixham Harbour and to North-West Water Ltd for work below mean high water springs in connection with the reconstruction of Willow Lane Pumping Station, Lancaster.

A warning letter was sent to Dwr Cymru for starting work on repairs to an outfall pipe on the River Ritec at Tenby, Dyfed before the licence application had been processed. (The licence was in due course issued).

In August 1996 a visit was made to inspect a farm at Llanfwrog, Angelsey, where some unlicensed coast defence works had apparently been undertaken. Although the works were said to have been necessary as an emergency measure to protect the land from erosion by the sea, the County Council, asked that an environmental statement be submitted in support of a planning application and called for the work at the site to be suspended.

In October 1996 reports were received about materials being seen to be dumped in Falmouth Bay from vessels whilst delivering rock to coast protection works at Plaidy being undertaken on behalf of Caradon District Council. An enforcement visit was made to the works and the Contractor's (Costain) Site Manager was interviewed about the allegations relating to their sub-contractors, South American Marine Operational Services, owners of the vessels concerned.

Enforcement action was taken against a husband and wife living on an island in the Menai Straits for depositing materials to build a causeway to the island. This culminated in a successful prosecution in 1997; both parties being conditionally discharged for twelve months and MAFF was awarded £500 towards its costs.

21.4 Report on licensing activities

Tables 38 to 44 give details, over the period 1992-1996 of the number of sea disposal licences issued, the quantity of waste licensed, and the quantity actually deposited, together with information on those contaminants in the wastes which the UK is required to report internationally to meet obligations under the OSPAR and London Conventions (Great Britain-Parliament, 1972 (a-b)).

21.5 Licensing of minestone disposal

Tables 38(a) and 38(b) give details of licences issued for the disposal of colliery wastes to sea during 1995 and 1996.

The final licence permitting the disposal of colliery waste at sea and onto beaches ended in December 1995. Subsequently, however, RJB Mining was permitted to deposit minestone on the foreshore as an interim measure to sustain coastal defences at Lynemouth, pending conclusion of a shoreline management plan offering longer-term strategy for the area.

21.6 Licensing of sewage sludge disposal

Table 39(a)and 39(b) give details of licences issued for the disposal of sewage sludge at sea. Total quantities of key metallic contaminants in sewage sludge actually disposed of at sea are shown in Table 39(c). Figures 66 and 67 show the location of the disposal sites for sewage sludge and the quantities deposited at each site in 1995 and 1996.

At the 1987 Second International Conference on the Protection of the North Sea, (Department of Environment, 1987), the Government indicated it was taking urgent action to reduce the contamination by persistent, toxic or bioaccumulable materials present in sewage sludge deposited in the North Sea and to ensure that the quantities of such contaminants deposited in the North Sea did not increase above 1987 levels. Earlier reports explained that to apply this control, limits were set for a series of key contaminants deposited under each licence. Further reductions in the licensed quantities for these metals proved possible in 1995 and 1996 and Table 40 shows how the aggregate figures authorised for disposal in the North Sea in those years compared with the estimated quantity at 1987 licensed levels. These are near background levels, with most of these contaminants coming from general domestic sources rather than from industry.

Table 38(a). Colliery wastes licensed for disposal at sea in 1995 (1)

Licensed quantity (tonnes)	Company and source of waste	Description of waste	Disposal sites	Quantity deposited (tonnes)
	Collieries			
500,000	Ellington	Minestone	Foreshore at Ellington	187,802

Notes: (1)*No solid industrial wastes were licensed or disposed of in Scotland or Northern Ireland during the period covered by this report*
Tonnages deposited : relate to quantities deposited in the calendar year 1995, which may be covered by two licences, including one issued in 1994

Table 38(b). Summary of colliery wastes licensed for disposal at sea in 1995 and 1996 (1)

Country	Year	Licences issued	Licensed quantity (tonnes)	Wet tonnage deposited	Quantities of metal contaminants in wastes deposited (tonnes)						
					Cd	Cr	Cu	Hg	Ni	Pb	Zn
England and Wales	1992	8	5,080,000	3,418,074	0.18	16	128	0.12	46	154	314
	1993	4	1,800,000	2,205,670	0.14	12	98	0.09	36	117	241
	1994	2	700,000	163,784	0.00	0	0	0.00	0	0	0
	1995	1	500,000	187,802	0.00	0	0	0.00	0	0	0
	1996	0	0	0	0.00	0	0	0.00	0	0	0

Notes: *No solid industrial wastes were licensed or disposed of in Scotland or Northern Ireland in the period covered by this report*
(1) *For information on licensed quantities and tonnages deposited see footnote to Table 38(a)*

Table 39(a). Sewage sludge licensed for disposal at sea in 1995

Country	Licensed quantity (tonnes) [1]	Company and source of waste	Disposal sites	Quantity deposited (tonnes) [1]
England and Wales	80,000	Anglian Water (Cliff Quay STW, Ipswich)	Roughs Tower	80,700
	179,000	Anglian Water (Tilbury STW)	Roughs Tower	149,100
	554,000	Northumbrian Water (Howdon, Chester-le-Street, Cramlington,Washington STWs)	Tyne/Spurn Head	361,145
	105,000	Northumbrian Water (Portrack, Billingham, Guisborough, Ayton STWs)	Tyne/ Spurn Head	68,981
	1,965,000	North West Water (Davyhulme, Liverpool, Warrington STWs)	Liverpool Bay	2,008,742
	5,000	North West Water (Walney Island)	Liverpool Bay	3,925
	300,000	Southern Water (Woolston, Portswood, Millbrook, Slowhill Copse STWs)	Nab Tower	283,972
	58,000	South West Water (Countess Wear STW)	Lyme Bay	43,953
	55,000	South West Water (Plympton, Radford, Camel's Head, Ernesettle, Ivybridge, Saltash STWs)	Plymouth	51,026
	1,400,000	Thames Water (Crossness STW)	Barrow Deep	1,342,155
	3,100,000	Thames Water (Beckton, Riverside and Deephams STWs)	Barrow Deep	3,011,151
	140,000	Yorkshire Water (Knostrop STW)	Spurn Head	120,896
Scotland	500,000	Lothian Regional Council	St Abb's Head/ Bell Rock	343,750
	2,500,000	Strathclyde Regional Council	Garroch Head	1,576,200
Northern Ireland	0	Dept. Environment (Northern Ireland)	Belfast Sludge	285,229 [2]

Notes: [1] *All figures are for tonnage in wet weight*
[2] *Disposed of by DOE (NI) Water Services under an administrative authorisation*
STW = Sewage Treatment Works
For information on licensed quantities and tonnages deposited see footnote to Table 38(a)

Table 39(b). Sewage sludge licensed for disposal at sea in 1996

Country	Licensed quantity (tonnes) [1]	Company and source of waste	Disposal sites	Quantity deposited (tonnes) [1]
England and Wales	74,000	Anglian Water (Cliff Quay STW, Ipswich)	Roughs Tower	66,640
	179,500	Anglian Water (Tilbury STW)	Roughs Tower	200,996
	499,000	Northumbrian Water (Howdon, Chester-le-Street, Cramlington,Washington STWs)	Tyne/Spurn Head	411,997
	105,000	Northumbrian Water (Portrack, Billingham, Guisborough, Ayton STWs)	Tyne/Spurn Head	67,753
	1,965,000	North West Water (Davyhulme, Liverpool, Warrington STWs)	Liverpool Bay	1,934,356
	0	North West Water (Walney Island)	Liverpool Bay	0
	330,000	Southern Water (Woolston, Portswood, Millbrook, Slowhill Copse STWs)	Nab Tower	274,437
	58,000	South West Water (Countess Wear STW)	Lyme Bay	42,613
	55,000	South West Water (Plympton, Radford, Camel's Head, Ernesettle, Ivybridge, Saltash, Newton Ferrers STWs)	Plymouth	52,228
	1,400,000	Thames Water (Crossness STW)	Barrow Deep	1,372,027
	3,600,000	Thames Water (Beckton, Riverside and Deephams STWs)	Barrow Deep	2,963,682
	140,000	Yorkshire Water (Knostrop STW)	Spurn Head	90,729
Scotland	500,000	Lothian Regional Council	St Abb's Head/ Bell Rock	360,065
	2,500,000	Strathclyde Regional Council	Garroch Head	1,697,200
Northern Ireland	60,000	Dept. Environment (Northern Ireland)	Belfast Sludge	375,136 [2]

Notes: [1] *All figures are for tonnage in wet weight*
[2] *329,015 t disposed of by DOE (NI) Water Services under an administrative authorisation*
STW = Sewage Treatment Works
For information on licensed quantities and tonnages deposited see footnote to Table 38(a)

Table 39(c). Summary of sewage sludge licensed and disposed of at sea in 1995 and 1996

Country	Year	Licences issued	Licensed quantity (tonnes)	Wet tonnage deposited	Quantities of metal contaminants in wastes deposited (tonnes)						
					Cd	Cr	Cu	Hg	Ni	Pb	Zn
England and Wales	1992	12	7,985,000	7,739,369	1.70	61	123	0.85	17	93	273
	1993	13	7,884,000	7,733,656	1.09	49	112	0.65	15	74	216
	1994	12	7,911,970	7,474,849	0.94	45	123	0.69	13	81	217
	1995	12	7,941,000	7,525,746	0.89	44	121	0.56	13	83	218
	1996	11	8,405,500	7,477,458	0.66	38	97	0.45	11	70	178
Scotland	1992	2	3,000,000	1,984,525	0.21	30	36	0.10	2	18	40
	1993	2	3,000,000	1,946,340	0.19	18	26	0.07	3	18	35
	1994	2	3,000,000	1,930,510	0.14	27	29	0.10	3	16	42
	1995	2	3,000,000	1,919,950	0.18	25	25	0.08	4	18	52
	1996	2	3,000,000	2,057,265	0.17	25	28	0.11	4	17	84
Northern Ireland	1992	0	0	261,000 $	0.04	2	3	0.02	0	3	10
	1993	0	0	243,200 @	0.04	2	3	0.02	0	3	9
	1994	0	0	251,860 %	0.03	4	4	0.03	1	2	12
	1995	0	0	285,229 *	0.03	6	6	0.02	1	2	23
	1996	1	60,000	375,136 #	0.02	7	5	0.03	1	3	22
UK Total	1992	14	10,985,000	9,984,894 $	1.95	93	163	0.97	19	114	323
	1993	15	10,884,000	9,923,196 @	1.31	69	141	0.75	18	95	260
	1994	15	10,911,970	9,657,219 %	1.10	77	156	0.83	17	99	270
	1995	15	10,941,000	9,730,925 *	1.10	75	152	0.66	18	103	293
	1996	15	11,465,500	9,909,859 #	0.85	71	130	0.59	15	91	285

Notes: *$ Includes 261,000 t disposed of by DOE(NI) Water Services under an administrative authorisation*
@ Includes 243,200 t disposed of by DOE(NI) Water Services under an administrative authorisation
% Includes 251,860 t disposed of by DOE(NI) Water Services under an administrative authorisation
** Includes 285,229 t disposed of by DOE(NI) Water Services under an administrative authorisation*
 # Includes 329,015 t disposed of by DOE(NI) Water Services under an administrative authorisation
For information on licensed quantities and tonnages deposited see footnote to Table 38(a)

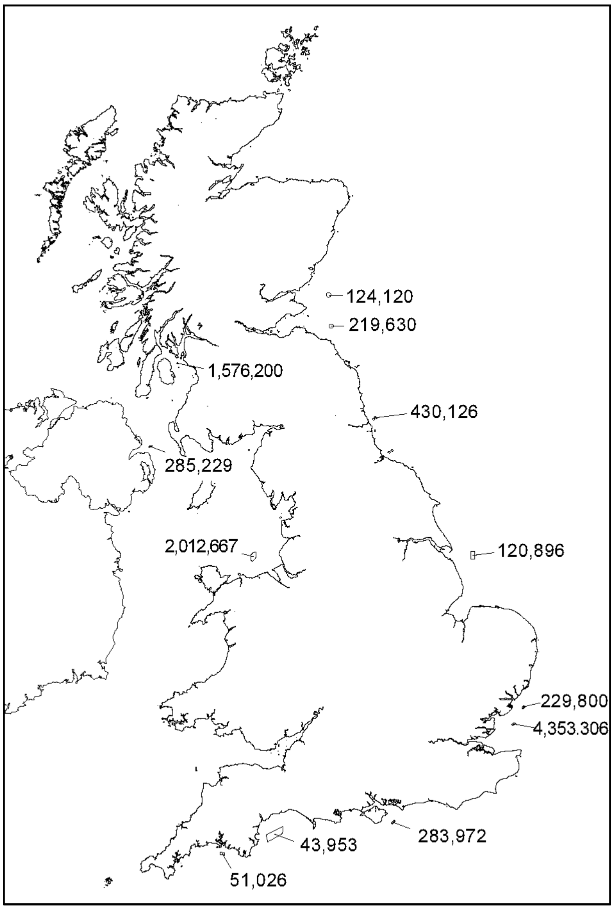


Figure 66. UK sewage-sludge disposal sites and amounts deposited in tonnes for 1995

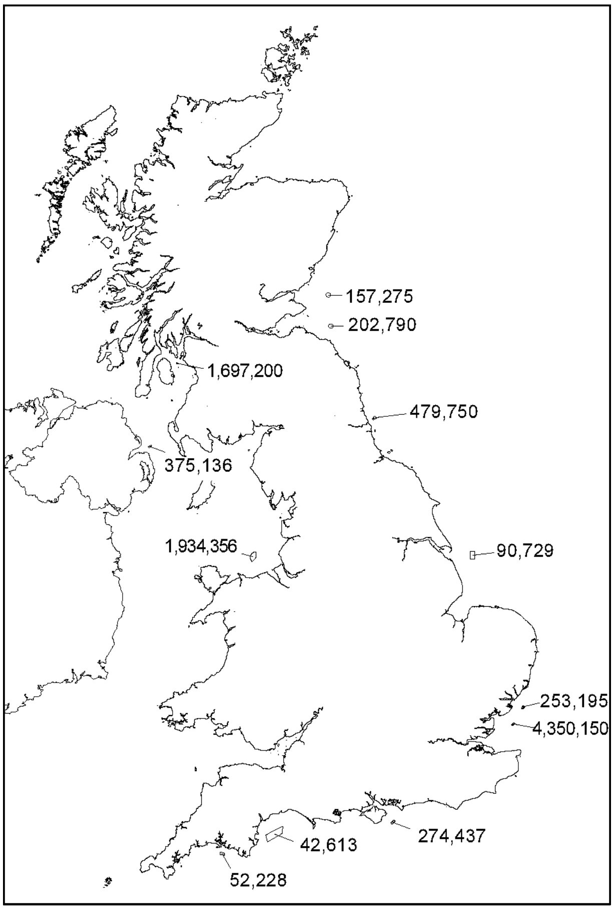


Figure 67. UK sewage-sludge disposal sites and amounts deposited in tonnes for 1996

Table 40. Contaminants in sewage sludge authorised for disposal in the North Sea in 1995 and 1996 compared against estimated quantities (tonnes) in 1987

Year	Cd	Cr	Cu	Hg	Ni	Pb	Zn
1987	3.7	56.2	133.6	1.2	19.4	146.4	468.2
1995	1.1	26.7	116.4	0.7	13.2	90.0	205.1
1996	0.7	20.9	100.4	0.6	10.9	80.2	174.0

21.7 Licensing of dredged material disposal

The bulk of the dredged material licensed for disposal at sea is silt and sand, but coarse sand and shingle can occur in 'maintenance' dredging and shingle, cobbles, rocks and heavy clay can be present in 'capital' material arising, for example from channel development and deepening. Table 41 shows the numbers of licences issued, the quantity licensed, and the quantity deposited, together with figures for the quantity of a range of trace metals which enter the sea in the dredged materials. As noted in previous reports, a proportion of the trace metals in dredged material is natural and occurs within the mineral structure or is otherwise tightly bound, such that it will not be available to marine organisms.

Figures 68 and 69 show the main disposal sites used in 1995 and 1996 and the quantities deposited at each site. However all applicants for licences are now required to show evidence that they have considered alternative disposal options including beneficial uses for dredged material and why such alternatives are not considered practical.

21.8 Licensing of an offshore installation for disposal

SOAEFD licensed an offshore installation - Brent Spar - for sea disposal in 1995. In the event the licensee decided not to dispose of the installation at sea and the licence expired. (see Table 42).

Table 41. Summary of dredged material licensed and disposed of at sea in 1995 and 1996

Country	Year	Licences issued	Licensed quantity (tonnes)	Wet tonnage deposited	Quantities of metal contaminants in wastes deposited (tonnes)						
					Cd	Cr	Cu	Hg	Ni	Pb	Zn
England and Wales	1992	123	55,741,813	24,243,998	6.0	812	512	4.2	291	876	2,271
	1993	110	66,074,966	26,086,503	7.3	875	606	5.2	458	1,004	2,461
	1994	106	53,187,009	34,049,468	8.0	1,295	734	5.9	587	1,375	3,375
	1995	109	54,300,948	35,215,761	5.8	1,298	625	5.2	548	1,380	3,161
	1996	120	82,395,490	48,516,353	8.8	1,556	744	6.9	673	1,731	3,991
Scotland	1992	35	5,920,005	3,841,296	0.9	108	82	1.7	39	111	245
	1993	26	3,174,050	2,025,525	2.4	50	44	0.8	21	63	132
	1994	23	3,643,250	1,822,053	0.9	42	36	0.5	20	56	122
	1995	32	6,186,600	4,782,421	1.1	155	120	3.5	66	153	349
	1996	30	3,971,045	2,601,864	0.4	56	89	0.7	26	81	155
Northern Ireland	1992	7	2,956,601	891,087	0.3	2	3	0.2	2	3	10
	1993	7	996,500	3,392,994	1.8	11	26	1.1	13	23	70
	1994	5	113,200	91,314	0.0	0	0	0.0	0	0	1
	1995	9	335,280	249,593	0.2	2	1	0.1	2	2	8
	1996	6	166,000	135,550	0.0	2	2	0.0	3	2	4
UK Total	1992	165	64,618,419	28,976,381	7.2	923	597	6.1	332	990	2,527
	1993	143	70,245,516	31,505,022	11.5	937	676	7.1	491	1,090	2,663
	1994	134	56,943,459	35,962,835	8.9	1,338	770	6.4	608	1,432	3,498
	1995	150	60,822,828	40,247,775	7.2	1,455	746	8.7	616	1,535	3,518
	1996	156	86,532,535	51,253,767	9.2	1,613	835	7.6	702	1,814	4,149

Notes: For information on licensed quantities and tonnages deposited see footnote to Table 38(a)

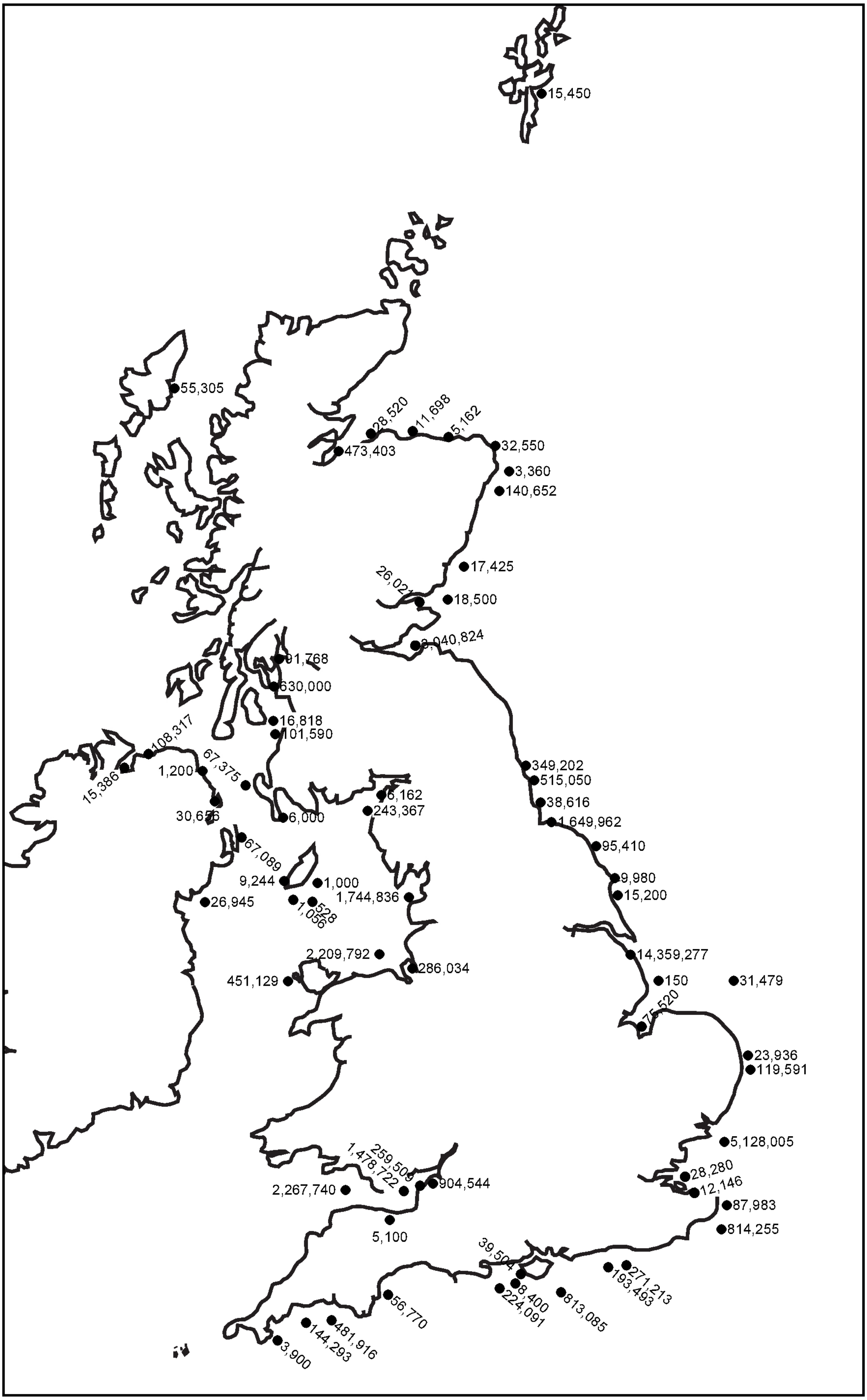


Figure 68. UK dredged material disposal sites and amounts deposited in tonnes for 1995

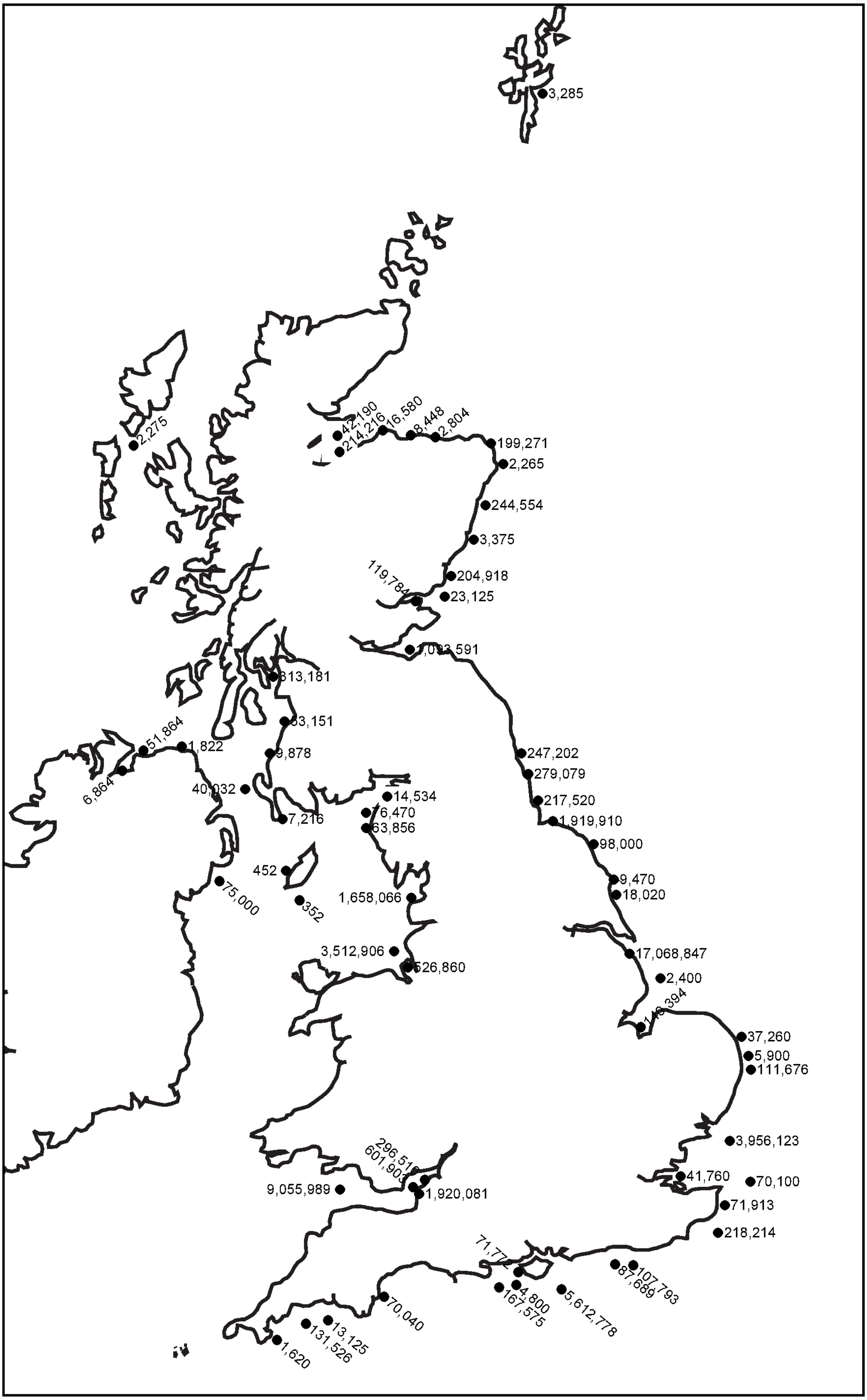


Figure 69. UK dredged material disposal sites and amounts deposited in tonnes for 1996

Table 42. Offshore structure licensed for disposal at sea in 1995

Country	Licensed quantity (tonnes) (1)	Company and source of waste	Disposal sites	Quantity deposited (tonnes) (1)
Scotland	14,500	Shell UK Exploration & Production - Brent Field	North Feni Ridge	0

Notes: Tonnage is dry weight
This licence was not used
For information on licensed quantities and tonnages deposited see footnote to Table 38(a)

21.9 Other materials deposited at sea

Under Part II of FEPA, licences are also required for certain activities other than for the disposal of wastes, but nevertheless involving the deliberate deposit of articles or substances in the sea below the mean high water spring tide mark. The majority of such cases relate to construction works and coastal defence schemes (including beach nourishment) . Each licence application is carefully considered, in particular, to assess the impact upon tidal and intertidal habitat the hydrological effects and potential interference to other users of the sea.

The UK has also licensed the sea disposal of small quantities of fish waste since 1996. These are included in Table 43.

Further activities involved the use of tracers, the application of biocides and burials at sea. Generally, the anticipated environmental impact from deposit of these substances is minimal and little or no monitoring is required. Table 44 shows the numbers of such licences issued in 1995 and 1996.

22. ADVICE ON FISHERY IMPLICATIONS OF PIPELINE DISCHARGES

This section gives a brief summary of activities carried out during 1995 and 1996 in connection with the provision of advice on fishery implications of pipeline discharges. The background to this work in relation to MAFF's responsibilities as a statutory consultee under the Water Resources Act, 1991 (Great Britain - Parliament, 1991) and the Environmental Protection Act 1990 (Great Britain - Parliament, 1990) was described in previous reports in this series (MAFF, 1991, 1992, 1993, 1994 and 1995(a) and CEFAS, 1997).

A total of 202 applications were sent to CEFAS for comment during 1995 and 200 in 1996. As in previous years, the majority of these were for sewage effluent or storm sewage overflows, of which the main risk to fisheries is contamination of bivalve shellfish. As noted in the previous report in this series (CEFAS, 1997), Water Companies are under no statutory obligation to design or modify a sewage disposal scheme for the sole

Table 43. Fish waste licensed for disposal at sea in 1996 (1)

Country	Licensed quantity (tonnes) (1)	Company and source of waste	Disposal sites	Quantity deposited (tonnes) (1)
England and Wales	750	Quay Fresh & Frozen Foods Ltd, New Quay	New Quay	16

Notes: (1) No Fish Wastes were licensed or disposed of in Scotland or Northern Ireland during the period covered by this report
(2) All figures are for tonnage in wet weight

Table 44. Other categories of licences issued in 1995 and 1996

Licence category	Year	England and Wales	Scotland	Northern Ireland	Total
Construction - new and renewal	1995	270	78	6	354
	1996	297	76	4	377
Tracers, biocides etc.	1995	20	2	0	22
	1996	26	0	0	26
Burial at Sea	1995	9	0	0	9
	1996	15	0	0	15

purpose of reducing contamination of shellfish by sewage micro-organisms. However, many of the shellfish beds in England and Wales are in areas for which major re-sewerage schemes are required in order to meet other commitments such as EC Directive 76/160 concerning the quality of bathing water (European Communities, 1976) and EC Directive 91/271 concerning urban waste water treatment (European Communities, 1991).

Although these commitments generally require improved levels of sewage treatment, these do not automatically benefit shellfisheries. For instance, in order to comply with bathing water standards, a Water Company may decide to treat the sewage by UV disinfection during the bathing season. However, the main harvesting season for shellfish is during the winter months so protection of shellfisheries may require UV treatment to be provided all year round. MAFF continues to need to use its role as statutory consultee to try and negotiate the best possible deal for shellfisheries in the design of such schemes.

Even when improvements to the main sewage discharge to an area are adequate to protect shellfisheries there may remain a risk of contamination from storm overflows. These overflows, which are required to minimise the risk of flooding, allow untreated sewage to by-pass the treatment works during times of heavy rainfall. For overflows which impact on Designated bathing waters, there is a statutory requirement to restrict overflow operation to a maximum of three spills per bathing season. However, there is no such requirement for shellfish waters so MAFF has needed to negotiate conditions for each outfall on a case by case basis. The aim has been to get overflows sited in a location where their operation will not impact on the shellfish water or, if that is not possible, to ensure that the spill frequency is as low as possible.

Discharges of domestic sewage to coastal waters pose few problems for species other than bivalve shellfish, unless they contain persistent plastics or other material which could foul fishing gear. These are being gradually reduced as all major discharges are upgraded in order to comply with the requirements of Directive 91/271 concerning urban waste water treatment (European Communities, 1991).

As noted in the previous report in this series (CEFAS, 1997) trade effluent discharges from the most potentially polluting or technologically complex industrial processes in England and Wales have, since 1 April 1991, been subject to Integrated Pollution Control (IPC) under Part I of the Environmental Protection Act 1990 (Great Britain - Parliament, 1990). New processes came under immediate control, with controls on existing processes being phased in between 1 April 1991 and 31 January 1996. The statutory consultation with MAFF for such processes is lead by Food Contaminants Division. However, all applications for new processes which include a discharge to tidal water, plus any existing processes identified as being of potential high risk to fisheries are sent to the Burnham Laboratory for assessment of fishery implications in the same way as those covered under the Water Resources Act. Four applications for new processes were received during 1995, and two during 1996, none of which posed a particular risk to fisheries.

In 1996, the final part of the phased assessment of existing processes required coating manufacturing industries to apply for authorisation under IPC. This included processes involving tributyl tin (TBT) removal and re-application, mainly at dockyards. A total of 25 such applications were received for assessment. Many of these were in areas which were sampled in connection with sea disposal licence applications under the Food and Environment Protection Act 1986 (Great Britain - Parliament, 1985(a)). Some of these indicated that levels of TBT, and in some cases other contaminants such as copper, were highly elevated in sediments adjacent to the process. This information was passed on to the Environment Agency so that they could take it into account in formulating conditions for the IPC authorisation. All of these processes were subsequently issued with interim authorisations which require them to achieve Best Practicable Environmental Option (BPEO) by October 1998. This will significantly reduce emissions to water, leaving historically contaminated sediments as the only remaining source of major TBT contamination. In July 1996, the first of a series of meetings between MAFF and the Environment Agency explored ways of dealing with this problem.

All applications, consents and authorisations continue to be entered onto a computerised database and Geographic Information System (GIS) which now contains details of over 8500 current discharges to saline water in England and Wales. This database has been used to provide information for the JNCC coastal directories and will appear in electronic form in the next version of UKDMAP. In July 1996 a paper presented at an Association of Geographic Information (AGI) seminar on Managing the UK Marine and Coastal Zone Environment (Franklin and Hull 1996) showed how the Burnham Laboratory is using developing Geographic Information Systems to integrate information and advice about various activities in the marine and coastal zone. GIS is proving to be an increasingly useful management tool for integrating information on human activities in the marine and coastal zone, such as the link between TBT inputs and contamination of dredged material described above.

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23. REFERENCES

AGUILAR, A., BORRELL, A. AND PASTOR, T. in press. Factors affecting variability of persistent pollutant levels in cetaceans. International Whaling Commission Special Issues.

ALEXANDER, W. B., SOUTHGATE, B. A. AND BASSINDALE, R., 1935. Survey of the River Tees. Part II. The estuary chemical and biological. Technical paper on water pollution research No.5. Her Majesty's Stationery Office, London, 1-71.

ALZIEU, C., 1991. Environmental problems caused by TBT in France: assessment, regulation, prospects. Mar. Environ. Res., ***32***, 7-17.

AMINOT, A. AND KIRKWOOD, D. S., 1994. The 1993 QUASIMEME laboratory performance study: nutrients in sea water and standard solutions. Marine Pollution Bulletin, ***29***: 159-165.

BACKHAUS, J. O., 1984. Estimates of the variability of low frequency currents and flushing times of the North Sea. ICES C:24.

BECKER, P. R., MACKEY, E. A., DEMIRALP, R., SUYDAM, R., EARLY, G., KOSTER, B. J. AND WISE, S. A., 1995. Relationship of silver with selenium and mercury in the liver of two species of toothed whales (odontocetes). Mar. Pollut. Bull. ***30***: 262-271.

BENING, J. C., KARBE, L. AND SCHUPFER, G., 1992. Liquid/solid phase extraction of water samples used for toxicity testing in the German Bight. Mar. Ecol. Prog. Ser. ***91***: 233-236.

BRAY, J. R. AND CURTIS, J. T., 1957. An ordination of the upland forest communities of Southern Wisconsin. Ecol. Monogr., ***27***: 325-349.

BRYAN, G. W., GIBBS, P. E., BURT, G. R. AND HUMMERSTONE, L. G., 1987. The effects of tributyltin (TBT) accumulation on adult dog whelks, *Nucella lapillus* : long-term field and laboratory experiments. J. Mar. Biol. Ass. UK, ***67***: 525-544.

BUCHANAN, J. B., SHEADER, M. AND KINGSTON, P. F., 1978. Sources of variability in the benthic macrofauna off the south Northumberland coast, 1971-1976. J. Mar. Biol. Ass. UK, ***58***:191-209.

BUCKE, D., 1989. Observations on visceral granulomatosis and dermal necrosis in populations of North Sea cod (*Gadus morhua*). ICES CM 1989/E:17, 9pp. (mimeo).

BUCKE, D., 1994. Methodologies for demonstrating pathological changes in flounder (*Platichthys flesus* (L.)). pp 131-143, *In*: Diseases and parasites of flounder in the Baltic sea. The Baltic Marine Biologists Publication No. 15.

BUCKE, D. AND FEIST, S. W., 1990. Marine fish diseases: an overview of 10 year's investigations by MAFF (UK). ICES CM 1990/E:12, 16pp. (mimeo).

BUCKE, D. and FEIST, S. W., 1993. Histological changes in the livers of dab, *Limanda limanda* (L.). J. Fish Dis., ***16***: 281-296.

CABIOCH, L., 1968. Contribution a la connaissance des peuplements benthiques de la Manche occidentale. Cah. Biol. Mar., ***9*** (suppl.): 493-720.

CADEE, G. C., BOON, J. P., FISCHER, C. V., MENSINK, B. P. AND TEN HALLERS-TJABBES, C. C., 1995. Why the whelk (*Buccinum undatum*) has become extinct in the Dutch Wadden Sea. Neth. J. Sea Res., ***34***: 337-339.

CEFAS, 1997. Monitoring and surveillance of non-radioactive contaminants in the aquatic environment and activities regulating the disposal of wastes at sea, 1994. Sci. Ser., Aquat. Environ. Monit. Rep., CEFAS, Lowestoft, ***47***: 59pp.

CLARKE, K. R. AND AINSWORTH, M., 1993. A method of linking multivariate community structure to environmental variables. Mar. Ecol. Prog. Ser., ***92***: 205-219.

CLARKE, K. R. AND WARWICK, R. M., 1994. Similarity-based testing for community pattern: the 2-way layout with no replication. Mar. Biol., ***118***: 167-176.

COOREMAN, K., ROOSE, P. AND VYNCKE, W., 1993. EROD monitoring in dab from the Belgian Continental shelf. International Council for the Exploration of the Sea, Copenhagen, Annual Science Conference report C.M. 1993/E:14.

COQUERY, M. AND COSSA, D., 1995. Mercury speciation in surface waters of the North Sea. Neth. J. Sea Res., ***34***: 245-257.

Cossa, D. and Fileman, C., 1991. Mercury concentrations in surface waters of the English Channel: A cooperative study. Mar. Pollut. Bull. ***22***: 197-200.

Cossa, D., Sanjuan, J. and Noel, J., 1994. Mercury transport in waters of the Strait of Dover. Mar. Pollut. Bull., ***28***: 385-388.

Dawes, V. J. and Waldock, M. J., 1994. The measurement of volatile organic compounds at UK National Monitoring Stations. Mar. Pollut. Bull., ***28***(5): 291-298.

Department of the Environment, 1987. 'Second International Conference on the Protection of the North Sea, London, November 1987. Ministerial Declaration'. DOE, London, unpaginated.

Department of the Environment, 1991. The Principles and Practice of Monitoring in UK Coastal waters. A Report from the Marine Pollution Management Group. 32pp.

Dietz, R., Heide-Jørgensen, M.-P. and Härkönen, T., 1989. Mass deaths of harbor seals (*Phoca vitulina*) in Europe. Ambio, ***18***: 258-264.

Dufault, S. and Whitehead, H., 1995. An encounter with recently wounded sperm whales (*Physeter macrocephalus*). Mar. Mamm. Sci., ***11***: 560-563.

Eggens, M., Bergman, A., Vethaak, D., van der Weiden, M., Celander, M. and Boon, J. P., 1995. Cytochrome P4501A indices as biomarkers of contaminant exposure: results of a field study with plaice (*Pleuronectes platessa*) and flounder (*Platichthys flesus*) from the southern North Sea. Aquat. Toxicol., ***32***: 211-225.

Eleftheriou, A. and Basford, D. J., 1989. The macrobenthic infauna of the offshore northern North Sea. J. Mar. Biol. Ass. UK, ***69***: 123-143.

Ellis, R., 1982. Dolphins and Porpoises. Robert Hale, London. 270pp.

European Communities, 1976. Council Directive 76/160/EEC of 8 December1975 concerning the quality of bathing water. Off. J. Eur. Commun., ***L31*** (1976): 1-7.

European Communities, 1991 (a). Council Directive 91/271/EEC of 21 May 1991 concerning urban waste water treatment. Off. J. Eur. Commun., ***L135*** (1991):40-45.

Evans, P. G. H., 1987. The Natural History of Whales and Dolphins. Christopher Helm Ltd., Bromley, England, 343pp.

Evans, P. G. H., 1992. Status Review of Cetaceans in British and Irish Waters. UK Mammal Cetacean Society, Oxford, 94pp.

Fileman, C., 1987. Preliminary studies of the distribution of mercury in sea water in the vicinity of the Humber, Tees and Tyne Estuaries. ICES CM 1987/E16, 7pp.

Fileman, C. F., Althaus, M., Law, R. J. and Haslam, I., 1991. Dissolved and particulate trace metals in surface waters over the Dogger Bank, Central North Sea. Mar. Pollut. Bull., ***22***: 241-244.

Franklin, F. L. and Hull, S L., 1996. Development of a PC-based GIS for Marine Environmental Impact Assessment. Paper presented to AGI Marine and Coastal Zone Management SIG seminar on Managing the UK Marine & Coastal Zone Environment, Manchester, 24 July 1996.

George, C. L. and Warwick, R. M., 1985. Annual production in a hard-bottom reef community. J. Mar. Biol. Ass. UK, ***65***: 713-735.

Gray, J. S., 1976. The fauna of the polluted River Tees Estuary. Estuar. Coast. Mar. Sci., ***4***: 653-676.

Gray, J. S., 1979. Pollution induced changes in populations. Phil. Trans. R. Soc. B, ***286***: 545-561.

Great Britain - Parliament, 1972(a). Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft, Oslo, 15 February 1972. Her Majesty's Stationery Office, London, 12pp (Cmnd 4984).

Great Britain - Parliament, 1972(b). Final Act of the Intergovernmental Conference on the Convention on the Dumping of Wastes at Sea, London, 13 November 1972. Her Majesty's Stationery Office, London, 200pp (Cmnd 5169).

Great Britain - Parliament, 1985(a). Food and Environment Protection Act, 1985. Chapter 48. Her Majesty's Stationery Office, London, 38pp.

Great Britain - Parliament, 1985(b). Marine Pollution. The Deposits in the Sea (Exemptions) Order, 1985. Her Majesty's Stationery Office, london, (Statutory Instrument, 1985, No. 1699).

Great Britain - Parliament, 1990. The Environmental Protection Act, 1990.
Chapter 43. Her Majesty's Stationery Office, London, 235 pp.

Great Britain - Parliament, 1991. Water Resources Act, 1991. Chapter 57. Her Majesty's Stationery Office, London, 259pp.

HALL, A. J., LAW, R. J., WELLS, D. E., HARWOOD, J., ROSS, H. M., KENNEDY, S., ALLCHIN, C. R., CAMPBELL, L. A. AND POMEROY, P. P., 1992. Organochlorine levels in common seals (*Phoca vitulina*) which were victims and survivors of the 1988 phocine distemper epizootic. Sci. Total Environ., ***115***, 145-162.

HAMILTON, R., 1835. *Mammalia. Whales and c.* pp. 228-232, *In:* W. Jardine (ed.). The Naturalist's Library. Volume 26,

HARPER, D. J., FILEMAN, C. F., MAY, P. V. AND PORTMANN, J. E., 1989. Methods of analysis for trace metals in marine and other samples. Aquat. Environ. Prot.: Analyt. Meth. MAFF Direct. Fish. Res., Lowestoft, ***3***: 1-38.

HARTLEY, J. P., 1979. On the offshore mollusca of the Celtic Sea. J. Conch., ***30***: 81-92.

HEIDE-JØRGENSEN, M.-P., HÄRKÖNEN, T., DIETZ, R. AND THOMPSON, P. M., 1992. Retrospective of the 1988 European seal epizootic. Dis. aquat. Org., ***13***, 37-62.

HENSLEY, R. H., 1996. Preliminary survey of benthos from the *Nephrops norvegicus* mud grounds in the north-western Irish Sea. Est. Cstl Shelf Sci., ***42***: 457-465.

HERMAN, J. S., KITCHENER, A. C., BAKER, J. R. AND LOCKYER, C., 1994. The most northerly record on Blainville's beaked whale, *Mesoplodon densirostris*, from the eastern Atlantic. Mammalia ***58***, 657-661.

HOLME, N. A., 1961. The bottom fauna of the English Channel. J. Mar. Biol. Ass. UK, ***41***: 397-461.

HOLME, N. A., 1966. The bottom fauna of the English Channel. Part II. J. Mar. Biol. Ass. UK, ***46***: 401-493.

HOLME, N. A. AND MCINTYRE, A. D., 1984. Methods for the study of marine benthos. 2nd Edition. Blackwell, Oxford. 387pp.

HOWSON, C. M. (Ed.), 1987. Species directory of British marine fauna and flora. Ross-on-Wye: Marine Conservation Society, 471pp.

HUTCHINSON, T. H. AND WILLIAMS, T. D., 1989. The use of sheepshead minnow (*Cyprinodon variegatus*) and benthic copepods (*Tisbe battagliai*) in short-term tests for estimating the chronic toxicity of industrial effluents. Hydrobiologia ***188/189***: 567:572.

ICES, 1989. Methodology of fish disease surveys. Co-op. Res. Rep. Int. Coun. Explor. Sea., ***166***: 1-43.

ICES, 1996. Common diseases and parasites of fish in the North Atlantic: Training guide for identification. ICES Techniques in Marine Environmental Sciences. No. 19. 27pp.

IWATA, H., TANABE, S., MIYAZAKI, N. AND TATSUKAWA, R., 1994. Detection of butyltin compound residues in the blubber of marine mammals. Mar. Pollut. Bull., ***28***, 607-612.

IWATA, H., TANABE, S., MIZUNO, T. and TATSUKAWA, R., 1995. High accumulation of toxic butyltins in marine mammals from Japanese coastal waters. Environ. Sci. Technol., ***29***, 2959-2962.

JACOB, J., 1995. Method development for the determination of polycyclic aromatic hydrocarbons (PAHs) in environmental matrices. pp , *In*: P. Quevauviller, E. Maier and B Griepink (Eds.). Quality Assurance for Environmental Analysis - Method Evaluation within the Measurements and Testing Programme (BCR). Elsevier Science B. V.

JENSEN, P., 1982. A new meiofauna sample splitter. Ann. Zool. Fenn., ***19***: 233-236.

KANNAN, K. AND FALANDYSZ, J., 1997. Butyltin residues in sediment, fish, fish-eating birds, harbour porpoise and human tissues from the Polish coast of the Baltic Sea. Mar. Pollut. Bull., ***34***: 203-207.

KANNAN, K., CORSOLINI, S., FOCARDI, S., TANABE, S. and TATSUKAWA, R., 1996. Accumulation pattern of butyltin compounds in dolphin, tuna, and shark collected from Italian coastal waters. Arch. Environ. Contam. Toxicol., ***31***: 19-23.

KANNAN, K., SENTHILKUMAR, K., LOGANATHAN, B. G., TAKAHASHI, S., ODELL, D. K. AND TANABE, S., 1997. Elevated accumulation of tributyltin and its breakdown products in bottlenose dolphins (*Tursiops truncatus*) found stranded along the U.S. Atlantic and Gulf coasts. Environ. Sci. Technol., ***31***: 296-301.

KENDALL, M. A., 1979. The stability of the deposit feeding community of a mud flat in the River Tees. Estuar. Coast. Mar. Sci., ***8***: 15-22.

KENNY, A. J., REES, H. L. AND LEES, R. G., 1991. An inter-regional comparison of gravel assemblages off the English east and south coasts: preliminary results. ICES CM 1991/E:27, 15pp (mimeo).

KERSTEN, M. AND KRONCKE, I., 1991. Bioavailability of lead in North Sea sediments. Helgolander Meeresunters., ***45***: 403-409.

KIM, G. B., LEE, J. S., TANABE, S., IWATA, H., TATSUKAWA, R. AND SHIMAZAKI, K., 1996. Specific accumulation and distribution of butyltin compounds in various organs and tissues of the Steller sea lion (*Eumetopias jubatus*): comparison with organo-chlorine accumulation pattern. Mar. Pollut. Bull., ***32***: 558-563.

KIRBY, M. F., BLACKBURN, M. A., THAIN, J. E. AND WALDOCK, M. J. (in prep). Assessment of water quality in estuarine and coastal waters of England and Wales using a contaminant concentration technique. Mar. Pollut. Bull.

KIRBY, M., NEALL, P. AND TYLOR, T., 1996. EROD levels measured in flatfish from the area of the *SEA EMPRESS* oil spill. Unpublished report to the *SEA EMPRESS* Environmental Evaluation Committee (SEEEC), CEFAS Burnham, November 1996, 16 pp. + tables and figures.

KIRKWOOD, D. S., 1996. Nutrients: Practical notes on their determination in sea water. ICES Techniques in Marine Environmental Sciences. ('TIMES' Series) No. 17, 25pp.

KIRKWOOD, D. S., AMINOT, A. AND CARLBERG, S. R., (IN PRESS). The 1994 QUASIMEME laboratory performance study: nutrients in sea water. Mar. Pollut. Bull.

KUIKEN, T., SIMPSON, V. R., ALLCHIN, C. R., BENNETT, P. M., CODD, G. A., HARRIS, E. A., HOWES, G. J., KENNEDY, S., KIRKWOOD, J. K., LAW, R. J., MERRETT, N. R. AND PHILLIPS, S., 1994. Mass mortality of common dolphins (*Delphinus delphis*) in south-west England due to incidental capture in fishing gear. Vet. Rec., ***134***: 81-89.

KUNITZER, A., BASFORD, D., CRAEYMEERSCH, J. A., DEWARUMEZ, J. M., DORJES, J., DUINEVELD, G. C. A., ELEFTHERIOU, A., HEIP, C., HERMAN, P., KINGSTON, P., NIERMANN, U., RACHOR, E., RUMOHR, H. AND DE WILDE, P. A. J., 1992. The benthic infauna of the North Sea: species distribution and assemblages. ICES J. Mar. Sci., ***49***: 127-143.

LANCE, G. N. AND WILLIAMS, W. T., 1967. A general theory of classificatory sorting strategies. Comput. J., ***9***: 373-380.

LANGE, U., SABOROWSKI, R., KARBE, L. AND SIEBERS, D., 1995. Towards application of EROD activity in dab (*Limanda limanda*) in biological effect monitoring of the North Sea: a model for the prediction of the basal EROD activity levels. International Council for the Exploration of the Sea, Copenhagen, Annual Science Conference report C.M. 1995/E:7.

LASLETT, R. E., 1995. Concentrations of dissolved and suspended particulate Cd, Cu, Mn, Ni, Pb and Zn in surface waters around the coasts of England and Wales and in adjacent seas. Est. Coast. Shelf Sci., ***40***: 67-85.

LAUGHLIN, R. B. JR. AND LINDÉN, O., 1987. Tributyltin - contemporary environmental issues. Ambio, ***16***: 252-256.

LAW, R. J., 1996. Metals in marine mammals. pp 357-376, *In*: (N. Beyer, G. Heinz and A.W. Redmon-Norwood, (eds.)). Interpreting Environmental Contaminants in Wildlife Tissues. Lewis Publishers, Inc., Chelsea, Michigan.

LAW, R. J. AND BISCAYA, J. L., 1994. Polycyclic aromatic hydrocarbons (PAH) - Problems and progress in sampling, analysis and interpretation. Mar. Pollut. Bull., ***29***: 235-241.

LAW , R. J., FILEMAN, T. W. AND PORTMANN, J. E., 1988. Methods of analysis of hydrocarbons in marine and other samples. Aquat. Environ. Prot.: Analyt. Meth., MAFF Direct. Fish. Res., Lowestoft, (*2*): 25pp.

LAW, R. J., FILEMAN, T. W. AND MATTHIESSEN, P., 1991(a). Phthalate esters and other industrial organic chemicals in the North and Irish Sea. Wat. Sci. Technol., ***24***(10): 593-597.

LAW, R. J., DAWES, V. J. , WOODHEAD, R. J. AND MATTHIESSEN, P., 1997(a)). Polycyclic aromatic hydrocarbons (PAH) in sea water around England and Wales. Mar. Pollut. Bull., ***34***: 306-322.

LAW, R. J., KELLY, C. A., GRAHAM, K. L., WOODHEAD, R. J., DYRYNDA, P. E. J. AND DYRYNDA, E. A., 1997(b)). Hydrocarbons and PAH in fish and shellfish from southwest Wales following the *Sea Empress* oilspill in 1996. Proceedings of the 1997 International Oil Spill Conference, Fort Lauderdale, Florida, 7 - 10 April 1997. American Petroleum Institute, Washington DC. Publication no. 4651. ISSN 75-4161. pp. 205-211.

LAW, R. J., ALLCHIN, C. R., JONES, B. R., JEPSON, P. D., BAKER, J. R. AND SPURRIER, C. J. H., 1997(c). Metals and organochlorines in tissues of a Blainville's beaked whale (*Mesoplodon densirostris*) and a killer whale*(Orcinus orca)* stranded in the UK. Mar. Pollut. Bull., ***34***, 208-212.

LAW, R. J., BLAKE, S. J., JONES, B. R. AND ROGAN, E., (IN PRESS (A)). Organotin compounds in liver tissue of harbour porpoises (*Phocoena phocoena*) and grey seals (*Halichoerus grypus*) from the coastal waters of England and Wales. Mar. Pollut. Bull.

LAW, R. J., MORRIS, R. J., ALLCHIN, C. R. AND JONES, B. R., (IN PRESS (B)). Metals and organochlorines in tissues of sperm whales (*Physeter macrocephalus*) and other cetacean species exploiting similar diets. Proceedings of the Sperm Whale Symposium, Koksijde, Belgium. 16-17 November 1995.

LEE, A. J. and RAMSTER, J. W., EDS., 1981. Atlas of the seas around the British Isles. London : Ministry of Agriculture, Fisheries and Food, 5pp; 75 sheets.

LEES, R. G., KENNY, A. J. AND REES, H. L., 1993. Studies on the effects of aggregate extraction. Aquat. Environ. Monit. Rep., MAFF Direct. Fish. Res., Lowestoft, ***36***: 46-49.

LEES, R. G., REES, H. L., LAMBERT, M. A., ROWLATT, S. M. AND LIMPENNY, D. S., 1990. Benthic studies in relation to dredging activity off the Isle of Wight, Southern England. ICES C. M. 1990/E:15, 9pp (mimeo).

LUKASEWYCZ, M. T. AND DURHAN, E. J., 1992. Strategies for the identification of non-polar toxicants in aqueous environmental samples using toxicity based fractionation and gas chromatography-mass spectrometry. J.Chromatog., ***580***: 215-228.

MAFF, 1991. Monitoring and surveillance of non-radioactive contaminants in the aquatic environment and activities regulating the disposal of wastes at sea, 1988-89. Aquat. Environ. Monit. Rep., MAFF Direct. Fish. Res., Lowestoft, ***26***: 90pp.

MAFF, 1992. Monitoring and surveillance of non-radioactive contaminants in the aquatic environment and activities regulating the disposal of wastes at sea, 1990. Aquat. Environ. Monit. Rep., MAFF Direct. Fish. Res., Lowestoft, ***30***: 66pp.

MAFF, 1993. Monitoring and surveillance of non-radioactive contaminants in the aquatic environment and activities regulating the disposal of wastes at sea, 1991. Aquat. Environ. Monit. Rep., MAFF Direct. Fish. Res., Lowestoft, *36*: 78pp.

MAFF, 1994. Monitoring and surveillance of non-radioactive contaminants in the aquatic environment and activities regulating the disposal of wastes at sea, 1992. Aquat. Environ. Monit. Rep., MAFF Direct. Fish. Res., Lowestoft, ***40***: 80pp.

MAFF, 1995. Monitoring and surveillance of non-radioactive contaminants in the aquatic environment and activities regulating the disposal of wastes at sea, 1993. Aquat. Environ. Monit. Rep., MAFF Direct. Fish. Res., Lowestoft, ***44***: 68pp.

MACKIE, A. S. Y., OLIVER, P. G. AND REES, E. I. S., 1995. Benthic biodiversity in the southern Irish Sea. Studies in Marine Biodiversity and Systematics from the National Museum of Wales. BIOMOR Reports, ***1***: 263pp.

MALINS, D. C., MCCAIN, B. B., LANDAHL, J. T., MYERS, M. S., KRAHN, M. M., BROWN, D. W., CHAN, S.-L. AND ROUBAL, W. T., 1988. Neoplastic and other diseases in fish in relation to toxic chemicals: an overview. Aquat. Toxicol., ***11***: 43-67.

MARTIN, A. R., 1990. Whales and Dolphins. Salamander Books Ltd., London.

MASON, R. P. AND FITZGERALD, W. F., 1990. Alkylmercury species in the equatorial Pacific. Nature (Lond.), ***347***: 457-459.

MATTHIESSEN, P., BIFIELD, S., JARRETT, F., KIRBY, M. F., LAW, R. J., MCMINN, W. R., SHEAHAN, D. A., THAIN, J. E. AND WHALE, G. F., 1998. An assessment of sediment toxicity in the River Tyne Estuary, UK by means of bioassays. Mar. Environ. Res., Vol. 45, No: 1, pp1-15.

MATTHIESSEN, P., THAIN, J. E., LAW, R. J. AND FILEMAN, T.W., 1993. Attempts to assess the environmental hazard posed by complex mixtures of organic chemicals in UK estuaries. Mar. Pollut. Bull., ***26***: 90-95.

MEAD, J. G., 1989. Beaked whales of the genus *Mesoplodon*. pp 349-430, *In*: (S.H. Ridgway and R. Harrison, (eds.)). Handbook of Marine Mammals. Volume 4. River Dolphins and the Larger Toothed Whales. Academic Press, London.

MEADOR, J. P., STEIN, J. E., REICHERT, W. L. AND VARANASI, U., 1995. Bioaccumulation of polycyclic aromatic hydrocarbons by marine organisms. Rev. Environ. Contam. Toxicol., ***143***: 79-165.

MONTEIRO, L. R., COSTA, V., FURNESS, R. W. AND SANTOS, R. S., 1996. Mercury concentrations in prey fish indicate enhanced bioaccumulation in mesopelagic environments. Mar. Ecol. Prog. Ser., ***141***: 21-25.

MORISHITA, S., 1993. Type analysis of aromatics in marine diesel fuel through their refractive index. Suisan Daigakko Kenkya Hokaku, ***41***(2): 43-50.

MPMMG, 1994. Marine Pollution Monitoring Management Group. Monitoring Co-ordination Sub-group. UK National Monitoring Plan. Her Majesty's Inspectorate of Pollution (HMIP), London, 39pp.

MPMMG, 1996. Monitoring and assessment of the marine benthos at U.K. dredged material disposal sites. Scottish Fisheries Information Pamphlet, ***21***: 1-35.

NSTF, 1990. North Sea Task Force Monitoring Master Plan. North Sea Environment Report No. 3. North Sea Task Force/Oslo and Paris Commissions/ICES: London, 37 pp.

NSTF, 1993. North Sea Quality Status Report 1993, Oslo and Paris Commissions. Olsen and Olsen, Fredensborg, Denmark, 132 + vi pp.

ONO, M., KANNAN, N, WAKIMOTO, T. AND TATSUKAWA, R., 1987. Dibenzofurans a greater global pollutant than dioxins ? Mar. Pollut. Bull. ***18***, 640-643.

PEARSON, T. H., AND ROSENBERG, R., 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr. Mar. Biol. Annu. Rev., ***16***: 229-311.

PIELOU, E. C., 1966. Species-diversity and pattern diversity in the study of ecological succession. J. Theoret. Biol., ***10***: 370-383.

REES, E. I. S., 1987. Benthos. *pp* 29-31, *In*: (Dickson, R. R., (ed.)). Irish Sea Status Report of the Marine Pollution Monitoring Management Group. Aquat. Environ. Monit. Rep., MAFF Direct. Fish. Res., Lowestoft, ***17***.

REES, H. L., 1987. A survey of the benthic fauna inhabiting gravel deposits off Hastings, southern England. ICES CM 1987/L:19, 9pp. (mimeo).

REES, E. I. S. AND WALKER, A. J. M.,1991. Indications of temporal variability in the benthos of Liverpool Bay. In: Elliott, M. and Ducrotoy, J.-P., eds. Estuaries and coasts: spatial and temporal intercomparisons. Olsen and Olsen, 217-220.

REES, H. L., ROWLATT, S. M., LIMPENNY, D. S., REES, E. I. S., ROLFE, M. S., 1992. Benthic studies at dredged material disposal sites in Liverpool Bay. Aquat. Environ. Monit. Rep. Dir. Fish. Res. Lowestoft, ***28***: 1-21.

ROSS, P. S., de SWART, R. L., REIJNDERS, P. J. H., LOVEREN, H. V., VOS, J. G. and OSTERHAUS, A. D. M. E., 1995. Contaminant-related suppression of delayed-type hypersensitivity and antibody responses in harbour seals fed herring from the Baltic Sea Environ. Health Perspect., ***103***: 162-167.

ROWLATT, S., 1988. Metal contamination in sediments from Liverpool Docks and the Mersey Estuary. ICES C.M. 1988/C:12, 10pp (mimeo).

ROWLATT, S. M. and LOVELL, D. R., 1994(a). Lead, zinc and chromium in sediments around England and Wales. Mar. Pollut. Bull., ***28***: 324-329.

ROWLATT, S. M. and LOVELL, D. R., 1994(b). Survey of contaminants in coastal sediments. London : Department of the Environment, Research Contract PECD 7/7/358, 35 pp + Tables and Figures.

RUMOHR, H., BREY, T. AND ANKAR, S., 1987. A compilation of biometric conversion factors for benthic invertebrates of the Baltic Sea. Baltic Marine Biologists, Publication No. **9**: 56pp.

SANVICENTE-ANORVE, L., LEPRETRE, A. AND DAVOULT, D., 1996. Large-scale spatial pattern of the macrobenthic diversity in the eastern English Channel. J. Mar. Biol. Assoc. U.K., ***76***: 153-160.

SHANNON, C. E. AND WEAVER, W., 1949. The mathematical theory of communication. Urbana: University of Illinois Press, 117pp.

SHELDRICK, M. C., GEORGE, J. D., CHIMONIDES, P. J. and PHILLIPS, S., 1991. An Analysis of Cetacean Strandings around the British Isles Between 1967 and 1990. A report for the UK Department of the Environment. The Natural History Museum, London. 175pp.

SLEIDERINK, H. M., BEYER, J., SCHOLTENS, E., GOKSØYR, A., NIEUWENHUIZE, J., VAN LIERE, J. M., EVERAARTS, J. M. AND BOON, J. P., 1995. Influence of temperature and polyaromatic contaminants on CYP1A levels in North Sea dab (*Limanda limanda*). Aquat. Toxicol., ***32***: 189-209.

SNOEIJ, N. J., PENNINKS, A. H. AND SEINEN, W., 1989. Thymus atrophy and immunosuppression induced by organotin compounds. Arch. Toxicol., ***13***: 171-174.

SOMERFIELD, P. J., REES, H. L., AND WARWICK, R. M., 1995. Interrelationships in community structure between shallow-water marine meiofauna and macrofauna in relation to dredgings disposal. Mar. Ecol. Prog. Ser., ***127***: 103-112.

SOMERFIELD, P. J., AND WARWICK, R. M., 1996. Meiofauna in marine pollution monitoring programmes. A laboratory manual. Ministry of Agriculture, Fisheries and Food, Dir. Fish. Res., Lowestoft, 71pp.

STAGG, R. M., MCINTOSH, A. AND MACKIE, P., 1995. Elevation of hepatic monooxygenase activity in the dab (*Limanda limanda* L.) in relation to environmental contamination with petroleum hydrocarbons in the northern North Sea. Aquat. Toxicol., ***33***: 245-264.

STEBBING, A. R. D., 1979. An experimental approach to the determination of biological water quality. Phil. Trans. R. Soc. Lond. ***B286***: 465-481.

STEBBING, A. R. D. AND DETHLEFSEN, V. D., 1992. Introduction to the Bremerhaven Workshop on biological effects of contaminants. Mar. Ecol. Prog. Ser., 91: 1-8.

SUZUKI, T., MATSUDA, R. AND SAITO, Y., 1992. Molecular species of tri-*n*-butyltin compounds in marine products. J. Agric. Food Chem., ***40***: 1437-1443.

TANABE, S. AND TATSUKAWA, R., 1992. Chemical modernization and vulnerability of cetaceans: increasing toxic threat of organochlorine contaminants. pp 161-177, *In*: (C. H. Walker and D. R. Livingstone, (eds)). Persistent Pollutants in Marine Ecosystems. Pergamon Press, Oxford.

TANABE, S., WATANABE, S., KAN, H. AND TATSUKAWA, R., 1988. Capacity and mode of PCB metabolism in small cetaceans. Mar. Mamm. Sci., ***4***: 103-124.

TARPY, C., 1979. Killer whale attack! National Geographic, ***155***: 542-545.

TEN HALLERS-TJABBES, C. C., KEMP, J. F. AND BOON, J. P., 1994. Imposex in whelks (*Buccinum undatum*) from the open North Sea: relation to shipping traffic intensities. Mar. Pollut. Bull., ***28***, 311-313.

THAIN, J. E., 1991. Biological effects of contaminants: Oyster (Crassostrea gigas) embryo bioassay. ICES Techniques in Marine Environmental Sciences, 11: 12pp.

THAIN, J. E. AND KIRBY, M., 1994. Improving the sensitivity of biological water quality measurements in marine waters. Proceedings of the Scientific Symposium on the North Sea Quality Status Report, April 18-21, 1994.

THAIN, J. E., ALLEN, Y. AND MATTHIESSEN, P., 1996. Monitoring sediment toxicity in UK estuaries and offshore waters from 1990-1993., Dav. and Prog. in Sed. Qual. Assess: Rationale, Challenges, Techniques and Strategies, pp. 127-142. Ecovision World Monograph Series. SPB Academic Publishing, Amsterdam, Netherlands.

THIEBAUT, E., CABIOCH, L., DAUVIN, J.-C., RETIERE, C. and GENTIL, F., 1997. Spatio-temporal persistence of the *Abra alba-Pectinaria koreni* muddy-fine sand community of the eastern Bay of Seine. J. Mar. Biol. Assoc. U.K., *77*: 1165-1185.

VANOSMAEL, C., WILLEMS, K. A., CLAEYS, D., VINCX, M. AND HEIP, C., 1982. Macrobenthos of a sublittoral sandbank in the southern bight of the North Sea. J. Mar. Biol. Assoc. UK, ***62***: 521-534.

VETHAAK, A. D. AND AP RHEINALLT, T., 1992. Fish disease as a monitor for marine pollution: the case of the North Sea. Rev. Fish Biol. and Fish., ***2***: 1-32.

VILLIERS, A. J., 1925. Whaling in the Frozen South: Being the story of the Norwegian Whaling Expedition to the Antarctic. Bolbs-Merrill. pp

VOS, J. G., DE KLERC, A., KRAJNC, E. I., KRUIZINGA, W., VAN OMMEN, B. AND ROZING, J., 1984. Toxicity of bis(tri-*n*-butyltin)oxide in the rat. II. Suppression of thymus-dependent immune responses and of parameters of non-specific resistance after short-term exposure. Toxic. Appl. Pharmac., ***75***, 387-408.

WAITE, M. E., WALDOCK, M. J., THAIN, J. E., SMITH, D. J. AND MILTON, S. M., 1991. Reductions in TBT concentrations in UK estuaries following legislation in 1986 and 1987. Mar. Environ. Res., ***32***, 89-111.

WARWICK, R. M. AND DAVIES, J. R., 1977. The distribution of sublittoral macrofauna communities in the Bristol Channel in relation to the substrate. Est. Cstl. Mar. Sci., ***5***: 267-288.

WARWICK, R. M. AND UNCLES, R. J., 1980. The distribution of benthic macrofauna associations in the Bristol Channel in relation to tidal stress. Mar. Ecol. Prog. Ser., ***3***: 97-103.

WELLS, D. E., KELLY, A., FINDLAYSON, D. M., EATON, S., ROBSON, J. AND CAMPBELL, L., 1989. Report of the survey for PCB contamination following the Piper Alpha incident. SOAFD Marine Laboratory, Aberdeen. 9-10.

WILLIAMS, T. D., 1992. Survival and development of copepod larvae *Tisbe battagliai* in surface microlayer, water and sediment elutriates from the German Bight. Mar. Ecol. Prog. Ser., ***91***: 221-229.

WOODHEAD, R. J., LAW, R. J. AND MATTHIESSEN, P., in prep. Polycyclic aromatic hydrocarbons (PAH) in sediments around England and Wales.

ZAMBRIBORSCH, F. S., CHERNYAVSKIY, A. V., SOLOV'YEVA, O. L., 1982. Effect of soil dumping at sea on benthic biocenoses. Hydrobiol. J., ***18***: 22-29.

ANNEX 1. Areas of monitoring mentioned in the text and staff responsible for the projects

UK NATIONAL MONITORING PROGRAMME

Dissolved trace metals in sea water	R Owens
Organics in sea water	C Allchin
PAH in sea water	R J Law
Nutrients in sea water	S J Malcolm
Assessment of water quality: oyster embryo bioassay	J E Thain
Bioassay of contaminants in solvent extracts of sea water	J E Thain M Kirby
Metals in sediments	S Rowlatt
Organics in sediments	C Allchin
PAH in surface sediments	R J Law
Assessment of sediment quality: oyster embryo bioassay	J E Thain Y Allen
Assessment of sediment quality: whole sediment bioassays using *Arenicola marina* and *Corophium volutater*	J E Thain Y Allen
Contaminants in Dab (*Limanda limanda*)	A Franklin J Jones
Benthos studies	H L Rees M A Pendle R Waldock
Measurement of ethoxyresofurin-o-deethylase (EROD) activity in flatfish	P Matthiessen M Kirby
Monitoring and surveillance for fish disease in marine fish 1993 to 1996	S Feist

SURVEYS OF CONTAMINANTS IN MARINE MAMMALS

Tributyltin (TBT)	R J Law
Contaminant concentrations in two species of whales	R J Law

ENVIRONMENTAL ASSESSMENT STUDIES

Hastings Shingle Bank	M Pendle H Rees
Sidescan survey of the Nab Tower dredged material disposal site	D Limpenny
Comparative studies of benthic changes at dredged material disposal sites	S Boyd

LICENSING AND RELATED ACTIVITIES

Licensing of deposits in the sea	G Boyes C M G Vivian
Advice on fishery implications of pipeline discharges	F L Franklin

ANNEX 2. Standards/guidelines for contaminants in fish and shellfish

A2.1 Metals

(a) Mercury

The European and Paris Commissions have adopted an Environmental Quality Standard (EQS) for mercury, which requires that the mean concentration of mercury in the flesh of a representative sample of fish, locally caught from areas receiving significant inputs of mercury, shall not exceed 0.3 mg kg^{-1} on a wet weight basis (EC Directive Nos. 82/176 and 84/156 - European Communities, 1982 and 1984).

Community Decision 93/351 EEC (European Communities, 1993) applies to samples of fishery products. This states that the mean total mercury content of the edible parts of fishery products must not exceed 0.5 mg kg^{-1} fresh weight, increased to 1.0 mg kg^{-1} fresh weight for some species listed in an annex.

For the purposes of the Joint Monitoring Programme (JMP) of the Oslo and Paris Commissions, the following arbitrary, purely descriptive, guidelines have been adopted.

Level	Fish flesh and crustaceans	Molluscs
Lower	<0.1 mg kg^{-1} wet weight	<0.6 mg kg^{-1} dry weight
Medium	0.1-0.3 mg kg^{-1} wet weight	0.6-1.0 mg kg^{-1} dry weight
Upper	>0.3 mg kg^{-1} wet weight	>1.0 mg kg^{-1} dry weight

(b) Cadmium

There are no standards or guidelines in England and Wales for fish flesh. The expected values are <0.2 mg kg^{-1} wet weight.

The JMP guidelines for cadmium in mussels are as follows:

Level	Mussel tissue	Approximate equivalent
Lower	<2 mg kg^{-1} dry weight	(<0.4 mg kg^{-1} wet weight)
Medium	2-5 mg kg^{-1} dry weight	(0.4-1.0 mg kg^{-1} wet weight)
Upper	>5 mg kg^{-1} dry weight	(>1.0 mg kg^{-1} wet weight)

From past CEFAS work, 'expected' values (i.e. using data from estuaries not known to be severely contaminated) would be up to 0.3 mg kg^{-1} wet weight for crustaceans but up to 10 mg kg^{-1} wet weight for crab 'brown' meat.

(c) Lead

From the Lead in Food Regulations 1979 (Great Britain - Parliament, 1979): lead in fish should not exceed 2.0 mg kg^{-1} wet weight, and lead in shellfish 10.0 mg kg^{-1} wet weight.

From past work, 'expected' values are 0.2-0.3 mg kg^{-1} wet weight in fish, up to 1.0 mg kg^{-1} wet weight in crustaceans, and up to 5.0 mg kg^{-1} wet weight in some molluscs.

(d) Copper

From the Food Standards Committee's Report on Copper (MAFF, 1956), revised recommendations for limits for copper content of food are as follows:

> 'levels of copper in food should not exceed 20 mg kg^{-1} wet weight (but higher levels in shellfish are permitted if copper is of natural occurrence).'

From past CEFAS work, 'expected' levels in fish are up to 0.6 mg kg^{-1} wet weight (in excess of 1.0 mg kg^{-1} wet weight in fatty fish such as herring), 20-30 mg kg^{-1} wet weight for crustaceans and up to 500 mg kg^{-1} wet weight for molluscs.

(e) Zinc

From the Food Standards Committee's Report on Zinc (Ministry of Food, 1953), as a guideline:

> 'levels of zinc in food should not exceed 50 mg kg^{-1} wet weight (but higher levels are permitted in food which naturally contain more than 50 mg kg^{-1}, such as herring and shellfish).'

'Expected' values commonly found are up to 6.0 mg kg^{-1} wet weight in most fish flesh, (though up to 10 mg kg^{-1} in flounder and considerably more in fatty fish), up to 100 mg kg^{-1} wet weight in crustaceans and well in excess of 100 mg kg^{-1} wet weight for some molluscs.

A2.2 Pesticides/PCBs

There are no standards in fish and shellfish from England and Wales.

(a) HCB

The 'expected' value is up to 0.10 mg kg^{-1} wet weight in fish liver.

(b) HCH

Codex Alimentarius Commission's maximum residue limit (MRL) (FAO/WHO, 1987) is 2 mg kg^{-1} in meat fat for γ-HCH. The 'expected' values are up to 0.05 mg kg^{-1} wet weight for each of α- and γ-HCH in fish liver.

(c) Dieldrin

Codex Alimentarius Commission's MRL is 0.2 mg kg^{-1} in meat fat. The 'expected' values are 0.2-0.3 mg kg^{-1} wet weight in fish liver.

(d) Total DDT

Codex Alimentarius Commission's MRL is 5 mg kg^{-1} in meat fat. The 'expected' values are up to 0.5 mg kg^{-1} wet weight for each of DDE, TDE and pp DDT in fish liver.

(e) PCBs

JMP guidelines are as follows (all mg kg^{-1} wet weight):

Level	Fish muscle	Cod[1] liver	Flounder[2] liver	Molluscs	Crustaceans
Lower	<0.01	<2.0	<0.50	<0.02	<0.01
Medium	0.01-0.05	2.0-5.0	0.50-1.0	0.02-0.10	0.01-0.05
Upper	>0.05	>5.0	>1.0	>0.10	>0.05

[1] *Values used for all roundfish in this report*
[2] *Values used for all flatfish in this report*

A2.3 References

European Communities, 1982. Council Directive 82/176/EEC of 22 March 1982 on limit values and quality objectives for mercury discharges by the chloralkali electrolysis industry. Off. J. Eur. Commun., ***L81*** (1982):29-34.

European Communities, 1984. Council Directive 84/156/EEC of 8 March 1984 on limit values and quality objectives for mercury discharges by sectors other than the chloralkali electrolysis industry. Off. J. Eur. Commun., ***L74*** (1984):49-54.

European Communities, 1993. Commission Decision 93/351/EEC 19 May 1993, determining analysis methods, sampling plans and maximum limits for mercury in fishery products. Off. J. Eur. Commun., ***L144*** (1993): 23-24.

Great Britain - Parliament, 1979. Food and drugs composition. The lead in food regulations 1979. Her Majesty's Stationery Office, London, 7pp. (Statutory Instrument No. 1254).

Food and Agriculture Organisation/World Health Organisation, 1987. Codex Alimentarius Commission. Recommendations concerning pesticide residues. Part 2. Maximum limits for pesticide residues. FAO, Rome, pag. var.

Ministry of Food, Food Standards Committee, 1953. Report on zinc. Her Majesty's Stationery Office, London, 4pp.

Ministry of Agriculture, Fisheries and Food, Food Standards Committee, 1956. Report on copper. Revised recommendations for limits for copper content of foods. Her Majesty's Stationery Office, London, 5pp.

CEFAS
The Centre for Environment, Fisheries & Aquaculture Science

The Centre for Environment, Fisheries & Aquaculture Science
Lowestoft Laboratory, Pakefield Road
Lowestoft , Suffolk NR33 OHT UK
Tel: +44 (0) 1502 562244
Fax: +44 (0) 1502 513865
http://www.cefas.co.uk

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