ICES J. mar. Sci., 50: 71–80. 1993

The ICES North Sea benthos survey: the sedimentary environment

D. J. Basford, A. Eleftheriou, I. M. Davies, G. Irion, and
T. Soltwedel

Basford, D. J., Eleftheriou, A., Davies, I. M., Irion, G., and Soltwedel, T. 1993. The ICES North Sea benthos survey: the sedimentary environment – ICES J. mar. Sci., 50: 71–80.

A large-scale co-operative project involving a number of countries bordering the North Sea was initiated in order to provide information on the status of the benthic communities and the sedimentary environment and to assess the possible impact of anthropogenic influences on the health of the sea. In this paper the data obtained on the environmental parameters—grain size, organic carbon, chlorophyllous pigment content, and the distribution of the trace metals—are discussed together with the benthic biomass and species richness. From this information it can be seen that while the southern North Sea exhibits signs of pollution having had an impact upon the environment, the northern part has remained in a relatively unimpacted state.

Key words: Sedimentary environment, benthos, North Sea.

Received 1 June 1992; accepted 10 September 1992.

D. J. Basford, and I. M. Davies: SOAFD Marine Laboratory, PO Box 101, Victoria Road, Aberdeen, Scotland, UK.
A. Eleftheriou: Department of Biology, University of Crete, PO Box 1470, Heraklion 71110, Crete, Greece.
G. Irion: Senckenberg Institute, Schleusenstr. 39a, D-2940 Wilhelmshaven, Germany.
T. Soltwedel: Institut für Hydrobiologie und Fischereiwissenschaft der Universität Hamburg, Zeiseweg 9, 2000 Hamburg 50, Germany.

Introduction

From the beginning of this century numerous attempts have been made to describe the benthic fauna of the North Sea and to delimit areas with similar communities. The earlier surveys were not carried out in a systematic way, for example using a sampling grid. Furthermore, these surveys did not sample the benthic physico-chemical environment, so that neither the spacial limits of the communities nor the effects of the environment on the fauna could be established. More recently the majority of the benthic information from the open North Sea has been of a localized nature, usually focused around points of anthropogenic activity, such as oil and gas production platforms. The aim in the present study is to describe the broad benthic environment so that the data may be used to aid the determination of the faunal distribution, and, in addition, to give a synoptic overview of those trace metals found in the sediments that may be of concern for the future.

Trace metals make their way into the sediments by two main routes, either from naturally weathered sediments or by man's impact. The metals may be introduced in several forms, in solution and suspended matter from rivers or as particulate material, e.g. from sewers or from dumping. They are adsorbed onto fine particles (Groot and Allerssma, 1973), although the speed and concentrations adsorbed may vary with the physico–chemical conditions, e.g. pH, Eh, or bacterial activity, etc. (Duursma and Eisma, 1973). The metals, which may be distributed by resuspension of the sediments or by bioturbation, are very persistent and their presence may be useful indicators of long-term processes (Förstner and Wittmann, 1979).

Samples from most of the area (Fig. 1), particularly south of 57°N, were collected by the ICES North Sea Benthos Working Group during April–May 1986 by the following participants: Dr A. Künitzer, Bremerhaven; Dr G. Duineveld, Texel; Dr U. Niermann, Hamburg; Dr J. Dörjes, Williamshaven; Dr J.-M. Dewarumez, Wimereux; Dr P. Kingston, Edinburgh; and Dr H. Rumohr, Kiel. The northern area, north of 56°N, was surveyed by Dr A. Eleftheriou and D. Basford, of the Marine Laboratory, Aberdeen, in the springs of 1980–1985 (Basford and Eleftheriou, 1988; Basford *et al.*, 1989, 1990; Eleftheriou and Basford, 1989).

Materials and methods

Trace metal analysis

At all the ICES stations sampled in 1986, trace metal concentrations were determined in fine-grained (< 2 μm) material separated from homogenized samples of the top

1054–3139/93/010071 + 10 $08.00/0

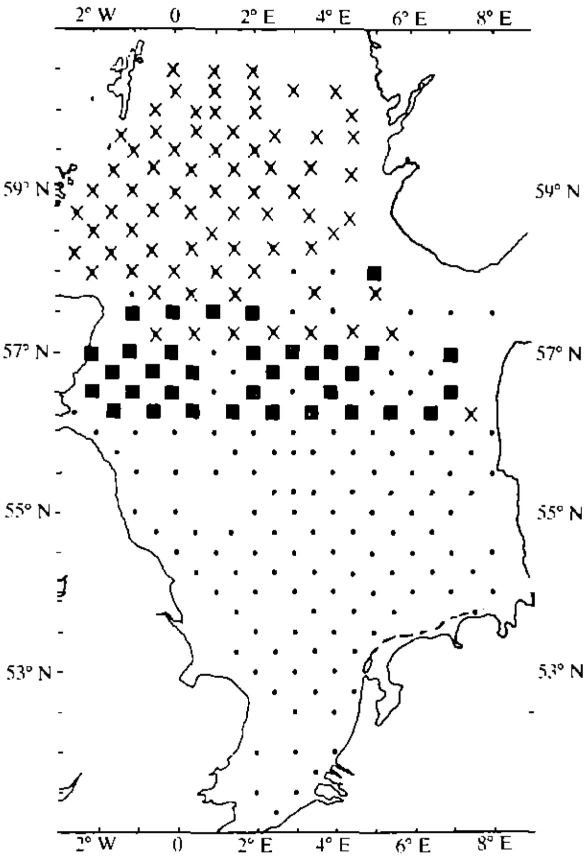

Figure 1. North Sea stations: ● = analysed by ICES Benthos Working Group, × = analysed by Marine Laboratory, Aberdeen, ■ = analysed by both groups.

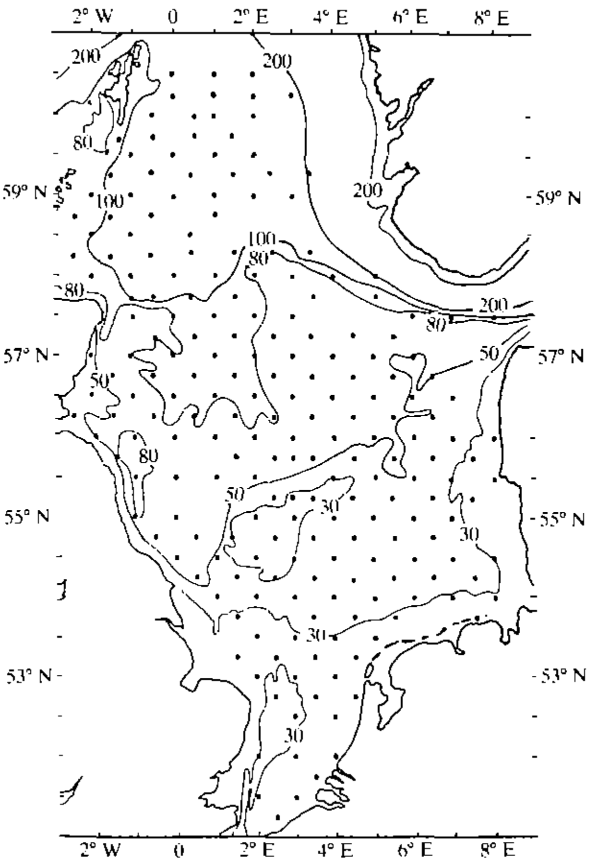

Figure 2. The bathymetry of the North Sea. Depth in metres.

10 cm of sediment from grab samples. At stations sampled by the Marine Laboratory, metal concentrations were also determined in whole sediment from the top 2 cm of similar samples. In both cases, sediment samples were digested in concentrated nitric acid, and metal concentration determined in the extracts by standard flame atomic absorption techniques (Basford and Eleftheriou, 1988; Irion and Müller, 1990).

In order to obtain a holistic view of the contamination of North Sea sediments by metals, it was necessary to combine the data sets from the ICES and Marine Laboratory programmes. While analysis techniques were similar, sampling methods were not. Fortunately, a subset of 34 stations had been sampled and analysed by both groups. Correlations between the data sets were established for each element, and conversion factors calculated and applied to the Marine Laboratory samples so that they might be compared with the ICES data.

Sediment analysis

The particle size of the sediments from the upper 5 cm was analysed by a combination of dry sieving and pipette analysis (Holme and McIntyre, 1984). Organic carbon from the upper 5 cm in sediment $<2\,\mu m$ was determined by wet oxidation. Pigments from the homogenized upper 5 cm of the sediment were determined by extraction followed by fluorometric techniques (Basford and Eleftheriou, 1988; Soltwedel, 1987). Pigments were expressed as chloroplastic pigment equivalents (CPE, a term incorporating both chlorophyll and its derivatives), since unaltered chlorophylls are negligible in sediments below the euphotic zone.

Faunal analysis

At each station the infauna was sampled either by box sampler or grab. Samples from the ICES survey were sieved over a 1 mm mesh (a 0.5 mm mesh in the northern North Sea), preserved in buffered formalin and sorted and identified by the participating laboratories (Künitzer *et al.*, 1992).

Results

Since bathymetry and hydrography are likely to have major effects on sediment distribution it will be useful to

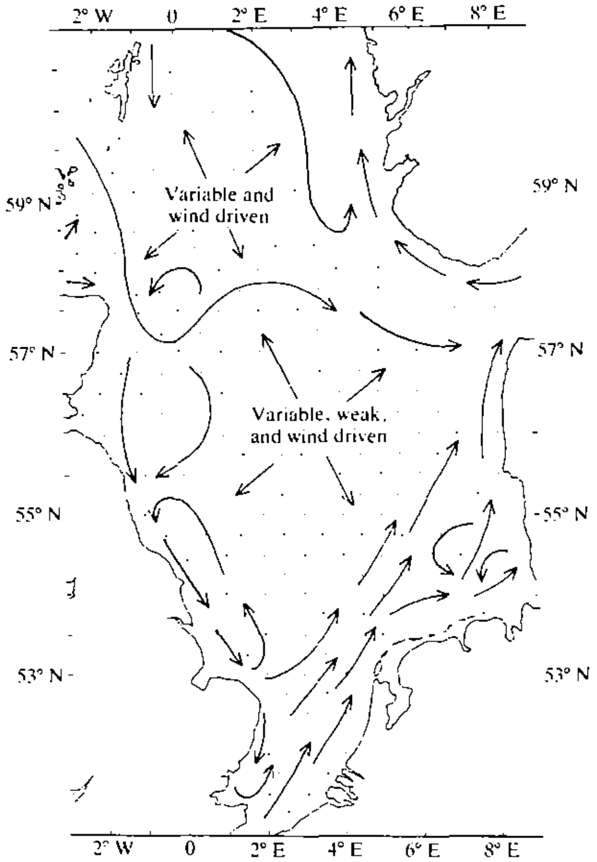

Figure 3. The hydrography of the North Sea (updated and redrawn from Lee, 1980).

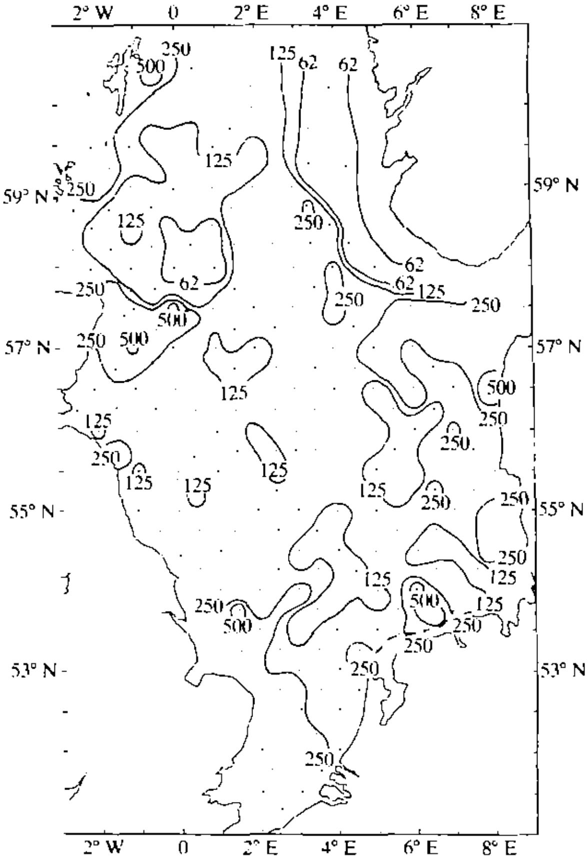

Figure 4. Contour map of the median diameter (µm) of the upper 5 cm of the sediment.

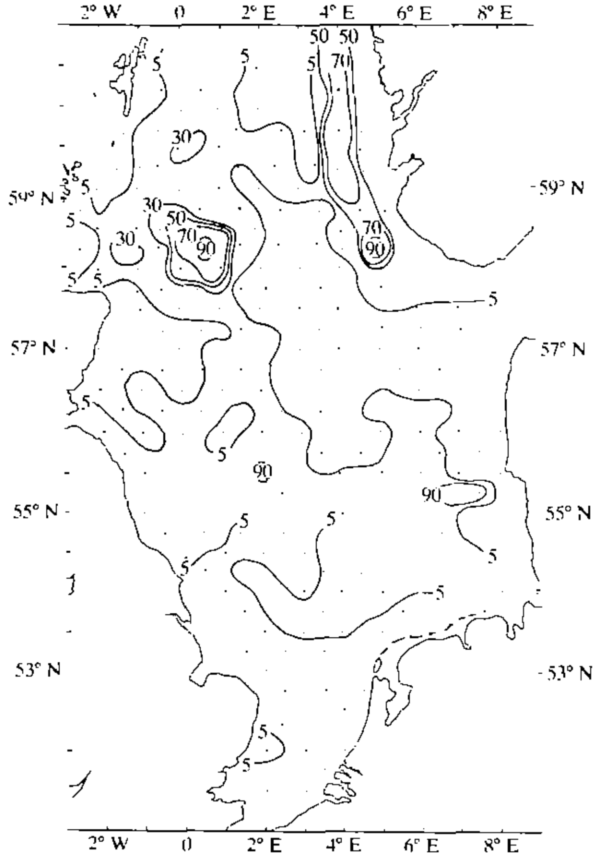

Figure 5. Contour map of the percentage silt (< 62 µm) in the upper 5 cm of the sediment.

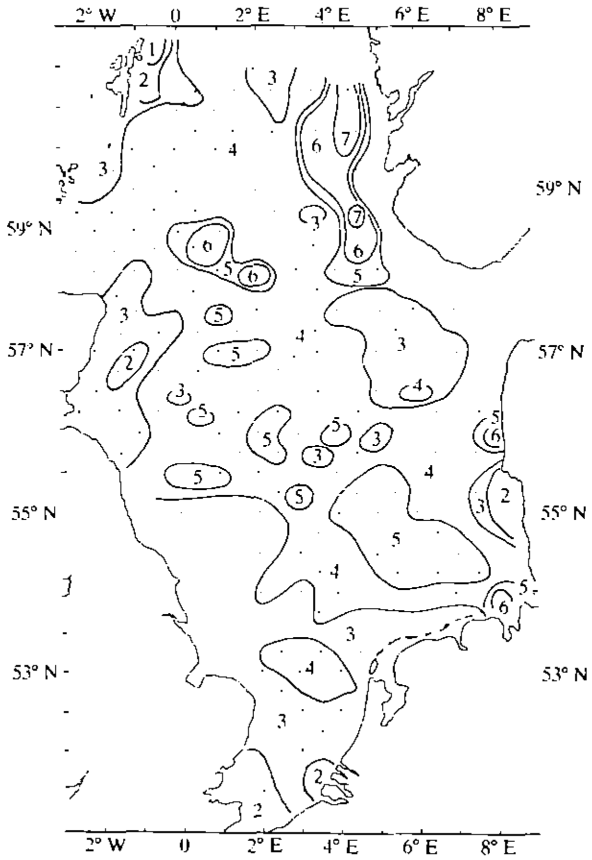

Figure 6. Contour map of the sediment description (Wentworth) in the upper 5 cm of the sediment. 1 = very coarse sand, 2 = coarse sand, 3 = medium, and 4 = fine sand, 5 = coarse silt, 6 = medium silt, 7 = fine silt.

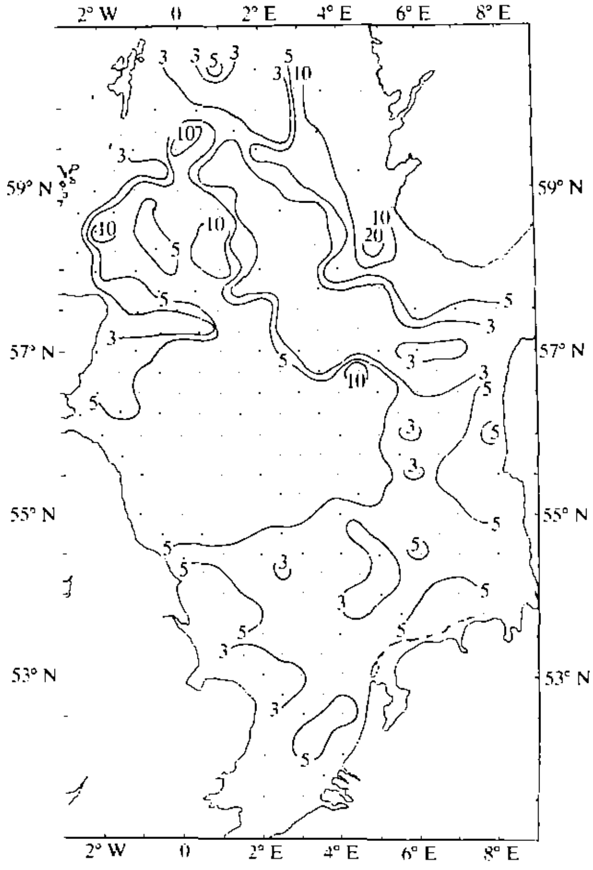

Figure 7. Contour map of the distribution of organic carbon (%) in the sediment < 2 µm from the upper 5 cm.

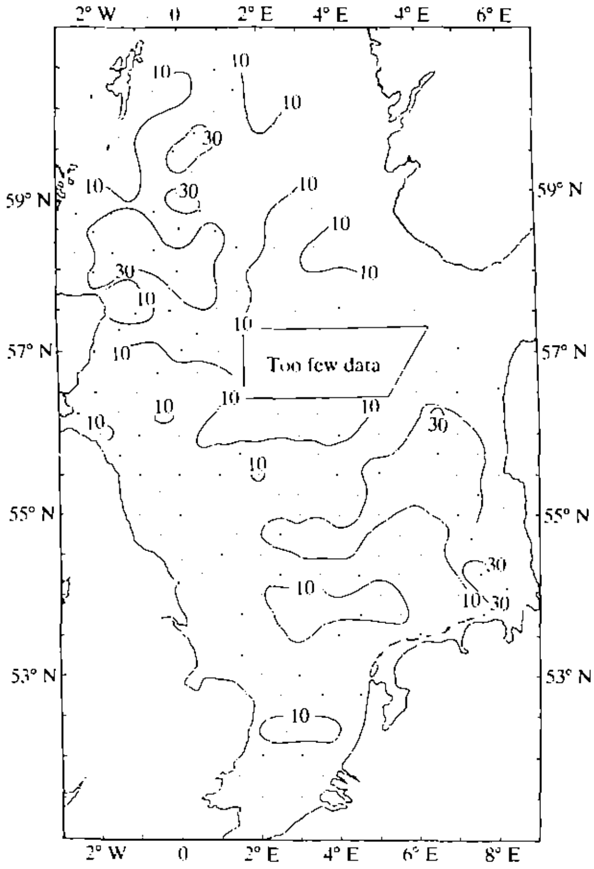

Figure 8. Contour map of the distribution of chloroplastic pigments (CPE) µg 5 cm^{-3} from the upper 5 cm.

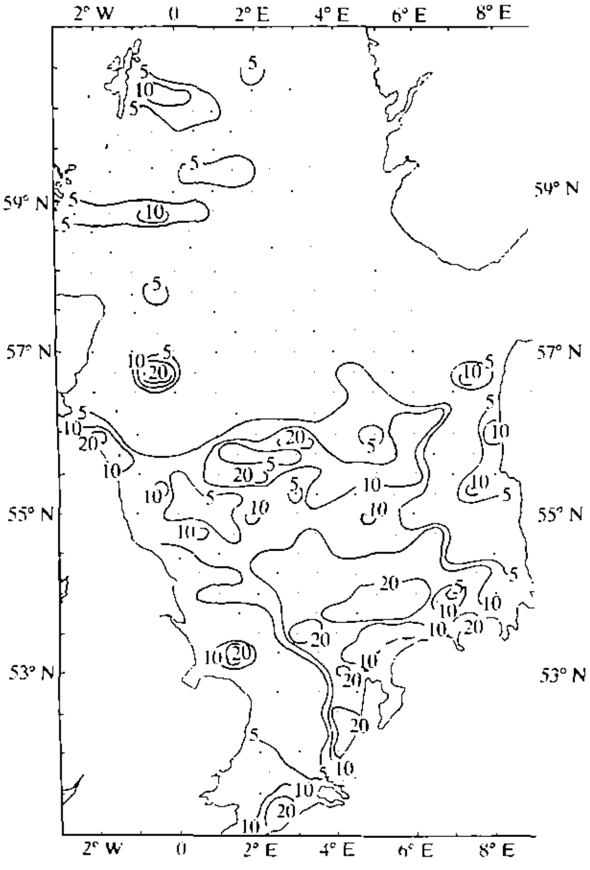

Figure 9. Contour map showing the macrofaunal biomass (grams ash free dry wt m^{-2}).

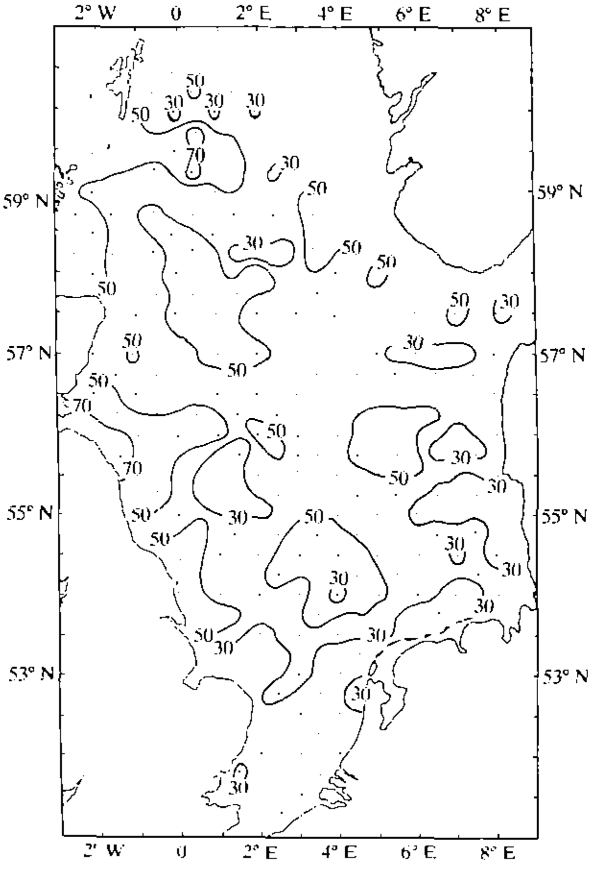

Figure 10. Contour map showing the macrofaunal species richness (number of species/sample).

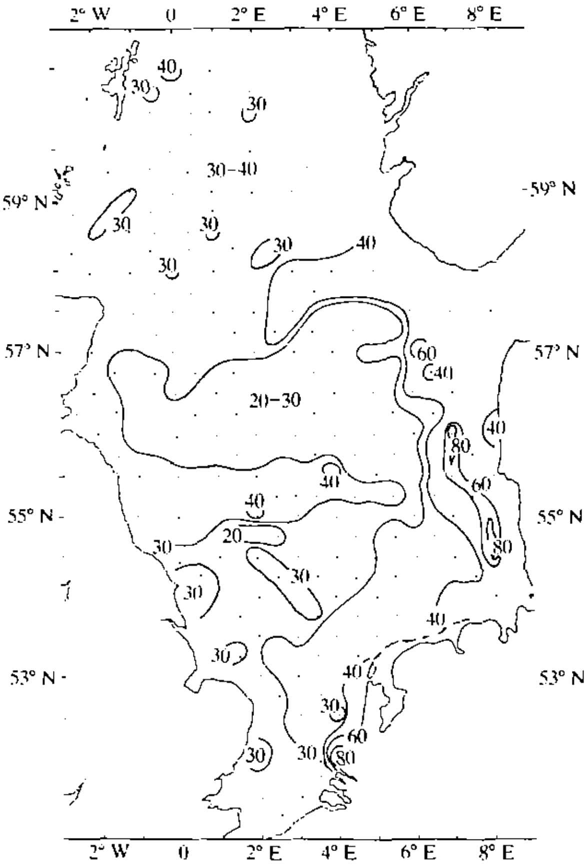

Figure 11. Contour map showing the distribution of copper ($\mu g\ g^{-1}$) in sediment $<2\ \mu m$.

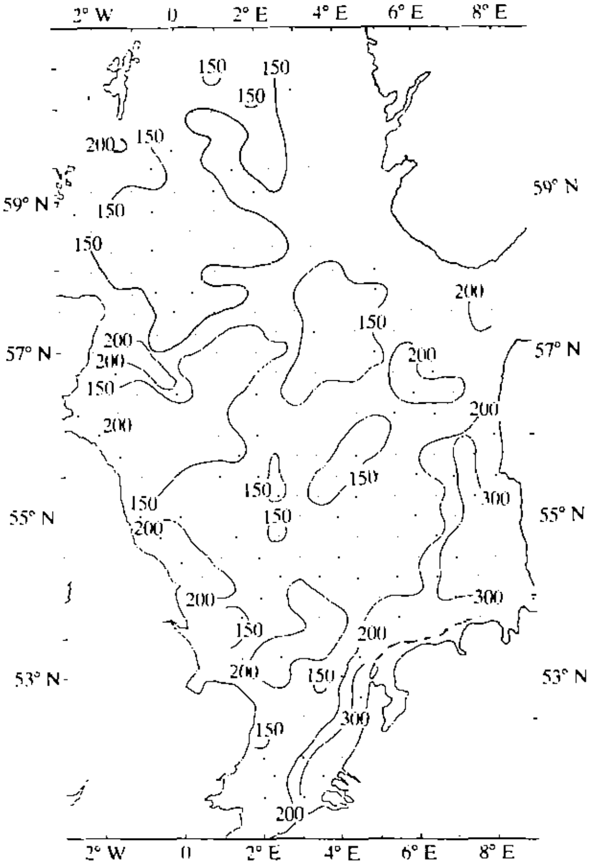

Figure 12. Contour map showing the distribution of zinc ($\mu g\ g^{-1}$) in sediment $<2\ \mu m$.

review briefly these factors prior to discussing the sediments and the trace metal data. The North Sea can be divided into three main areas according to the bathymetry (Fig. 2).

- The Norwegian Trough, which runs parallel to the Norwegian coast along the eastern side of the North Sea and curves southwards into the Skagerrak. The area is flat-floored, steep-sided, and generally between 200–300 m deep, but extending down to more than 700 m in the south.
- The northern North Sea, extending between the British coast and the western edge of the Norwegian Trough north of 56°N. It deepens rapidly to 100 m off the Scottish coast, the sea floor being covered with an apparently haphazard pattern of banks (approximately 60 m) and deeper areas (Fladen Ground > 150 m). Generally, this area is shallower to the south and east and deeper to the north.
- The southern North Sea, which can be divided into:
  (1) The German Bight, an area bounded on the east and south by the Danish and German coasts, to the north by a line of banks bordering the southern edge of the Norwegian Trough (approximately 55.3°N) and to the west by the Dogger Bank. The area is shallow and flat (30–50 m) with gradually shelving coastal edges. To the south there is a belt of shallow water (30 m) extending from the English coast to the Dutch coast which separates this area from the Southern Bight.
  (2) The Southern Bight, an area bordered to the north by the Dogger Bank and the east and west by the Netherlands and British coasts with Belgium and France to the south. Here the topography is smoother and shallower (20–30 m) to the east, with banks and troughs to the west along the English coast.

The 100 m contour (approximately 57.3°N) separates two hydrographic zones (Fig. 3). North of this contour the main water inflow enters the North Sea from between the Orkney Islands and the Scottish mainland (the Fair Isle inflow), weakening as it travels south and then east along the 100 m contour. There is a further subsurface inflow at approximately 3°E flowing south along the western edge of the Norwegian Trough. To the east, water

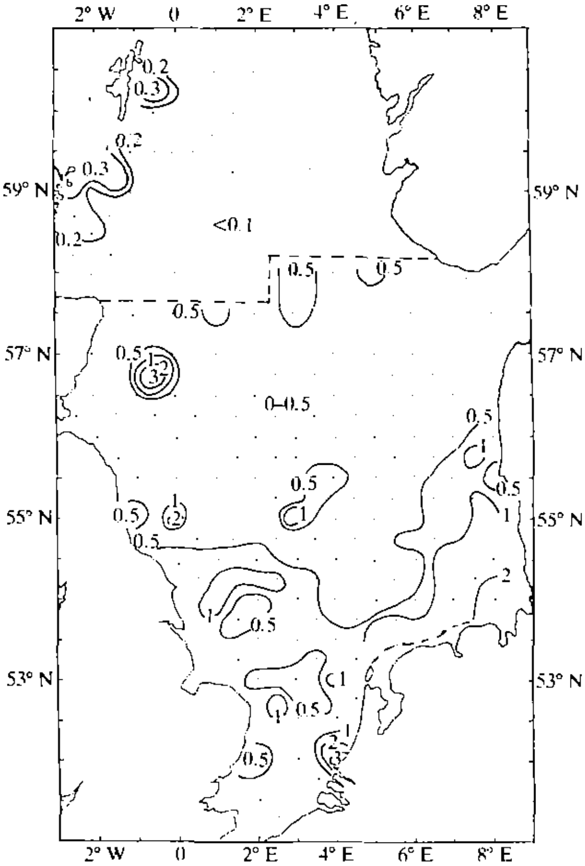

Figure 13. Contour map showing the distribution of cadmium ($\mu g\ g^{-1}$) in sediment $<2\ \mu m$.

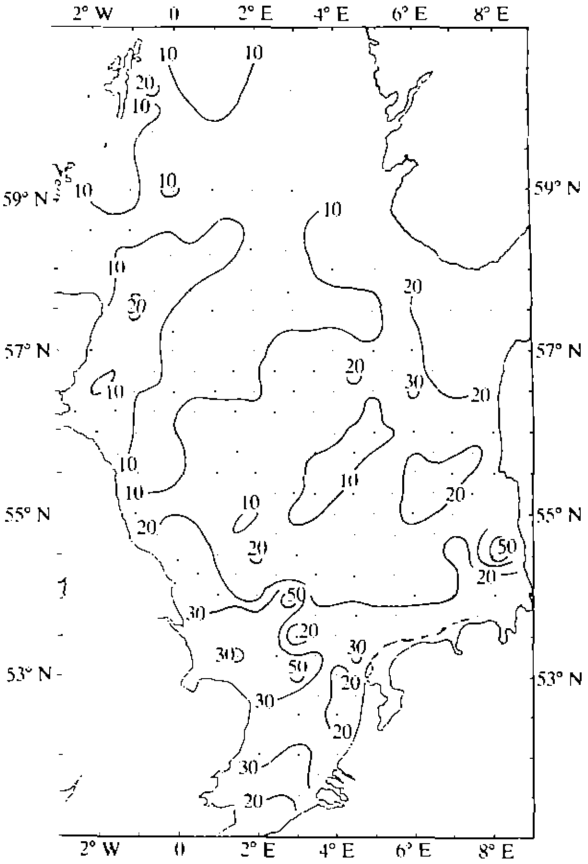

Figure 14. Contour map showing the distribution of cobalt ($\mu g\ g^{-1}$) in sediment $<2\ \mu m$.

flows northwards from the Skagerrak out of the North Sea. The centre of this area has variable and wind-driven currents. In the deeper areas the bottom water remains thermally stratified throughout the summer. To the south of the 100 m contour there is a residual southerly flow along the English coast which meets the Channel inflow water and then flows northeast through the Southern Bight and German Bight eventually to enter the Skagerrak and flow out of the North Sea via the Norwegian Trough. There are several coastal eddies both in the German Bight and along the English coast. The flows in this shallower southern area may be reversed by meteorological changes (wind) and the water is both homohaline and homothermal all the year round due to the effects of winds and tides (Lee, 1980). There is a further flow easterly across the north of the Dogger Bank which may be reversed in early summer (Ramster *et al.*, 1975).

Sediment distributions

The sediments can be described by three parameters: the median particle diameter (Fig. 4), percentage of silt (Fig. 5), and the Wentworth (Buchanan, 1984) sediment description (Fig. 6). The sediments are coarsest in the shallower more turbulent areas, i.e. in the vicinity of the inflows at both Fair Isle to the north and the English Channel to the south. In the deeper holes (Fladen Ground and Norwegian Trough) and where water movement is slight the sediments have a silt content in excess of 90%. In general, the sediments have a median diameter between 125–250 μm (Fig. 4) with >5% silt (Fig. 5) and are described as "fine sand" (Fig. 6).

Carbon and pigments

The carbon concentrations in the <2 μm fraction of the upper 5 cm of sediment (Fig. 7) were low (3–5%) over the majority of the southern North Sea and the southern part of the northern North Sea, increasing to >10% downstream of the Fair Isle inflow and in the silty sediments of the Norwegian Trough. Pigment values (Fig. 8) were generally less than 10 μg CPE: 5 cm^{-3} in the south with >30 μg in the vicinity of the Elbe and Weser. In the north the values were generally between 10–30 μg, tending to increase to the north and east where >30 μg was recorded at several stations downstream of the Fair Isle inflow.

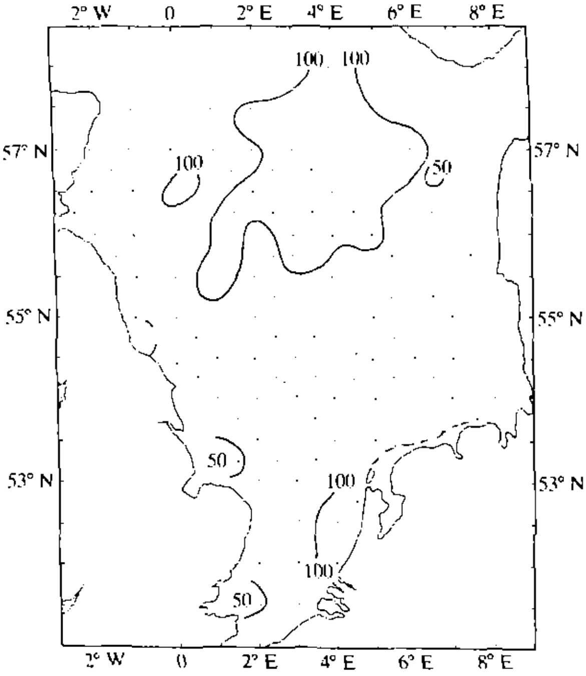

Figure 15. Contour map showing the distribution of chromium (μg g^{-1}) in sediment <2 μm.

Fauna

A more detailed description of the faunal communities and their relationships with the physical environment is presented elsewhere (Künitzer *et al.*, 1992; Heip *et al.*, 1992). Here we reproduce two maps, the total biomass (grams ash free dry wt m^{-2}) (Fig. 9) and species richness (number of species per sample) (Fig. 10). The biomass is low (generally <5 g) to the north of 56°N, but increases to >20 g to the south of this line. In contrast the species richness increases from the south to the north and east (<30–>70 species).

Trace metals

Major inputs of metals to the North Sea occur from the rivers Rhine, Maas, and Scheldt of Holland and Belgium, Humber and Thames of Britain, and the Weser and Elbe from Germany. In addition, there are inputs from coastal discharges, and the dumping of sewage and (historically) industrial wastes (Förstner and Wittmann, 1979).

The present survey shows higher levels of copper (Fig. 11), zinc (Fig. 12), cadmium (Fig. 13), and cobalt (Fig. 14) along the coasts associated with the above rivers. There was also an increase in levels in the German Bight, particularly of copper (Fig. 11) and zinc (Fig. 12). Cadmium (Fig. 13) levels were so near the analytical detection levels that they could not be correlated between the ICES survey and the Marine Laboratory survey. However, the Marine Laboratory data are included since there were higher concentrations around Orkney which have been related to geological inputs (Topping, 1973). Chromium (Fig. 15) was only recorded from the southern area and was generally low with higher values off the Humber and the Scheldt. Lead (Fig. 16) showed a more varied distribution, being generally low in the northern North Sea and irregularly accumulated into the southern sediments, peaking in the region of the Dogger Bank. Nickel (Fig. 17) was primarily found in the mineral lattice of both fine and mixed sediments and was also irregularly distributed with a tendency to increase in the fine sediments (e.g. Fladen Ground). Manganese (Fig. 18) was only recorded from the southern area and was highest in the coastal areas, with particularly high values off the Scottish coast and off the mouth of the Scheldt, the Meuse, and the Rhine delta.

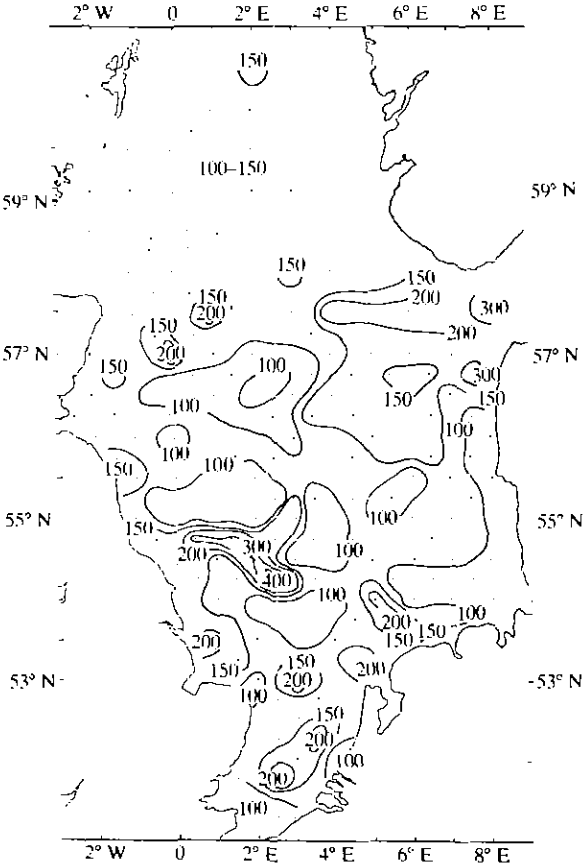

Figure 16. Contour map showing the distribution of lead (μg g^{-1}) in sediment <2 μm.

Correlations

Most factors were correlated with depth and the sediment median diameter (Table 1), silt was correlated with two metals (zinc and manganese). CPE was correlated with all

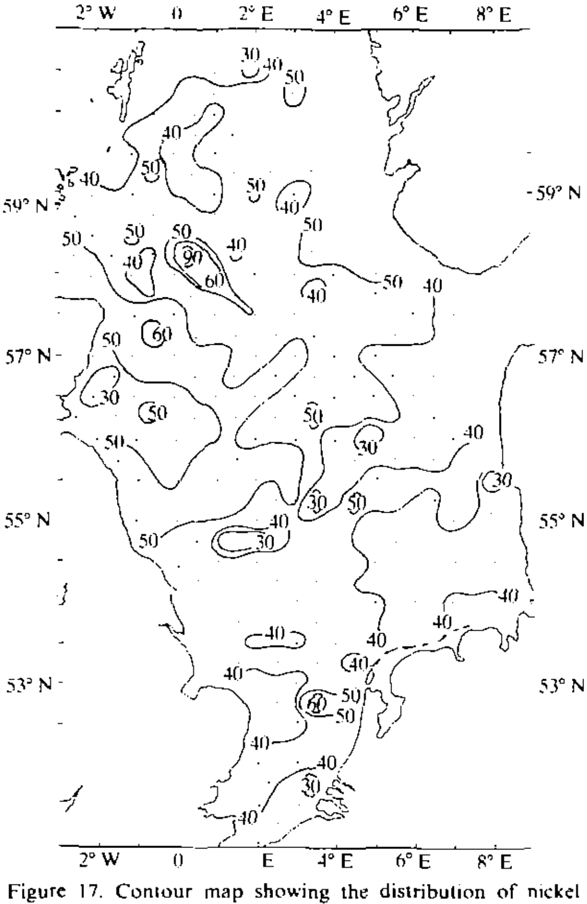

Figure 17. Contour map showing the distribution of nickel (μg g^{-1}) in sediment <2 μm.

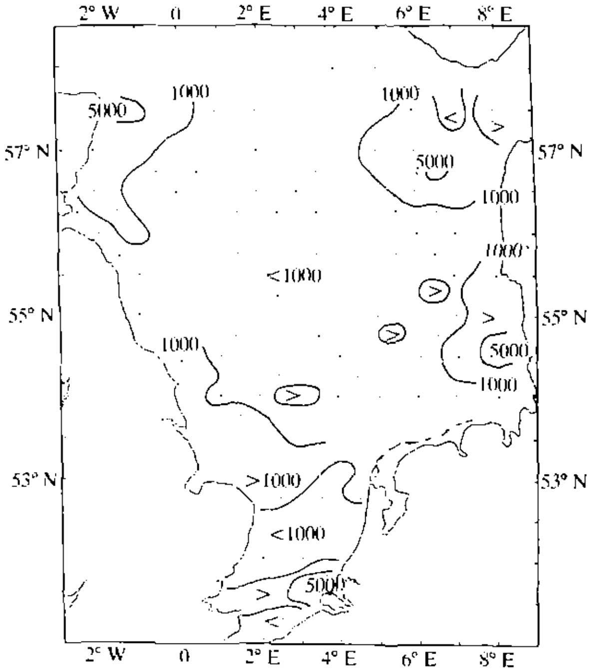

Figure 18. Contour map showing the distribution of manganese (μg g^{-1}) in sediment <2 μm.

the sediment parameters, whereas carbon was only correlated with the sediment description (Wentworth). In general, the metals were not correlated with silt and showed a varying degree of inter-correlation. Of the faunal factors, species richness was correlated with the sediment median diameter, CPE, and all the metals except copper, chromium, and lead, whereas the biomass was correlated with silt, and only two metals, cadmium and manganese.

Discussion

The North Sea sediments are mainly of Holocene age, their distribution reflecting the glacial history of the North Sea and more recent hydrodynamic processes. In the northern North Sea sedimentary inputs are negligible, and due to the greater depths in this region hydrographic redistribution of the sediments is limited to the shallower areas with stronger tides, e.g. Orkney–Shetland Channel and off the Pentland Firth. The deeper parts of the North Sea, like the Fladen Ground and Devil's Hole, have muddy sediments which are, in the main, being reworked *in situ*, there being little deposition (Eisma, 1973). In contrast, in the shallow southern North Sea, mud is introduced from the major rivers (Thames, Weser, and Elbe) and via the English Channel. Eisma (1973) suggests that through the influence of tidal currents and wave action the sediments south of a line between Flamborough Head and the Skagerrak are probably being reworked hydrographically. The suspended mud follows the general pattern of the major water flow, taking it northwards to be deposited in the Norwegian Trough or further north into the Norwegian Sea.

The same forces that influence the sediment transport also determine the distribution of the organic material. Thus, organic carbon and chlorophyll pigments were higher in the deeper holes (Fladen and Devil's Hole). However, these values depend on the primary production and deposition of dead material, and in these regions they probably reflect the volume of material imported via the currents from adjacent areas of high production (e.g. in the region of the Fair Isle inflow) rather than localized production. Similarly high organic carbon in the Norwegian Trough is probably due to the deposition of material from the primary production further south in the southern North Sea. Higher pigment levels in the southern German Bight might reflect the sediment deposition and the increased production due to the input of nutrients from the continental rivers.

Since most heavy metals adsorb onto fine particles the historical source of the material is of prime importance.

Table 1. Spearman's rank correlations. X = correlations significant at 1% level ($p < 0.1$) or above.

	Water depth	Sediment		Description	Carbon	CPE	Cu	Zn	Cd	Co	Cr	Pb	Ni	Mn	Number species
		Median	Per cent silt												
Median	X														
Per cent silt	X	X													
Description		X	X												
Carbon				X											
CPE	X	X	X	X											
Cu															
Zn	X	X	X				X								
Cd	X							X							
Co	X				X	X		X	X						
Cr	X				X				X	X					
Pb				X											
Ni	X				X						X				
Mn		X	X	X		X		X		X					
Number species	X	X				X		X	X	X			X	X	
AFDW	X		X	X					X					X	

Localized inputs to areas of coarse sediments may produce only small increases in sediment metal concentrations but in fine deposits accumulations of metals may be more substantial. Therefore, not only is it necessary to monitor localized areas around the inputs (e.g. river mouths) but also the areas where the fine material settles. Thus, high levels of zinc, copper, cadmium, and, to a lesser extent, cobalt and chromium, which are readily adsorbed onto fine particles, were associated with the inputs from the industrialized rivers (e.g. Elbe, Weser, and Rhine), whereas atmospherically distributed lead and the less readily adsorbed nickel could not be associated with any point source. High values in the German Bight may reflect metals with a high affinity for organic material which are being deposited in more stable hydrographic conditions. Iron and manganese both tend to be of geogenic origin, their concentrations tending to depend on redox conditions, thus explaining their widespread distributions (Irion and Müller, 1990). The latter authors compared the southern survey values with the mean concentrations in pre-industrial sediments and concluded that lead, cadmium, and zinc showed appreciable enrichment, whilst copper, cobalt, chromium, and nickel showed only weak or no enrichment.

In conclusion, there would appear to be a fairly strong division, both environmentally and biologically, of the North Sea into two areas, the most northerly being deeper, hydrographically more stable, with relatively high carbon and pigment levels. It appears to support a more diverse fauna with a relatively low biomass and in general lower trace metal levels with no obvious coastal high spots. In contrast, the shallower, more dynamic, southern North Sea has lower carbon and pigment levels, and a greater biomass associated with a lower diversity. There are also several coastal areas associated with river mouths where the trace metal values are high.

In recent times, considerable public and scientific concern has been expressed over the state of health of the North Sea. If measurements of heavy metals are taken as indicators of the degree of pollution and used as pointers to the possible consequences for the sedimentary environment and the benthic fauna, we might conclude from the biological data and the higher values of the sediment trace metals that the southern North Sea appears to be under stress. In contrast, the northern North Sea appears to be less affected and we can conclude that it is still in a relatively unimpacted state. However, the need for further co-operative work at the ICES level, in order to monitor pollution and its effects in the North Sea, cannot be overemphasized.

References

Basford, D. J., and Eleftheriou, A. 1988. The benthic environment of the North Sea (56–61°N). Journal of the Marine Biological Association of the UK, 68: 125–141.

Basford, D. J., Eleftheriou, A., and Raffaelli, D. 1989. The epifauna of the northern North Sea (56–61°N). Journal of the Marine Biological Association of the UK, 69: 387–407.

Basford, D. J., Eleftheriou, A., and Raffaelli, D. 1990. The infauna and epifauna of the northern North Sea. Netherlands Journal of Sea Research, 25: 165–173.

Buchanan, J. B. 1984. Sediment analysis. *In* Methods for the study of marine benthos, IBP Handbook No. 16, 2nd edn, pp. 41–65. Ed. by N. A. Holme and A. D. McIntyre. Blackwell, Oxford.

Duursma, E. K., and Eisma, D. 1973. Theoretical, experimental and field studies concerning diffusion of radioisotopes in sediments and suspended solid particles of the sea. Part C: Field studies. Netherlands Journal of Sea Research, 6: 265–324.

Eisma, D. 1973. Sediment distribution in the North Sea in relation to marine pollution. *In* North Sea science, pp. 131–150. Ed. by E. D. Goldberg. MIT Press, Cambridge, Massachusetts.

Eleftheriou, A., and Basford, D. J. 1989. The macrobenthic infauna of the offshore northern North Sea. Journal of the Marine Biological Association of the UK, 69: 123–143.

Förstner, V., and Wittmann, G. T. W. 1979. Metal pollution in the aquatic environment. Springer-Verlag, Berlin.

Groot, A. J. de, and Allersma, E. 1973. Field observations on the transport of heavy metals in sediments. *In* Heavy metals in the aquatic environment, pp. 85–89. Ed. by P. A. Krenkel. Pergamon Press, Oxford.

Heip, C., Basford, D., Craeymeersch, J. A., Dewarumez, J.-M., Dörjes, J., de Wilde, P., Duineveld, G., Eleftheriou, A., Herman, P. M. J., Niermann, U., Kingston, P., Künitzer, A., Rachor, E., Rumohr, H., Soetaert, K., and Soltwedel, T. 1992. Trends in biomass, density and diversity of North Sea macrofauna. ICES Journal of Marine Science, 49: 13–22.

Holme, N. A., and McIntyre, A. D. 1984. IBP Handbook 16. Methods for the study of marine benthos. Blackwell, Oxford. 387 pp.

Irion, G., and Müller, G. 1990. Lateral distribution and sources of sediment-associated heavy metals in the North Sea. *In* Facets of modern biochemistry. Ed. by V. Ihekkot, S. Kempe, W. Michaelis, and A. Spitzy. Springer-Verlag, Berlin.

Künitzer, A., Basford, D., Craeymeersch, J. A., Dewarumez, J.-M., Dörjes, 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: distribution and assemblages. Journal of Marine Science, 49: 127–143.

Lee, A. J. 1980. North Sea: physical oceanography. *In* The north-west European shelf seas: the sea bed and the sea in motion. II. Physical and chemical oceanography and physical resources, pp. 467–493. Ed. by F. T. Banner, M. B. Collins, and K. S. Massie. Elsevier, Amsterdam.

Ramster, J. W., Medler, K. J., Dooley, H. D., and Payne, R. 1975. Residual drift regimes in the northern North Sea in April–May 1973. ICES CM 1975/C: 13, 5 pp.

Soltwedel, T. 1987. Verteilung sedimentgebundener chloroplastischer Pigmente und Proteine in der Nordsee. MSc thesis. University of Hamburg. 94 pp.

Topping, G. 1973. Heavy metals in shellfish from Scottish waters. Aquaculture, 1: 379–384.