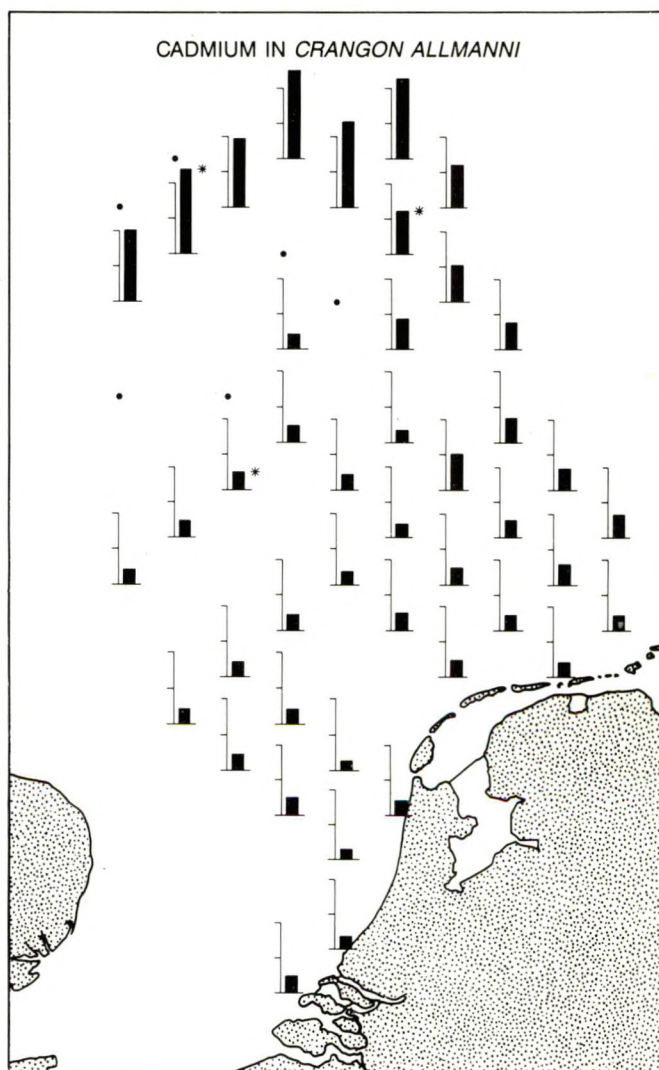


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# MICRO CONTAMINANTS IN SURFACE SEDIMENTS AND MACROBENTHIC INVERTEBRATES OF THE NORTH SEA

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Nederlands Instituut voor Onderzoek der Zee

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**MICRO CONTAMINANTS IN SURFACE SEDIMENTS  
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**NETHERLANDS INSTITUTE FOR SEA RESEARCH**

**SYNOPTIC MAPPING PROGRAM NORTH SEA 1986  
NORTH SEA BENTHOS SURVEY (ICES)**

## SUMMARY

Trace metal concentrations (copper, zinc, cadmium and lead) were measured in the silt fraction (grain-size  $< 63 \mu\text{m}$ ) of surface sediment of the North Sea. The concentrations varied in different areas of the Dutch continental shelf of the North Sea. The trace metal concentrations were highly related with the fine grain-size fraction. High concentrations, especially of cadmium and lead, were related with a low percentage of the silt fraction. In the Southern Bight enhanced levels of copper and zinc and particular high values of cadmium and lead were measured.

The concentrations of copper, zinc and cadmium in whole body of the benthic invertebrate species brown shrimp (*Crangon crangon*) and starfish (*Asterias rubens*) did not vary significantly in specimens obtained from the different areas of the North Sea. In the shrimp *Crangon allmanni* the whole body concentration of zinc did not vary; the copper concentration tended to be lower in specimens from the northern part of the area studied (Dogger Bank), whereas the concentrations of cadmium were significantly ( $p < 0.01$ ) higher in specimens from the north Dogger Bank area, compared with any other area of the North Sea.

The concentration of the total of 35 individual polychlorinated biphenyls ( $\Sigma\text{PCB}$ ) was highest in specimens of the brown shrimp *Crangon crangon* and the starfish *Asterias rubens* occurring in the coastal zone of the Southern Bight, compared with the central and northern part of the Dutch continental shelf of the North Sea. The  $\Sigma\text{PCB}$  concentrations in the shrimp *Crangon allmanni* were considerably lower than in the closely related species *C. crangon*. The concentrations of  $\Sigma\text{PCB}$  in the polychaete annelid *Nephtys hombergii* did not show significant differences in specimens from different areas of the North Sea.

On the basis of PCB patterns identified in the organisms analysed, the North Sea can be divided into three areas: The northern part of the North Sea, with lowest  $\Sigma\text{PCB}$  concentrations with a relatively high contribution of low chlorinated congeners; the central part of the North Sea with increasing  $\Sigma\text{PCB}$  concentrations with an equal contribution of low and high chlorinated congeners to the PCB pattern; the Southern Bight, especially the coastal zone, with high  $\Sigma\text{PCB}$  concentrations and a relatively high contribution of high chlorinated congeners to the PCB pattern.

## 1. INTRODUCTION

Rivers discharge various substances into the sea, both in solution and in colloidal or particulate form. The effects of these substances (for example trace metals or chlorinated hydrocarbons) on the marine environment depend on their physical/chemical properties and their concentrations. The impact of these substances will be exerted most directly and intensively in the adjacent coastal area. However, the regions in the marine environment where riverborne materials or anthropogenic chemicals exert their effects are not limited to the estuaries or nearby coastal zone. Further transport to coastal seas and finally to the ocean system takes place. In the regions where riverwater and seawater interact, substances transported by rivers are subjected to processes that modify the characteristics of their physical distribution in solution and particulates and change their chemical speciation. Due to processes such as adsorption, desorption, complexation, aggregation and sedimentation, chemical substances and suspended matter may remain behind in the estuarine and adjacent coastal area. The mixture of the chemical substances finally carried away to the sea may be very different, both in composition and quantities, as compared to the river supply.

The natural equilibrium in the complex system of estuaries, coastal seas and oceans has been influenced, mainly prejudicially, frequently by human activities. The exploration and exploitation of the sea and the increasing use of the marine environment as dumping site for all kinds of waste, implicates a conflict situation with respect to the future and legal utilization of the sea.

For the evaluation of the influence of the discharge of chemical substances in general and the toxic action of contaminants in particular, it is of essential importance to know the emission and fate of the substances concerned. Measurements of the concentrations of contaminants in the environment should be correlated to the quantities being disposed. These results will give information about transport, distribution and chemical fate of contaminants in the abiotic compartment of the environment. Next, it is essential to know the fate of the substances in the biotic compartment: uptake, distribution, elimination, biotransformation (Fig. 1). Finally, knowing all these facts, it should be possible to correlate any effect of a contaminant with its active concentration in the biophase (that is the body compartment where the contaminant exerts its effect).

The North Sea is a shallow coastal sea with a high

biological production. Large quantities of sewage of the heavily populated and highly industrialised northwestern part of the European continent are introduced into this marine environment. There are a number of criteria for answering the question whether the North Sea is polluted or to what extent its environment is contaminated with chemical substances: (1) threatening of the human health, (2) deterioration of the recreative and aesthetic functions of the environment and (3) damage (short or long term) to natural communities or its separate components. A definition of the conception of damage is subjective. The determination of the concentration levels of certain contaminants in different compartments of the (marine) environment is firstly required to get insight in the status of contamination.

Organisms, especially benthic species, inhabit for long periods of time certain compartments of the marine environment. Depending on habitat, the mechanisms of food uptake, the physiological status, the nature and the uptake/elimination ratio of the contaminants, organisms reflect the condition of the environment. If concentrations of chemical substances in organisms are measured for characterizing the status of contamination of a certain area, it is important that specimens of certain species occur in sufficient numbers and the species are representative for that particular area. Besides, for a comparison of contamination of organisms sampled from different geographical areas, concentrations should be measured in specimens of a particular species of corresponding life-stages and internal physiological conditions.

## 2. RESEARCH PROGRAM

An international research program was carried out on the North Sea to which research vessels from institutes of the United Kingdom, the Netherlands, Germany and Denmark participated in several surveys during 1986.

The 'Synoptic Mapping Program North Sea 1986' was carried out by the Dutch participants (Netherlands Institute for Oceanic Sciences) in the 'Cooperative North Sea Program 1986' of the Benthos Working Group of the International Council of Exploration of the Sea (ICES). Collaboration with and financial support of the Tidal Waters Division of Rijkswaterstaat (Federal Waters Authority) of the Ministry of Transport and Public Works is kindly acknowledged. The program consisted of two major projects: (1) Synoptic mapping of the macrobenthos of the Dutch part of the continental shelf (DE WILDE & DUINEVELD,

1988) and (2) Micro contaminants in sediment and macrobenthic invertebrates of the North Sea (present study).

Sampling sites are equally distributed over the Dutch part of the continental shelf of the North Sea (Fig. 2). Because of the international character of the synoptic sampling program, the sampling stations are also numbered according to the 'North Sea Benthos Survey' (ICES).

To obtain information on the uptake (accumulation) of a number of selected contaminants (trace metals: copper, zinc and cadmium and polychlorinated biphenyls) in macrobenthic invertebrates from the North Sea, a number of species were collected. Whole body analyses were carried out. Species from which specimens are sampled represent a number of different animal groups:

1. worms (Annelida, Polychaeta) - *Nephtys hombergii*
2. arthropods (Arthropoda, Crustacea) - *Crangon allmanni* - *Crangon crangon*
3. echinoderms (Echinodermata, Asteroidea) - *Asterias rubens*

Surface sediment (upper 2 cm) was sampled for the analysis of the selected trace metals copper, zinc, cadmium and lead.

### 3. MATERIAL AND METHODS

All samples were collected during a cruise with the research vessel 'TYRO' (Dutch Council for Ocean Research) from april 16. till may 2., 1986.

The macrobenthic organisms were collected with a 5 m beam-trawl; trawling time was 5 minutes. Specimens of the polychaete annelid *Nephtys* were sampled by sieving (1 mm mesh-size) from sediment obtained with a van Veen bottom-grab.

Sediment samples were collected by means of sub-sampling the upper 2 cm layer of sediment cores obtained with a Reineck box-core. The grain-size distribution in the sediments was determined after weighing 10 to 20 gram dry sediment and subsequent sieving with demineralized water (to disintegrate aggregates of fine material) over a sieve with a pore size of 63  $\mu\text{m}$ , dilution to 1  $\text{dm}^3$  and filtering over a preweighed 0.45  $\mu\text{m}$  filter. The rest of the sediment suspension (grain-size > 63  $\mu\text{m}$ ) was dried at 70°C and sieved (pore sizes 500, 315, 200 and 100  $\mu\text{m}$ ) for 10 minutes at 50 Hz. After weighing the different fractions, grain-size distribution was established.

### 3.1 ANALYSIS OF TRACE METALS

Samples to be analysed for trace metals were stored in polypropylene bags at  $-20^\circ\text{C}$ , up to processing at the Netherlands Institute for Oceanic Sciences (previously Netherlands Institute for Sea Research, Texel). The samples were freeze-dried to constant dry weight and homogenized.

From the samples of the organisms, about 400 mg, measured to the nearest 0.1 mg, were decomposed by an acid destruction bomb technique (PAUS, 1972). For the decomposition of the organic material 3  $\text{cm}^3$  of 65% nitric acid was added and the bombs were kept for 2 hours at 120°C. The decomposed samples were transferred quantitatively to polypropylene tubes and diluted with double-distilled water to 10  $\text{cm}^3$ .

The metal content of the silt fraction (grain-size < 63  $\mu\text{m}$ ) was determined after decomposition of about 500 mg, measured to the nearest 0.1 mg, with a mixture of 1  $\text{cm}^3$  aqua regia (1 part  $\text{HNO}_3$  + 3 parts HCl) and 5  $\text{cm}^3$  HF in a teflon destruction bomb (LORING & RANTALA, 1977), for 2 hours at 120°C, and subsequent dilution with 30  $\text{cm}^3$  saturated  $\text{H}_3\text{BO}_3$ -solution and double-distilled water to 50  $\text{cm}^3$ .

To avoid contamination of the samples, all chemicals used were suprapur (Merck). All materials used were rinsed for 12 hours with 6 N HCl and subsequently rinsed three times with double-distilled water.

Zinc and copper were measured with a flame atomic absorption spectrometer (Perkin Elmer, model 403). Cadmium and lead were measured with a heated graphite-furnace atomizer (HGA 500) coupled to an atomic absorption spectrometer (Perkin Elmer, model 5000). To calculate the metal concentrations, the standard addition method was applied and calibration curves were made with standard solutions of copper, zinc, cadmium and lead, respectively. The AAS-measurements were carried out in duplicate on each sample.

### 3.2 ANALYSIS OF POLYCHLORINATED BIPHENYLS

Samples to be analysed for polychlorinated biphenyls (PCBs) were stored in special treated glass containers at  $-20^\circ\text{C}$ , up to elaboration and analysis. The samples were freeze-dried to constant dry weight and homogenized with a teflon pestle in a mortar of porcelain. The methods applied in present study concerning sample extraction, clean-up, fraction separation between PCBs and most pesticides and the analysis by means of capillary gaschromatography are described comprehensively by HOLDEN & MARSDEN (1969), DUINKER & HILLEBRAND (1978, 1983a,b) and BOON *et al* (1985).

From the samples of the organisms about 2 to 5 g, measured to the nearest 0.01 g, were mixed homogeneously with 5 g anhydrous  $\text{Na}_2\text{SO}_4$ , and subsequently Soxhlet extracted during 8 h with 150  $\text{cm}^3$  pentane. Each series of five samples was accompanied by a blank sample of pure  $\text{Na}_2\text{SO}_4$  to detect any peak due to contamination of the samples during the entire procedure. The extract was concentrated to approximately 1  $\text{cm}^3$  applying a Kuderna-Danish evaporator, by which the solvent pentane evaporates. Subsequently the extract was dried applying a gentle stream of very pure nitrogen gas. The resulting residue (lipid extract) was air-dried at 60°C in an oven to constant dry weight. Lipid contents were determined gravimetrically.

To remove interfering substances, mainly lipids, from the organochlorines, the lipid extracts of the organisms were treated on micro liquid-solid chromatography (LSC) columns filled with 2.00 g of basic  $\text{Al}_2\text{O}_3$ . The eluates were concentrated to about 1  $\text{cm}^3$  on boiling water, using a micro-Snyder column.

A fraction separation between a first fraction containing apolar compounds such as PCBs, HCB and p,p'-DDE and a second fraction containing polar compounds (most organochlorine pesticides) was performed using micro LSC columns filled with 2.00 g pre-treated  $\text{SiO}_2$ . After separation, the eluates were concentrated to about 0.5  $\text{cm}^3$  by evaporation on boiling water. The resulting samples were transferred quantitatively to vials for the autosampler used for GC-analysis and diluted with hexane to a volume of 1  $\text{cm}^3$ .

The analysis of the samples were performed applying a Gas-Chromatograph (Hewlett-Packard 5880a) equipped with a capillary fused silica column (Chrompack wall coated, open tubular SE-54 column, length 60 m; inner diameter 0.34 mm) and a electron capture detector ( $^{63}\text{Ni}$ -ECD). The carrier gas through the column was helium (He, 210 kPa), make-up gas nitrogen (30  $\text{cm}^3 \cdot \text{min}^{-1}$ ), septum purge He (5  $\text{cm}^3 \cdot \text{min}^{-1}$ ), injector purge He (20  $\text{cm}^3 \cdot \text{min}^{-1}$ ), and the temperature of the injector and detector 230 and 320°C, respectively. The temperature program consisted of isothermal phases at 60°C (2 min), 180°C (8 min), 220°C (5 min) and 250°C (15 min), with intermediate temperature increase rates of 10°, 4° and 4°C·min<sup>-1</sup>, respectively. Splitless injection of a volume of 1  $\text{mm}^3$  sample was applied, with an autosampler (Hewlett-Packard 7672a).

For the identification and quantification of the different polychlorinated biphenyl congeners in the samples, a synthetic mixture of 66 individual PCB congeners and penta- and hexachlorobenzene was

applied as external standards. This standard mixture was injected every 8th injection for recalibration of retention time and response factors of the congeners. The retention time of a single congener present in the mixture and its response factor should not change more than 0.02 min and 10% respectively, between two standard mixtures. The retention time of two co-eluting congeners (eg. 70, 98 and 200, 157) and four co-eluting congeners (eg. 93, 66, 80, 95 and 115, 87, 90, 116) in the sample should not change more than 0.03 and 0.05 min., respectively. All organic solvents used were of nanograde quality (Mallinckrodt). Inorganic chemicals used were pretreated:

—Sodiumsulphate ( $\text{Na}_2\text{SO}_4$  - Baker): Soxhlet extracted during 12 h with an 1 : 1 acetone/hexane mixture and after drying on a waterbath, subsequently heated at 350°C during 10 h.

—Aluminiumoxide ( $\text{Al}_2\text{O}_3$ -Woelm B, super I): deactivated with 10% of double-distilled water, taken directly from the outlet of the quartz distillation apparatus to avoid any contamination from plastic tubing.

—Siliciumoxide ( $\text{SiO}_2$  - Merck): washing of about 300 g in a Buchner funnel with 5  $\text{dm}^3$  boiling demineralized water and subsequently, after discarding the water, washing three times with diethyl-ether. After drying on a waterbath to remove the diethyl-ether, the  $\text{SiO}_2$  was dried in an oven at 120°C for 2 h, followed by deactivation with 8% (w/w) of double-distilled water and shaken during 30 min for optimal homogenation. All glassware used for storing the samples, extraction and chromatographical procedures was degreased with a soap solution, rinsed with both tap and demineralized water, subsequently heated at 350°C for 8 h and rinsed with nanograde pentane.

Temperature and salinity of the surface seawater were measured using a portable combined salinity-temperature meter (EIL, sal/temp bridge type MC5) equipped with a temperature sensor and a conductivity cell. Water depth was measured using the echosounder of the research vessel 'TYRO'.

#### 4. RESULTS

The geographical position of the sampling stations and some hydrographical parameters (salinity, temperature and depth) are summarized in Table 1. Due to specific geomorphic conditions and geological composition of the bottom (eg. sand-dunes, canyons with steep changes in depth, areas with gravel and large cobbles) it was not possible to obtain sufficient or any sediment samples and/or benthic organisms from all sampling stations.

#### 4.1 TRACE METALS

##### 4.1.1 COPPER, ZINC, CADMIUM AND LEAD IN SEDIMENT

The grain-size distribution of the sediment from the bottom surface layer (upper 2 cm) from the different stations are given in Table 2.

The concentrations of the trace metals analysed in the silt fraction of the sediment (grain-size < 63  $\mu\text{m}$ ) are summarized in Table 3. Highest copper concentrations in the silt fraction of the sediment are found at some sampling stations in the Southern Bight, and west and north of the Dogger Bank (Fig. 3). The zinc concentration was found to be highest in the silt fraction from sampling stations in the Southern Bight and western part of the Dogger Bank (Fig. 4), and the same was found for the distribution of cadmium in the silt fraction (Fig. 5). The cadmium concentration in sediment from the Southern Bight (west of the Dutch coast) showed particular high values (10.6 - 31.1  $\mu\text{g.g}^{-1}$  dry wt). The concentration of lead in the sediment from the different stations is given in Fig. 6. In general, highest concentrations were found in the Southern Bight. Especially for cadmium and lead, high concentration levels are related with a very low percentage of the silt fraction (grain-size < 63  $\mu\text{m}$ ) of 0.07 to 0.20.

##### 4.1.2 COPPER, ZINC AND CADMIUM IN MACROBENTHIC INVERTEBRATE ORGANISMS

*Crangon allmanni*: The concentrations of copper, zinc and cadmium in the shrimp *Crangon allmanni* are given in Table 4.

Copper concentrations varied between 24 and 87  $\mu\text{g.g}^{-1}$  dry wt. There was no general trend in the distribution pattern of copper in the shrimp, though specimens obtained from sampling sites north of the Dogger Bank showed somewhat lower concentrations, whereas the concentrations in specimen from the central part of the North Sea tended to be higher (Fig. 7).

Zinc concentrations varied between 49 and 105  $\mu\text{g.g}^{-1}$  dry wt, and there were no specific areas with significant higher or lower concentrations, though highest concentrations were measured in specimens from the coastal zone (eg. station nrs 6-13 and 66-37; Fig. 8).

Cadmium concentrations in specimens from different parts of the North Sea varied considerably. Highest concentrations were found in specimens obtained from sampling sites situated north of the Dogger Bank (4 - 5  $\mu\text{g.g}^{-1}$  dry wt). In specimens from the

Dogger Bank itself and eastern side of it concentrations were still higher (1.3 - 2.4  $\mu\text{g.g}^{-1}$  dry wt) compared to the other areas of the North Sea, as the central part and Southern Bight with concentration levels of 0.6 to 1.2  $\mu\text{g.g}^{-1}$  dry wt (Fig. 9).

*Crangon crangon*: The concentrations of copper, zinc and cadmium in the brown shrimp *Crangon crangon* are summarized in Table 5.

Copper and zinc concentrations in the brown shrimp, varying from 49 to 74  $\mu\text{g.g}^{-1}$  dry wt and 62 to 96  $\mu\text{g.g}^{-1}$  dry wt respectively, were in the same range as in the shrimp *C. allmanni* (Figs. 10 and 11).

The cadmium concentrations, however, were considerably lower (0.27 to 0.55  $\mu\text{g.g}^{-1}$  dry wt) in specimens of the brown shrimp than in the shrimp *C. allmanni* (Fig. 12).

*Asterias rubens*: The concentrations of copper, zinc and cadmium in the starfish *Asterias rubens* are summarized in Table 6.

No differences in the concentrations of both copper (Fig. 13) and zinc (Fig. 14) in specimens from different areas in the North Sea could be detected. The copper concentrations varied between 5.9 and 28.7  $\mu\text{g.g}^{-1}$  dry wt, whereas the zinc concentration varied between 80 and 293  $\mu\text{g.g}^{-1}$  dry wt. Compared to the concentration of these metals in the two shrimp species analysed, it was seen that the level of the copper concentration was much lower and that of zinc much higher.

Significantly higher cadmium concentrations were found in specimens obtained from sampling sites north of the Dogger Bank (1.2 - 2.0  $\mu\text{g.g}^{-1}$  dry wt) compared to the other areas of the North Sea (0.4 - 1.2  $\mu\text{g.g}^{-1}$  dry wt) (Fig. 15).

#### 4.2. POLYCHLORINATED BIPHENYLS

##### 4.2.1. PCBs IN MACROBENTHIC INVERTEBRATE ORGANISMS

The number of individuals of each species investigated, the mean wet weight per animal and the amount of pentane extractable lipid (PEL, expressed as a percentage of the wet weight) are summarized in Table 7 (*Crangon allmanni*, *Crangon crangon* and *Asterias rubens*) and in Table 11 (*Nephtys hombergii*).

*Crangon allmanni*: The sum concentration of 35 individual PCB congeners ( $\Sigma\text{PCB}$ ) varied between 0.34 and 1.15  $\mu\text{g.g}^{-1}$  PEL (Table 7). There was no evidence for higher concentrations in individuals from the Southern Bight compared to the levels in organisms from the Central North Sea and Dogger Bank area (Fig. 16). The numbering of individual PCB congeners was done according to



BALLSCHMITER & ZELL (1980). In this system numbers 1-3 represent mono-, 4-15 di-, 16-39 tri-, 40-81 tetra-, 82-127 penta-, 128-169 hexa-, 170-193 hepta-, 194-205 octa-, 206-208 nonachlorobiphenyls and 209 decachlorobiphenyl. The PCB patterns, *i.e.* the contribution of each component to  $\Sigma$ PCB, were very similar in most samples of *C. allmanni*, irrespective the concentrations (Table 8). Only specimens from station 15-29 and 16-24 showed a higher presence of higher chlorinated congeners.

*Crangon crangon*: Specimens of the brown shrimp were only obtained from the coastal area and the concentration of  $\Sigma$ PCB, varying between 1.04 and 2.98  $\mu\text{g.g}^{-1}$  PEL., was significantly higher than in the closely related species *C. allmanni* (Table 7; Fig. 16). The highest  $\Sigma$ PCB concentrations were found in specimens from the coastal area, indicating that with respect to PCBs the impact of river outflow is restricted to a relatively small coastal area. The PCB patterns were highly similar in all samples of *C. crangon*, with only one octa- chlorobiphenyl (IUPAC 196) not detectable in the sample (Table 9).

*Asterias rubens*: The  $\Sigma$ PCB concentration in specimens from the coastal area was considerably higher than in specimens from the central North Sea and the Dogger Bank area (Fig. 17). These data confirm the results obtained for shrimp, indicating that the uptake of PCBs in biota occurred to highest levels in organisms living in coastal habitats. The relative contribution of the 35 individual PCB congeners selected to the PCB pattern is not similar in specimens from different sampling sites (Table 10). In specimens from a number of sampling sites (station 40-98, 46-106, 65-45 and 70-36) the lower chlorinated congeners contribute to a greater extent to the total PCB concentration.

*Nephtys hombergii*: The  $\Sigma$ PCB concentration varied between 0.1 and 2.4  $\mu\text{g.g}^{-1}$  PEL (Table 11). No significant differences in concentration levels in specimens from different areas in the North Sea were found, though somewhat lower concentrations were measured in specimens from the Dogger Bank area (Fig. 18). The PCB pattern is not similar in specimens from different sampling sites (Table 12). In specimens from the coastal zone (station 1-21, 6-13, 7-10 and 66-37) most higher chlorinated congeners could be identified and contribute to a great extent to the total PCB concentration.

## 5. DISCUSSION

### 5.1 TRACE METALS

#### 5.1.1 COPPER, ZINC, CADMIUM AND LEAD IN SEDIMENT

The texture of the sediments, especially in the surface layers changes constantly due to currents and turbulence, bioturbating activity of benthic organisms and trawling. Sediments thus seldom reflect the most recent contamination. Analysis of bulk sediment for trace metals often result in a great variability, reflecting the inhomogeneity of the sediments. Various grain-size fractions contain different concentrations of trace elements, the highest concentration being found in the finest grain-size fraction (in present study the grain-size fraction  $< 63 \mu\text{m}$ ), because most contaminants will be transported as fine grained suspended matter possessing a relatively large surface area. Thus the metal contamination of sediments can be explained by the concentration in the silt fraction. In present study the concentration of copper, zinc, cadmium and lead in the silt fraction varied considerably and a high concentration was very much related to a very low percentage ( $< 0.4 \%$ ) of the silt fraction (*cf.* Tables 2 and 3; eg. station 3-20, 9-9, 10-12, 71-31).

Comparison of the data with metal levels in sediments of marine systems from various climatological latitudes leads to the following conclusions: The concentration of copper in the silt fraction of North Sea surface sediments is in the same order of magnitude as the copper levels in sediment of the Dutch Wadden Sea (KRAMER *et al.*, 1985), Australian waters (TALBOT, 1983; TALBOT & CHEGWIDEN, 1983) and some tropical marine waters (WINDOM *et al.*, 1984; EVERAARTS & SWENNEN, 1987; EVERAARTS, 1989). Sediments from only three sampling sites (station 3-20, 7-10, 71-31; nearby coastal area) showed a considerably higher copper concentration, probably due to local river input or dumping site. Comparison of the results of the above cited studies with the data of North Sea sediments reveal that the concentrations of zinc and cadmium are higher than in other areas; sediments of the North Sea have to be considered as highly contaminated for cadmium and zinc. Highest concentrations are specially found in the Southern Bight. The concentrations of lead are in the same order of magnitude as in sediments of some coastal areas, to be considered as contaminated, of the Malay Peninsula (EVERAARTS & SWENNEN, 1987) and the Gulf of Thermaikos, Mediterranean (VOUSINOU-TALIADOURI & SATSMAD-

JIS, 1983). Data on the distribution of trace metals in surface sediments from the northern part of the North Sea (56° N to 61° N) indicate that despite the enhanced concentrations of cadmium, nickel, lead and cobalt, there was no evidence of any important or large-scale contamination of North Sea as a whole (BASFORD & ELEFThERIOU, 1988). However, the concentrations, expressed in ppm, apparently were measured in bulk sediment.

#### 5.1.2 COPPER, ZINC AND CADMIUM IN MACROBENTHIC INVERTEBRATE ORGANISMS

In the shrimp *Crangon allmanni* the whole body concentration of both copper (cf. Fig. 7) and zinc (cf. Fig. 8) did not vary significantly in specimens obtained all over the sampling area. Nevertheless, there is some evidence for lower copper concentrations in specimens occurring at the north edge of the Dogger Bank and higher concentrations in the central North Sea (especially in the sedimentation area in between 54° N and 55° N; cf. Fig. 7). The cadmium concentrations in specimens sampled just north of the Dogger Bank are significantly higher than in other areas of the North Sea, varying from 2.4 to 5.1  $\mu\text{g.g}^{-1}$  dry weight (cf. Fig. 9).

No differences in the whole body concentration of copper, zinc and cadmium were found in the brown shrimp *Crangon crangon* obtained from the different sampling sites (cf. Figs. 10, 11, 12). Individuals of this species could be obtained only from the coastal zone of the Southern Bight. A comparison of the concentrations of the three metals in whole body of *C. crangon* and *C. allmanni* obtained from corresponding sampling stations, indicates a significant ( $p < 0.01$ ) difference in the cadmium concentrations in both species: mean concentration ( $\pm$  S.D.) of 0.40 ( $\pm$  0.09) and 0.99 ( $\pm$  0.24) in *C. crangon* and *C. allmanni*, respectively (N=15). However, there is no significant difference between the species in copper and zinc concentrations: Cu: 57.3 ( $\pm$  8.2) and 56.1 ( $\pm$  12.7)  $\mu\text{g.g}^{-1}$  dry wt, and Zn: 83.1 ( $\pm$  11.4) and 82.8 ( $\pm$  11.9) in *C. crangon* and *C. allmanni*, respectively (N=15). In specimens of the brown shrimp obtained from the Dutch Wadden Sea, the mean concentrations ( $\mu\text{g.g}^{-1}$  dry wt; N=9) of copper, zinc and cadmium were 54.3 ( $\pm$  25.2), 69.2 ( $\pm$  5.4) and 0.17 ( $\pm$  0.14), respectively (Everaarts unpublished data 1986). In comparison with the North Sea data, the cadmium concentration in specimens of the Dutch Wadden Sea appeared to be significantly ( $p < 0.01$ ) lower. Thus, the data indicate a gradient of increasing contamination of cadmium from the estuarine area (Wadden Sea) to the coastal zone of the North sea, and

further to the open sea, when taking into account the cadmium levels in shrimp from the Dogger Bank area.

A comparison of the metal concentrations in the asteroid echinoderm *Asterias rubens* from 57 sampling sites (cf. Figs 13, 14, 15) showed no significant differences in copper and zinc, whereas the cadmium concentration was significantly higher in specimens from the area north and east of the Dogger Bank. Besides, in specimens from a small coastal zone slightly increased cadmium levels could be observed.

Comparison of concentration levels in corresponding species from tropical regions (EVERAARTS & SWENNEN, 1987; EVERAARTS *et al.*, 1989) give evidence for the conclusion that copper and zinc concentrations are higher or similar, whereas the cadmium concentration is considerably lower, except the cadmium levels in *Crangon allmanni* from the area north of the Dogger Bank. The concentration levels and the distribution patterns found in present study agree well with data obtained for other selected macrobenthic invertebrate species, showing enhanced cadmium and lead levels in those species from the northeastern part of the Dogger Bank (KRONCKE, 1987) and north of the Dogger Bank (KARBE, 1987).

#### 5.2. POLYCHLORINATED BIPHENYL IN MACROBENTHIC ORGANISMS

Polychlorinated biphenyls are extremely lipophilic. The lipid content of the organisms therefore is an important parameter with respect to the concentration of PCB congeners. In the baltic tellin *Macoma balthica* the PCB concentrations were found to be twice as high at low lipid contents, when compared with the highest lipid contents (BOON & DUINKER, 1986). During winter an increase in wet weight takes place, without a corresponding increase in lipid content, causing a lower percentage of lipid. For this reason and because lipid contents of various species are not the same, the concentrations of the individual PCB congeners and  $\Sigma$ PCB are expressed on base of pentane extractable lipid, for an accurate comparison of contents in various species and specimens of one species from different areas of the North Sea. Also the chemical composition of the lipid may determine the PCB concentration. The lipid composition of the specimens may change during the season and reproductive cycle. In the starfish *Asterias rubens* significant changes were found, both in total lipid content and the chemical composition of the lipid, in the pyloric caeca and ovaries during the reproductive cycle (OUDEJANS & VAN DER SLUIS, 1979) The stan-

standard deviation of the lipid contents (mean value of S.D. 0.15) is much higher in starfish than in the shrimp species *Crangon allmanni* (mean value of S.D. 0.04) and *C. crangon* (mean value of S.D. 0.08) (cf. Table 7), indicating that in present study, even while samples were taken within a relatively short period of time, also differences in lipid content may affect the total amount of PCBs accumulated in starfish.

Polychlorinated biphenyls have been synthesized in the form of technical mixtures and therefore PCBs will always be present in certain patterns in environmental samples. However, large differences exist between the relative contribution of individual PCB congeners to the total PCB in the different environmental compartments water, suspended matter, sediment and organisms as well as between different animal species (DUINKER & HILLEBRAND, 1983b; DUINKER *et al.*, 1983; BOON *et al.*, 1989). A comparison of the PCBs present in a certain environmental compartment or organisms may be done either on basis of the concentration of single congeners or the sum-concentration of a number or all identified congeners. For monitoring purposes it has been suggested to select congeners 52, 44 (tetra-CBs), 84, 101, 118 (penta-CBs), 149, 153, 138, 128 (hexa-CBs), 187, 183, 180 and 170 (hepto-CBs) (BOON & DUINKER, 1986) (The congeners are given in sequence of elution from the capillary column). In the present study as many congeners as possible to be identified and quantified with respect to the standard mixtures used, and present in the species analysed, were taken into account for determination of the  $\Sigma$ PCB concentration.

In the benthic invertebrates *Arenicola marina* (lugworm), *Macoma balthica* (baltic tellin) and *Crangon crangon* (brown shrimp) from the same area of the Wadden Sea the concentration of chlorinated hydrocarbons on fat weight base are similar (DUINKER *et al.*, 1983). The data of present study give some indication for slightly higher  $\Sigma$ PCB concentrations in starfish compared to brown shrimp, from corresponding areas. However, the  $\Sigma$ PCB concentration in starfish and the shrimp *C. allmanni* from corresponding areas is the same (cf. Figs. 16 and 17). In *Nephtys hombergii*, the  $\Sigma$ PCB concentrations show the same range as in *C. allmanni*, the mean value being somewhat lower than in the coastal species *C. crangon*. A comparison of  $\Sigma$ PCB concentration in various species from different geographical areas of the North Sea give evidence for enhanced levels in specimens of shrimp and starfish obtained from the coastal zone. This may indicate that the impact of outflow of the river Rhine is restricted to the coastal

zone. These data agree with the results of a study of BOON *et al.* (1985) on the distribution of organochlorines in *Nephtys* and sediment from the southern North Sea. On the contrary, however, the data on *Nephtys* in present study (cf. Fig. 18) do not indicate evidently higher  $\Sigma$ PCB levels in specimens from the coastal zone. Moreover, the concentrations in *Nephtys* (present study) are significantly lower than the PCB levels reported by BOON *et al.* (1985). In specimens from sampling sites in the coastal zone (station 1-21, 6-13, 7-10, 66-37 and to a lesser extent 68-52 and 71-31) almost all congeners distinguished, contribute to the  $\Sigma$ PCB concentration, whereas in specimens from the other areas in the North Sea the persistent, high chlorinated congeners could not be detected.

The contribution of low chlorinated PCB congeners to the sum-concentration of PCB is higher in starfish than in shrimp and *Nephtys*. These higher concentrations of low chlorinated congeners in starfish could be due to a low metabolism of PCBs (low mixed function oxygenase enzyme activity; cf. BOON *et al.*, 1989) and to strongly varying lipid contents.

The highest concentration of  $\Sigma$ PCB was measured in *Crangon crangon* and *Asterias rubens* from a coastal area nearby the mouth of the rivers Rhine and Ems.

In general, on the basis of PCB patterns occurring in the samples, the North Sea can be divided into three areas: The northern part of the North Sea, with lowest  $\Sigma$ PCB concentrations with a relatively high contribution of low chlorinated congeners; the central part of the North Sea with increasing  $\Sigma$ PCB concentrations with an equal contribution of low and high chlorinated congeners to the total PCB pattern; the Southern Bight, especially the coastal zone, with high  $\Sigma$ PCB concentrations and a relatively high contribution of high chlorinated congeners to the total PCB pattern.

## 6. REFERENCES

- BALLSCHMITER, K. & M. ZELL, 1980. Analysis of polychlorinated biphenyls (PCB) by glass capillary gas chromatography. Composition of technical Arochlor and Clophen-PCB mixtures.—Z. analyt. Chem. **302**: 20-31.
- BASFORD, D. & A. ELEFTHERIOU, 1988. The benthic environment of the North Sea (56° to 61° N).—J. mar. biol. Ass. U.K. **68**: 125-141.
- BOON, J.P., 1986. The kinetics of individual polychlorinated biphenyl (PCB-) congeners in marine organisms; a comparative approach.—Thesis, University of Groningen: 1-54.
- BOON, J.P. & J.C. DUINKER, 1986. Monitoring of cyclic organochlorines in the marine environment.—

- Environmental Monitoring and Assessment 7: 189-208.
- BOON, J.P., F. EIJGENRAAM, J.M. EVERAARTS & J.C. DUINKER, 1989. A structure-activity relationship (SAR) approach towards metabolism of PCBs in marine animals from different trophic levels.—Mar. Environm. Res., in press.
- BOON, J.P., M.B. VAN ZANTVOORT, M.J.M.A. GOVAERT & J.C. DUINKER, 1985. Organochlorines in benthic polychaetes (*Nephtys* spp.) and sediments from the southern North Sea. Identification of individual PCB components.—Neth. J. Sea Res. 19: 93-109.
- DUINKER, J.C. & M.T.J. HILLEBRAND, 1978. Minimizing blank values in chlorinated hydrocarbon analysis.—J. Chromat. 150: 195-199.
- DUINKER, J.C. & M.T.J. HILLEBRAND, 1983a. Characterization of PCB components in Clophen formulations by capillary GC-MS and GC-ECD techniques.—Environ. Sci. Technol. 17: 449-456.
- DUINKER, J.C. & M.T.J. HILLEBRAND, 1983b. Composition of PCB mixtures in biotic and abiotic marine compartments (Dutch Wadden Sea).—Bull. Environ. Contam. Toxicol. 31: 25-32.
- DUINKER, J.C., M.T.J. HILLEBRAND & J.P. BOON, 1983. Organochlorines in benthic invertebrates and sediments from the Dutch Wadden Sea; identification of individual PCB components.—Neth. J. Sea Res. 17: 19-38.
- EVERAARTS, J.M., 1986. Is monitoring of respiratory properties of the haemoglobin of the lugworm *Arenicola marina* meaningful?—Environmental Monitoring and Assessment. 7: 273-283.
- , 1989. Heavy metals (Cu, Zn, in sediment of the Java Sea, estuarine and coastal areas of East Java and some deep sea areas.—Neth. J. Sea Res., 23: in press.
- EVERAARTS, J.M., J.P. BOON, W. KASTORO, C.V. FISCHER, H. RAZAK & I. SUMANTA, 1989. Copper, zinc and cadmium in benthic organisms from the Java Sea and estuarine and coastal areas around East-Java.—Neth. J. Sea Res., 23: in press.
- EVERAARTS J.M. & C. SWENNEN, 1987. Heavy metals (Zn, Cu, Cd, Pb) in some benthic invertebrate species and in sediment from three coastal areas in Thailand and Malaysia.—J. Sci. Soc. Thailand 13: 189-203.
- HOLDEN, A.V. & K. MARSDEN, 1969. Single stage clean-up of animal tissue abstract for organal chlorine residue analysis.—J. Chromat. 44: 481-492.
- KARBE, L., 1987. Biologisches Monitoring zur Bestimmung der Verfügbarkeit von Schadstoffen. In: Zirkulation und Schadstoffumsatz in der Nordsee, BMFT-Projekt MFU 0545, pp.: 76-85.
- KRAMER, C.J.M., J.P. BOON, J.C. DUINKER, J.M. EVERAARTS, M.T.J. HILLEBRAND, R.F. NOLTING & E.M. VAN DER VLIES, 1985. Contaminants in the Dutch Wadden Sea and a comparison with surrounding areas.—Report no. M201 of the Ministry of Public Health and Environment, pp.: 127 (in Dutch).
- KRONCKE, I., 1987. Lead and cadmium contents in selected macrofauna species from the Dogger Bank and eastern North Sea.—Helgoländer Meeresunters. 41: 465-475.
- LORING, D.H. & R.T.T. RANTALA, 1977. Geochemical analysis of marine sediments and suspended particulate matter.—Fish. Mar. Serv. Canada, Techn. Report no. 700.
- OUDEJANS, R.C.H.M. & I. VAN DER SLUIS, 1979. Storage and depletion of lipid components in the pyloric caeca and ovaries of the seastar *Asterias rubens* during its annual reproductive cycle.—Mar. Biol. 53: 239-247.
- PAUS, P.E., 1972. Bomb decomposition of biological materials.—Atomic Absorption Newsletter 11: 129-130.
- TALBOT, V., 1983. Lead and other trace metals in the sediments and selected biota of Princess Royal Harbour, Albany, Western Australia.—Environm. Pollut. (Series B) 5: 35-49.
- TALBOT, V. & A. CHEGWIDDEN, 1983. Heavy metals in the sediments of Cockburn Sound, Western Australia, and its surrounding areas.—Environm. Pollut. (Series B) 5: 187-205.
- VOUTSINOU-TALIADOURI, F. & J. SATSMADJIS, 1983. Metals in polluted sediments from the Thermaikos Gulf, Greece.—Mar. Poll. Bull. 14: 234-236.
- WILDE, P.A.W.J. DE & G.C.A. DUINEVELD, 1988. Macrobenthos of the Dutch Continental Shelf, Data Report North Sea Benthos Survey, April 1986, pp. 107 (In Dutch).
- WINDOM, H.L., S. SILPIPAT, A. CHANPONGSANG, R.G. SMITH JR. & M. M. HUNGSPREUGS, 1984. Trace metal composition of and accumulation rates of sediments in the Upper Gulf of Thailand.—Estuarine, Coastal and Shelf Science 19: 133-142.

**Table 1.** The geographical position of the sampling stations of the Synoptic Mapping Programme North Sea 1986; the salinity ( $^{\circ}/_{00}$ ) and temperature ( $^{\circ}\text{C}$ ) of the surface water (at 1 m depth), and the depth (m) measured at the sampling stations.

Sampling-station Tyro-ICES #	Geographical position		Salinity ( $^{\circ}/_{00}$ )	Temperature ( $^{\circ}\text{C}$ )	Depth (m)
	N	E			
1- 21	52 <sup>0</sup> 45 <sup>˘</sup> 3	4 <sup>0</sup> 30 <sup>˘</sup> 2	31.90	4.8	23
2- 25	53 <sup>0</sup> 00 <sup>˘</sup> 8	3 <sup>0</sup> 59 <sup>˘</sup> 1	35.32	5.1	20
3- 20	52 <sup>0</sup> 45 <sup>˘</sup> 5	3 <sup>0</sup> 30 <sup>˘</sup> 2	35.53	5.0	27
4- 18	52 <sup>0</sup> 29 <sup>˘</sup> 7	4 <sup>0</sup> 00 <sup>˘</sup> 5	33.50	4.6	25
5- 15	52 <sup>0</sup> 16 <sup>˘</sup> 5	3 <sup>0</sup> 31 <sup>˘</sup> 3	34.65	4.7	35
6- 13	52 <sup>0</sup> 03 <sup>˘</sup> 2	4 <sup>0</sup> 08 <sup>˘</sup> 9	21.80	6.8	12
7- 10	51 <sup>0</sup> 44 <sup>˘</sup> 7	3 <sup>0</sup> 30 <sup>˘</sup> 9	30.70	5.1	20
8- 7	51 <sup>0</sup> 30 <sup>˘</sup> 8	3 <sup>0</sup> 01 <sup>˘</sup> 5	33.74	5.9	29
9- 9	51 <sup>0</sup> 44 <sup>˘</sup> 7	2 <sup>0</sup> 29 <sup>˘</sup> 7	35.57	6.1	40
10- 12	52 <sup>0</sup> 00 <sup>˘</sup> 2	2 <sup>0</sup> 59 <sup>˘</sup> 2	35.37	5.4	40
11- 14	52 <sup>0</sup> 14 <sup>˘</sup> 1	2 <sup>0</sup> 29 <sup>˘</sup> 2	35.30	6.0	45
12- 17	52 <sup>0</sup> 29 <sup>˘</sup> 5	3 <sup>0</sup> 00 <sup>˘</sup> 6	34.92	4.7	39
13- 19	52 <sup>0</sup> 43 <sup>˘</sup> 7	2 <sup>0</sup> 23 <sup>˘</sup> 7	34.40	4.8	53
14- 23	52 <sup>0</sup> 59 <sup>˘</sup> 2	2 <sup>0</sup> 01 <sup>˘</sup> 7	34.68	4.8	34
15- 29	53 <sup>0</sup> 13 <sup>˘</sup> 6	2 <sup>0</sup> 34 <sup>˘</sup> 8	34.90	4.7	34
16- 24	52 <sup>0</sup> 56 <sup>˘</sup> 7	3 <sup>0</sup> 00 <sup>˘</sup> 8	35.00	4.8	43
17- 30	53 <sup>0</sup> 11 <sup>˘</sup> 0	3 <sup>0</sup> 27 <sup>˘</sup> 1	35.30	5.2	27
18- 35	53 <sup>0</sup> 29 <sup>˘</sup> 3	3 <sup>0</sup> 54 <sup>˘</sup> 2	34.92	4.7	30
19- 42	53 <sup>0</sup> 46 <sup>˘</sup> 2	3 <sup>0</sup> 27 <sup>˘</sup> 9	35.06	4.8	37
20- 34	53 <sup>0</sup> 29 <sup>˘</sup> 2	3 <sup>0</sup> 04 <sup>˘</sup> 1	34.88	4.7	33
21- 41	53 <sup>0</sup> 44 <sup>˘</sup> 8	2 <sup>0</sup> 30 <sup>˘</sup> 1	34.94	4.8	26
22- 33	53 <sup>0</sup> 29 <sup>˘</sup> 9	2 <sup>0</sup> 00 <sup>˘</sup> 3	34.84	4.9	20
23- 49	53 <sup>0</sup> 59 <sup>˘</sup> 8	2 <sup>0</sup> 02 <sup>˘</sup> 4	35.07	5.2	69
24- 58	54 <sup>0</sup> 15 <sup>˘</sup> 5	2 <sup>0</sup> 29 <sup>˘</sup> 5	35.05	5.2	41
25- 50	54 <sup>0</sup> 00 <sup>˘</sup> 2	3 <sup>0</sup> 00 <sup>˘</sup> 9	34.92	4.4	43
26- 59	54 <sup>0</sup> 15 <sup>˘</sup> 4	3 <sup>0</sup> 31 <sup>˘</sup> 2	35.01	4.6	44
27- 51	54 <sup>0</sup> 00 <sup>˘</sup> 4	3 <sup>0</sup> 59 <sup>˘</sup> 9	34.92	4.6	48
28- 60	54 <sup>0</sup> 15 <sup>˘</sup> 0	4 <sup>0</sup> 30 <sup>˘</sup> 0	34.86	5.8	49
29- 79	54 <sup>0</sup> 44 <sup>˘</sup> 8	4 <sup>0</sup> 30 <sup>˘</sup> 7	34.92	4.5	51
30- 69	54 <sup>0</sup> 29 <sup>˘</sup> 9	4 <sup>0</sup> 00 <sup>˘</sup> 4	35.05	4.8	48
31- 78	54 <sup>0</sup> 44 <sup>˘</sup> 8	3 <sup>0</sup> 28 <sup>˘</sup> 8	35.00	4.6	41
32- 68	54 <sup>0</sup> 30 <sup>˘</sup> 6	3 <sup>0</sup> 01 <sup>˘</sup> 2	35.10	5.2	39
33- 77	54 <sup>0</sup> 45 <sup>˘</sup> 7	2 <sup>0</sup> 27 <sup>˘</sup> 6	35.07	5.3	23
34- 67	54 <sup>0</sup> 30 <sup>˘</sup> 3	2 <sup>0</sup> 00 <sup>˘</sup> 1	35.60	5.8	24
35- 86	55 <sup>0</sup> 01 <sup>˘</sup> 8	1 <sup>0</sup> 59 <sup>˘</sup> 7	35.10	5.0	32
36- 96	55 <sup>0</sup> 14 <sup>˘</sup> 9	2 <sup>0</sup> 29 <sup>˘</sup> 6	35.15	4.8	40
37- 87	54 <sup>0</sup> 59 <sup>˘</sup> 8	3 <sup>0</sup> 00 <sup>˘</sup> 9	34.98	5.2	27
38- 97	55 <sup>0</sup> 15 <sup>˘</sup> 1	3 <sup>0</sup> 30 <sup>˘</sup> 2	35.00	4.9	30
39- 88	54 <sup>0</sup> 59 <sup>˘</sup> 1	3 <sup>0</sup> 57 <sup>˘</sup> 5	34.95	5.0	50

Table 1. Continued

Sampling- station Tyro-ICES #	Geographical position		Salinity ( $^{\circ}/_{00}$ )	Temperature ( $^{\circ}$ C)	Depth (m)
	N	E			
40- 98	55 <sup>0</sup> 15'5	4 <sup>0</sup> 29'5	34.95	4.7	50
41-119	55 <sup>0</sup> 44'7	4 <sup>0</sup> 29'9	34.98	4.7	44
42-108	55 <sup>0</sup> 30'3	4 <sup>0</sup> 00'2	34.95	4.9	32
43-118	55 <sup>0</sup> 44'9	3 <sup>0</sup> 29'6	35.13	5.2	54
44-107	55 <sup>0</sup> 30'2	3 <sup>0</sup> 00'6	35.06	5.3	41
45-117	55 <sup>0</sup> 45'3	2 <sup>0</sup> 29'9	35.11	4.8	83
46-106	55 <sup>0</sup> 28'7	2 <sup>0</sup> 00'1	35.21	5.0	80
47-127	56 <sup>0</sup> 00'2	1 <sup>0</sup> 59'9	35.37	5.3	86
48-139	56 <sup>0</sup> 15'4	2 <sup>0</sup> 31'8	35.48	6.0	78
49-128	56 <sup>0</sup> 00'1	2 <sup>0</sup> 59'8	35.38	5.6	84
50-140	56 <sup>0</sup> 15'7	3 <sup>0</sup> 30'7	35.33	5.6	68
51-129	56 <sup>0</sup> 00'1	4 <sup>0</sup> 00'8	35.25	5.4	54
52-141	56 <sup>0</sup> 15'1	4 <sup>0</sup> 30'1	35.32	5.7	60
53-142	56 <sup>0</sup> 15'1	5 <sup>0</sup> 29'3	35.02	5.2	60
54-130	56 <sup>0</sup> 00'1	4 <sup>0</sup> 59'7	35.12	5.3	56
55-120	55 <sup>0</sup> 45'4	5 <sup>0</sup> 29'6	34.97	5.4	54
56-109	55 <sup>0</sup> 29'3	4 <sup>0</sup> 58'9	34.95	5.5	45
57- 99	55 <sup>0</sup> 15'2	5 <sup>0</sup> 31'1	35.00	5.5	45
58- 89	55 <sup>0</sup> 01'0	4 <sup>0</sup> 59'9	34.90	5.2	42
59- 80	54 <sup>0</sup> 44'9	5 <sup>0</sup> 30'3	34.77	5.3	45
60- 70	54 <sup>0</sup> 30'7	4 <sup>0</sup> 59'7	34.88	4.8	45
61- 61	54 <sup>0</sup> 15'1	5 <sup>0</sup> 29'8	34.77	5.2	42
62- 71	54 <sup>0</sup> 29'5	6 <sup>0</sup> 00'5	34.42	5.6	44
63- 62	54 <sup>0</sup> 15'3	6 <sup>0</sup> 30'0	34.02	5.1	39
64- 53	53 <sup>0</sup> 59'9	5 <sup>0</sup> 59'8	33.45	6.0	35
65- 45	53 <sup>0</sup> 42'0	6 <sup>0</sup> 28'9	32.12	6.5	22
66- 37	53 <sup>0</sup> 36'6	5 <sup>0</sup> 59'8	31.40	6.7	26
67- 44	53 <sup>0</sup> 45'5	5 <sup>0</sup> 30'4	33.27	6.4	32
68- 52	53 <sup>0</sup> 59'0	5 <sup>0</sup> 01'8	35.03	6.0	41
69- 43	53 <sup>0</sup> 44'9	4 <sup>0</sup> 29'6	34.92	6.3	42
70- 36	53 <sup>0</sup> 32'0	5 <sup>0</sup> 00'7	34.23	6.6	28
71- 31	53 <sup>0</sup> 14'8	4 <sup>0</sup> 28'5	34.93	6.7	29

Table 2. The texture of the surface layer (upper 2 cm) of sediment from the North Sea.

Sampling- station Tyro-ICES #	% grain-size fraction ( $\mu\text{m}$ )					
	>500	315-500	200-315	100-200	63-100	<63
3- 20	.16	2.12	62.01	35.36	.27	.07
5- 15	.77	27.33	65.12	6.43	.19	.16
6- 13	.85	1.82	5.07	56.45	20.67	15.14
7- 10	19.44	62.97	15.44	1.83	.20	.11
8- 7	15.50	38.11	33.14	12.67	.21	.37
9- 9	24.62	63.10	11.19	.77	.12	.20
10- 12	6.82	49.63	40.94	2.33	.16	.12
12- 17	1.22	11.33	76.44	9.38	.28	1.35
15- 29	.55	2.75	83.18	13.06	.23	.23
18- 35	.05	.35	1.52	91.89	4.05	2.14
19- 42	.05	1.09	16.11	81.17	1.30	.28
23- 49	.27	1.03	1.90	82.18	7.64	6.98
24- 58	1.06	1.06	22.84	72.34	2.33	.38
26- 59	.22	1.11	12.41	75.22	8.90	2.14
28- 60	.34	1.47	3.62	34.46	41.98	18.14
30- 69	.17	.45	.95	41.38	51.57	5.49
31- 78	.16	.16	.60	40.92	56.68	1.47
32- 68	.23	.17	.57	66.74	30.90	1.39
33- 77	5.00	5.15	17.44	69.29	2.90	.22
34- 67	4.27	7.88	28.29	58.01	1.42	.12
35- 86	2.69	6.56	18.96	69.42	1.81	.57
37- 87	3.42	3.64	18.56	71.33	2.57	.49
38- 97	2.20	2.37	18.79	73.24	2.80	.59
39- 88	.64	1.23	2.04	25.68	63.50	6.91
40- 98	.22	1.21	5.47	70.41	19.66	3.03
41-119	.50	4.26	17.70	71.97	4.76	.81
43-118	1.21	3.79	14.70	75.82	3.27	1.20
45-117	.70	1.52	6.38	37.83	47.32	6.25
46-106	.47	1.32	3.63	84.24	7.42	2.92
47-127	1.61	2.80	8.50	62.39	17.82	6.88
48-139	.94	2.39	9.77	81.10	3.74	2.06
49-128	1.29	3.15	15.85	71.39	4.44	3.88
51-129	.57	5.27	29.21	60.88	3.32	.76
52-141	2.38	2.93	18.80	68.47	5.15	2.28
53-142	.33	1.27	1.16	30.20	50.76	16.28
57- 99	.21	.21	.70	67.55	28.45	2.87
60- 70	.05	.27	5.85	87.00	5.25	1.58
61- 61	.54	3.30	17.09	68.09	8.17	2.81
62- 71	.68	1.10	3.14	65.56	18.52	11.00
64- 53	2.90	10.43	27.90	53.38	4.09	1.30
68- 52	1.97	1.92	3.09	54.73	22.60	15.69
69- 43	3.85	1.34	2.57	28.34	34.69	29.22
71- 31	6.34	24.58	45.64	23.05	.26	.14

**Table 3.** The concentration of copper, zinc, cadmium and lead in the silt fraction (grain-size < 63  $\mu\text{m}$ ) of the surface layer (upper 2 cm) of sediment from the North Sea.

Sampling-station Tyro-ICES #	<u>Sediment</u> - grain-size < 63 $\mu\text{m}$ Concentration in $\mu\text{g}\cdot\text{g}^{-1}$ dry weight			
	Copper	Zinc	Cadmium	Lead
3- 20	241.5	1269.0	10.62	84.6
5- 15	22.6	250.8	2.92	109.7
6- 13	18.9	226.8	1.39	59.0
7- 10	104.9	3158.2	6.80	233.6
8- 7	17.1	323.5	2.37	180.1
9- 9	62.2	1014.4	16.83	255.6
10- 12	44.4	1775.8	12.34	252.3
12- 17	16.5	147.1	5.01	104.6
15- 29	24.9	2032.7	2.17	166.9
18- 35	90.2	554.7	2.18	132.5
19- 42	25.2	727.0	3.37	224.4
23- 49	15.4	120.5	.66	75.3
24- 58	97.7	481.6	6.40	84.5
26- 59	10.8	169.6	--	54.8
28- 60	20.6	125.2	.17	57.2
30- 69	50.9	126.2	.32	78.1
31- 78	27.1	304.1	.53	73.2
32- 68	11.9	177.6	1.10	70.1
33- 77	99.1	2422.8	2.20	29.7
34- 67	53.2	2528.3	5.50	117.4
35- 86	46.2	857.2	3.92	30.7
37- 87	16.3	631.9	.92	73.4
38- 97	23.4	880.6	3.30	63.8
39- 88	24.2	192.2	.17	67.5
40- 98	43.0	169.7	.78	113.3
41-119	28.9	231.1	1.29	198.4
43-118	32.7	294.4	1.00	106.4
45-117	9.8	119.0	.25	54.7
46-106	15.8	520.6	1.07	98.1
47-127	54.1	167.1	1.04	88.2
48-139	55.2	172.4	1.06	235.4
49-128	60.3	265.4	5.62	217.6
51-129	84.1	273.2	--	104.5
52-141	9.8	199.7	2.34	74.2
53-142	24.5	106.5	.51	66.7
57- 99	52.6	167.4	.63	72.0
60- 70	32.7	274.1	.42	39.3
61- 61	12.5	411.9	1.46	94.4
62- 71	43.7	265.4	.89	77.3
64- 53	11.2	447.7	1.25	87.2
68- 52	26.7	142.7	.32	82.4
69- 43	13.7	115.2	.56	66.8
71- 31	144.0	4165.1	31.07	631.5



Table 4. The concentration of copper, zinc and cadmium in whole-body of the shrimp Crangon allmanni (Arthropoda, Crustacea, Natantia).

Sampling-station Tyro-ICES #	<u>Crangon allmanni</u> Concentration in $\mu\text{g}\cdot\text{g}^{-1}$ dry weight		
	Copper	Zinc	Cadmium
1- 21	49.3	90.9	.84
2- 25	66.3	64.6	.55
3- 20	67.8	69.2	.99
4- 18	33.0	88.0	.62
6- 13	43.0	100.6	.77
7- 10	53.7	89.0	.95
15- 29	64.9	86.4	.86
16- 24	51.9	72.6	.90
17- 30	65.4	92.7	.84
19- 42	70.6	88.7	.92
20- 34	86.9	92.8	.93
23- 49	65.4	89.6	.85
24- 58	54.8	76.8	.99
27- 51	59.2	73.1	.78
28- 60	72.0	76.7	.79
29- 79	74.8	81.2	.71
30- 69	64.3	78.4	.88
31- 78	56.2	71.4	1.00
32- 68*	60.2	79.8	1.00
38- 97	58.8	70.6	.86
40- 98	59.1	82.7	1.75
41-119**	40.3	79.4	2.39
45-117***	36.0	72.7	4.82
46-106	40.1	62.0	4.06
49-128	35.5	73.2	3.86
50-140	24.0	75.0	5.08
51-129	32.2	68.9	4.87
52-141	35.7	77.2	4.54
54-130	49.2	74.7	2.39
56-109	41.6	79.9	2.08
57- 99	57.3	77.4	1.58
59- 80	60.7	71.6	1.38
60- 70	61.5	65.8	2.03
61- 61	59.9	66.0	1.03
62- 71	60.5	73.5	1.26
63- 62	60.3	70.0	1.38
64- 53	54.3	85.8	1.20
65- 45	53.8	93.7	.90
66- 37	44.2	104.8	.85
67- 44	56.0	83.7	.89
68- 52	45.3	49.1	1.01
69- 43	67.1	80.8	1.09
70- 36	44.5	71.6	.98

\* mixed sample from stations 32-68, 35-86 and 37-87

\*\* mixed sample from stations 41-119, 42-108 and 43-118

\*\*\* mixed sample from stations 45-117, 47-127 and 48-139

Table 5. The concentration of copper, zinc and cadmium in the brown shrimp Crangon crangon (Arthropoda, Crustacea, Natantia).

Sampling-station Tyro-ICES #	<u>Crangon crangon</u> Concentration in $\mu\text{g.g}^{-1}$ dry weight		
	Copper	Zinc	Cadmium
1- 21	49.4	85.8	.39
3- 20	54.7	86.0	.48
4- 18	50.9	92.3	.55
6- 13	47.4	90.5	.41
7- 10	46.9	83.6	.34
17- 30	65.9	91.2	.38
20- 34	73.3	95.0	.35
60- 70*	59.7	62.5	.49
63- 62	50.6	66.6	.32
64- 53	65.1	87.7	.51
65- 45	56.5	88.6	.30
67- 44	56.7	69.6	.29
68- 52**	67.8	67.8	.54
70- 36	56.8	95.5	.27

\* mixed sample from stations 60-70 and 61-61

\*\* mixed sample from stations 68-52 and 69-43

Table 6. The concentration of copper, zinc and cadmium in the starfish Asterias rubens (Echinodermata, Asteroidea).

Sampling-station Tyro-ICES #	<u>Asterias rubens</u> Concentration in $\mu\text{g}\cdot\text{g}^{-1}$ dry weight		
	Copper	Zinc	Cadmium
1- 21	11.7	199.6	.60
2- 25	13.7	213.6	.49
3- 20	13.1	199.4	.77
4- 18	5.9	118.1	.49
6- 13	15.8	172.5	.75
7- 10	9.8	191.9	1.01
9- 9	13.1	192.0	.84
16- 24	12.3	179.8	.60
17- 30	7.7	145.4	.44
18- 35	13.1	137.9	.61
19- 42	12.8	141.6	.46
20- 34	22.7	150.3	.75
23- 49	28.7	159.4	.59
24- 58	10.6	143.3	.62
26- 59	10.1	180.2	.94
27- 51	13.7	130.7	.77
29- 79	13.5	176.8	.86
30- 69	12.4	182.9	--
31- 78	14.4	143.2	1.07
32- 68	16.4	223.8	1.12
33- 77	9.0	106.0	.46
34- 67	8.1	131.4	.75
35- 86	9.0	89.9	1.51
36- 96	9.7	135.0	1.30
37- 87	10.9	147.0	.88
38- 97	9.0	144.7	.90
39- 88	11.1	261.7	--
40- 98	11.4	124.7	1.55
41-119	10.0	200.5	.96
42-108	8.8	168.8	1.74
43-118	8.9	137.7	1.22
45-117	8.3	124.8	1.27
46-106	7.7	171.3	.73
47-127	7.6	173.1	1.79
48-139	11.4	187.9	.73
49-128	8.0	186.9	1.76
50-140	8.7	110.2	1.31
51-129	10.3	152.0	2.03
52-141	9.2	293.5	1.84
53-142	10.3	162.4	1.45
54-130	9.2	193.9	1.38
55-120	12.0	127.3	1.28
56-109	8.7	148.0	1.89
57- 99	10.8	124.3	1.49
58- 89	11.9	195.1	1.21
59- 80	19.4	182.3	1.03
60- 70	11.5	111.4	.83
61- 61	10.3	109.8	.71
62- 71	12.8	144.2	.72
63- 62	14.2	79.5	.51
64- 53	7.0	124.6	.42
65- 45	11.7	195.7	.70
66- 37	20.8	281.3	1.18
67- 44	6.5	147.3	.38
68- 52	12.9	142.0	.82
69- 43	16.2	221.2	.77
70- 36	12.3	216.6	1.22

Table 7. Number of individuals ( $\underline{n}$ ) of different species homogenized, mean wet weight of each specimen (g), the amount of pentane extractable lipid (PEL) expressed as a percentage of wet weight and the  $\Sigma$  PCB concentrations ( $\mu\text{g}\cdot\text{g}^{-1}$  PEL).

Sampling-station Tyro-ICES #	Species	$\underline{n}$	mean wet weight per animal	Lipid % of wet weight ( $\pm$ S.D.)	$\Sigma$ PCB
15- 29	<u>Crangon</u> <u>allmanni</u>	25	0.66	1.33	1.11
16- 24		20	0.53	1.24	1.15
17- 30		35	0.54	1.41	0.75
23- 49		50	0.61	1.20 (0.01)	0.57
28- 60		32	0.73	1.19 (0.06)	0.60
29- 79		25	0.40	1.10	0.46
40- 98		34	0.38	1.40 (0.04)	0.48
46-106		24	0.42	1.11	0.34
49-128		20	1.24	0.83 (0.04)	0.46
50-140		11	0.62	1.06	0.53
57- 99		39	0.43	0.94 (0.01)	0.49
59- 80		50	0.46	0.84 (0.04)	0.70
60- 70		40	0.54	0.71 (0.10)	0.69
	<u>Crangon</u> <u>crangon</u>				
1- 21		12	1.57	0.99 (0.07)	2.22
3- 20		8	1.88	1.21 (0.17)	1.04
4- 18		20	1.47	1.03 (0.08)	1.72
6- 13		15	2.29	1.13 (0.03)	2.98
7- 10		12	2.05	1.33 (0.05)	2.83
66- 37		50	1.68	0.93 (0.07)	1.54
70- 36		25	0.35	0.94 (0.10)	1.52
	<u>Asterias</u> <u>rubens</u>				
7- 10		10	23.19	0.78 (0.11)	4.88
19- 42		6	25.53	1.57 (0.27)	1.23
29- 79		7	19.41	1.59 (0.21)	0.99
35- 86		5	56.94	1.24 (0.16)	0.62
40- 98		10	13.58	1.36	0.90
46-106		12	14.24	0.74 (0.24)	0.65
58- 89		8	23.30	0.93 (0.04)	0.72
65- 45		9	22.02	0.71 (0.10)	2.72
70- 36		7	25.09	0.80 (0.03)	1.02

**Table 8.** The concentration (ng.g<sup>-1</sup> pentane extractable lipid, PEL) of 35 individual polychlorinated biphenyl congeners in the shrimp Crangon allmanni from the North Sea. Numbering of the congeners according to IUPAC rules, as suggested by Ballschmiter & Zell (1980). The congeners are given in order of elution from the GLC column.

PCB-congener IUPAC #	Sampling-station / Tyro-ICES #												
	15- 29	16- 24	17- 30	23- 49	28- 60	29- 79	40- 98	46-106	49-128	50-140	57- 99	59- 80	60- 70
18	-	-	-	38	17	19	19	-	16	16	24	23	17
28	-	11	-	-	12	15	14	-	11	12	15	15	14
52	31	37	24	19	22	22	22	24	19	20	23	25	24
49	-	-	-	-	-	-	-	-	-	34	-	-	60
75,47	-	-	-	14	-	-	-	-	10	10	8	9	-
44	-	11	-	-	10	11	10	-	-	10	11	12	11
61	5	8	3	5	4	4	-	-	-	3	4	5	5
70,98	26	32	17	14	17	17	15	14	12	15	16	19	19
93,66,80,95	21	25	16	12	14	15	13	12	11	13	14	16	16
60,71	-	5	-	5	-	-	-	-	-	-	-	-	-
92	85	106	71	65	57	48	41	-	35	36	42	61	58
84	31	-	-	9	-	-	-	-	5	-	-	-	-
101	63	70	44	41	35	29	28	25	27	26	30	40	37
83	31	8	5	11	-	-	-	-	-	-	-	-	-
115,87,90,116	8	9	6	-	4	-	-	-	-	3	-	4	-
136	9	-	-	-	-	-	-	-	-	-	-	-	-
107	12	11	9	10	6	5	5	-	5	5	4	7	7
139,149,123	26	29	21	18	17	14	14	13	14	-	15	19	8
118,140	126	125	84	56	59	40	48	42	48	50	45	62	59
153	211	232	155	97	126	81	93	77	93	94	91	142	135
141,179	11	12	7	-	5	4	5	-	6	6	5	6	6
138	97	127	95	52	65	44	50	43	48	53	49	80	75
187	76	84	68	42	53	37	41	38	38	41	38	62	60
183	18	15	9	-	-	-	-	-	-	9	-	9	-
128	19	15	12	-	8	-	-	-	-	-	7	10	9
167	19	17	-	-	-	-	-	-	-	-	-	-	-
177	31	30	25	13	17	13	14	13	13	14	10	18	20
156,171	10	8	7	-	-	-	-	-	-	-	4	5	-
200,157	10	5	4	-	4	-	-	-	5	-	-	-	-
172	12	8	-	-	-	-	-	-	-	-	-	-	-
180	54	69	46	27	29	22	26	23	27	32	22	32	33
201	30	23	19	17	18	15	17	18	19	15	11	14	15
196	16	12	-	-	-	-	-	-	-	8	-	-	-
194	12	8	-	-	-	-	-	-	-	-	-	-	-
209	12	-	-	-	-	-	-	-	-	-	-	-	-

**Table 2.** The concentration ( $\text{ng.g}^{-1}$  pentane extractable lipid, PEL) of 35 individual polychlorinated biphenyl congeners in the shrimp Crangon crangon from the North Sea. Numbering of congeners according to IUPAC rules as suggested by Ballschmiter & Zell (1980). The congeners are given in order of elution from the GLC column.

PCB- Congener IUPAC #	Sampling-station / Tyro-ICES #						
	1-21	3-20	4-18	6-13	7-10	66-37	70-36
18	50	32	54	50	60	33	35
28	43	25	34	42	51	27	32
52	100	52	88	156	166	85	94
49	-	11	17	-	37	22	27
75, 47	23	11	16	86	33	19	17
44	53	29	42	32	97	54	60
61	16	7	11	22	24	11	12
70, 98	56	30	41	86	74	62	64
93, 66, 80, 95	55	28	41	82	106	48	52
60, 71	11	7	9	18	22	13	14
92	200	84	154	288	255	135	130
84	16	8	14	16	19	10	11
101	79	32	58	109	118	63	63
83	13	-	13	9	10	4	5
115, 87, 90, 116	14	8	11	24	30	17	18
136	8	4	6	7	8	3	4
107	35	20	26	41	37	25	24
139, 149, 123	48	18	30	54	52	27	24
118, 140	237	101	181	273	260	146	147
153	271	93	196	326	283	142	129
141, 179	15	6	10	22	19	8	8
138	239	112	185	290	260	155	147
187	165	93	134	220	191	126	124
183	33	15	23	52	37	18	17
128	16	6	12	18	17	11	7
167	46	25	35	60	53	32	30
177	91	43	72	108	101	65	61
156, 171	24	12	17	32	28	15	14
200, 157	8	4	6	8	8	5	5
172	23	12	17	36	32	13	12
180	175	86	129	327	262	100	95
201	30	17	23	46	43	23	21
196	-	-	-	-	-	-	-
194	15	8	11	23	22	10	10
209	12	5	7	17	13	8	5

**Table 10.** The concentration ( $\text{ng.g}^{-1}$  pentane extractable lipid, PEL) of 35 individual polychlorinated biphenyl congeners in the starfish *Asterias rubens* from the North Sea. Numbering of congeners according to IUPAC rules as suggested by Ballschmiter & Zell (1980). The congeners are given in order of elution from the GLC column.

PCB-Congener IUPAC #	Sampling-station / Tyro-ICES #								
	7- 10	19- 42	29- 79	35- 86	40- 98	46-106	58- 89	65- 45	70- 36
18	28	25	24	16	-	22	26	36	23
28	50	19	20	12	14	25	18	41	19
52	136	27	29	21	19	39	22	66	30
49	77	-	-	13	-	19	-	37	-
75, 47	61	-	21	-	-	14	-	26	13
44	54	22	26	13	-	14	-	23	20
61	31	10	8	5	8	7	8	19	8
70, 98	74	23	26	17	21	21	-	33	21
93, 66, 80, 95	136	25	22	14	29	29	22	76	28
60, 71	13	9	9	5	12	7	-	8	6
92	348	78	67	-	90	78	-	171	71
84	24	41	36	32	13	-	13	10	-
101	315	58	51	35	62	54	45	177	64
83	13	36	31	28	-	4	-	-	6
115, 87, 90, 116	39	-	-	-	-	7	-	21	9
136	28	10	9	8	-	4	-	9	6
107	41	14	9	8	-	5	-	28	9
139, 149, 123	261	32	25	16	40	29	24	161	50
118, 140	489	149	111	86	79	53	57	313	104
153	926	235	152	109	163	95	116	546	210
141, 179	29	7	5	-	21	-	-	9	-
138	614	121	76	44	118	62	73	410	145
187	336	81	44	30	71	38	58	184	89
183	37	17	13	-	-	-	17	23	-
128	104	31	23	14	30	13	34	77	28
167	60	23	20	-	39	-	24	-	-
177	143	39	28	17	34	16	39	84	36
156, 171	31	-	14	8	16	-	15	68	10
200, 157	9	13	9	8	-	-	13	10	-
172	34	-	9	-	-	-	12	-	-
180	189	30	17	15	-	8	31	58	18
201	80	-	19	23	-	-	-	-	-
196	26	21	9	8	-	-	23	-	-
194	26	11	9	7	-	-	12	-	-
209	16	18	15	11	19	-	19	-	-

Table 11. Number of individuals (n) of *Nephtys hombergii* homogenized, mean wet weight of each specimen (g), the amount of pentane extractable lipid (PEL) expressed as a percentage of wet weight and the  $\Sigma$  PCB concentrations ( $\mu\text{g}\cdot\text{g}^{-1}$  PEL).

Sampling-station Tyro-ICES #	n	mean wet weight per animal	Lipid % of wet weight ( $\pm$ S.D.)	$\Sigma$ PCB
1- 21	7	1.31	0.91	0.88
6- 13	30	0.34	0.57	0.72
7- 10	15	0.61	0.45	0.53
10- 12	11	0.29	0.77	0.88
14- 23	15	0.19	0.77	0.92
17- 30	10	0.41	0.74	0.85
18- 35	19	0.33	0.46	0.73
24- 58	10	0.36	0.77	0.45
29- 79	10	0.19	0.45	0.48
31- 78	12	0.15	0.37	0.81
34- 67	15	0.28	0.54	0.80
41-119	13	0.22	0.50	0.59
46-106	18	0.19	0.50	0.57
48-139	10	0.17	0.97	0.40
51-129	10	0.25	0.62	1.08
52-141	15	0.21	0.69	0.82
56-109	15	0.12	0.72	0.52
57- 99	25	0.16	1.38	0.75
58- 89	10	0.27	0.96	0.75
60- 70	10	0.34	0.66	0.75
62- 71	11	0.17	0.45	0.60
63- 62	20	0.46	0.23	0.43
66- 37	15	0.74	0.56	2.41
68- 52	12	0.42	1.00	0.76
71- 31	12	0.23	0.82	1.05
I	10	0.19	0.41	0.29
II	17	0.09	0.35	0.30
III	20*	1.28	0.33	0.11
IV	13	0.37	1.22	0.16
V	15*	0.33	0.54	0.25
VI	14	0.29	0.55	1.08
VII	15*	0.29	0.57	0.47
VIII	17**	0.67	0.59	0.49
IX	16	0.60	0.62	0.43

Stations:

I = 45-117 + 47-127  
 II = 49-128 + 50-140  
 III = 53-142 + 54-130 + 55-120  
 IV = 42-108 + 43-118 + 44-107  
 V = 37- 87 + 38- 97  
 VI = 39- 88 + 40- 98  
 VII = 26- 59 + 28- 60  
 VIII = 19- 42 + 20- 34  
 IX = 15- 29 + 16- 24

\* = 1 *Nereis fucata*  
 \*\* = 1 *Nereis fucata* +  
 1 *Nereis* sp.



**Table 12.** The concentration ( $\text{ng.g}^{-1}$  pentane extractable lipid, PEL) of 35 individual polychlorinated biphenyl components in the polychaete annelid *Nephtys hombergii* from the North Sea. Numbering of congeners according to IUPAC rules as suggested by Ballschmiter & Zell (1980). The congeners are given in order of elution from the GLC column.

PCB- Congener IUPAC #	Sampling-station / Tyro-ICES #								
	1- 21	6- 13	7- 10	10- 12	14- 23	17- 30	18- 35	24-58	29- 79
18	-	63	43	-	73	-	-	-	-
28	-	89	54	56	92	58	44	45	120
52	15	155	86	56	74	63	44	-	-
49	-	-	-	-	-	-	-	-	-
75, 47	-	86	34	-	-	-	-	-	-
44	-	97	49	-	49	45	-	-	-
61	6	45	20	-	-	-	-	-	-
70, 98	23	226	82	48	72	65	49	42	-
93, 66, 80, 95	26	167	-	-	-	-	-	-	-
60, 71	6	49	17	-	-	16	-	13	25
92	65	546	318	-	-	-	-	-	-
84	-	61	19	-	-	-	-	-	-
101	56	465	263	64	92	89	73	61	111
83	-	55	23	-	-	-	-	-	-
115, 87, 90, 116	9	68	39	-	-	20	-	11	-
136	-	39	20	-	-	-	-	-	-
107	9	52	39	-	-	-	-	-	-
139, 149, 123	51	382	276	47	48	52	45	35	59
118, 140	114	610	445	99	89	105	89	58	-
153	151	1160	977	234	129	166	148	90	163
141, 179	7	76	49	-	-	-	-	-	-
138	123	736	704	144	90	110	93	59	97
187	51	351	369	60	42	54	52	31	-
183	15	129	87	-	-	-	-	-	-
128	21	144	112	-	-	-	-	-	-
167	-	105	95	-	-	-	-	-	-
177	39	212	212	-	-	-	-	-	-
156, 171	8	58	48	-	-	-	-	-	-
200, 157	-	25	17	-	-	-	-	-	-
172	-	74	59	-	-	-	-	-	-
180	63	600	505	73	66	-	95	-	-
201	12	105	103	-	-	-	-	-	-
196	-	66	46	-	-	-	-	-	-
194	7	67	58	-	-	-	-	-	-
209	5	55	19	-	-	5	-	-	-



Table 12. Continued. The concentration ( $\text{ng}\cdot\text{g}^{-1}$  pentane extractable lipid, PEL) of 35 individual polychlorinated biphenyl congeners in the polychaete annelid *Nephtys hombergii* from the North Sea. Numbering of congeners according to IUPAC rules as suggested by Ballschmiter & Zell (1980). The congeners are given in order of elution from the GLC column.

PCB-Congener IUPAC #	Sampling-station / Tyro-ICES #						
	58- 89	60- 70	62- 71	63- 62	66- 37	68- 52	71- 31
18	-	-	-	-	42	35	-
28	61	58	-	-	59	36	72
52	75	60	-	-	66	41	67
49	37	-	-	-	-	24	-
75, 47	-	-	-	-	26	-	-
44	49	-	-	-	49	27	46
61	12	-	-	-	17	-	-
70, 98	75	58	-	-	76	34	58
93, 66, 80, 95	58	52	-	-	68	-	50
60, 71	24	24	-	-	21	9	-
92	-	-	-	-	171	-	-
84	-	-	-	51	12	-	-
101	95	103	110	-	138	51	85
83	-	-	-	48	14	15	-
115, 87, 90, 116	26	-	-	-	22	12	-
136	-	-	-	-	12	-	-
107	-	-	-	10	23	-	-
139, 149, 123	36	48	69	-	116	43	51
118, 140	68	77	95	110	252	56	104
153	74	131	197	127	355	116	226
141, 179	-	-	-	-	14	-	-
138	60	88	124	27	300	79	151
187	-	48	-	-	125	50	66
183	-	-	-	-	34	-	-
128	-	-	-	-	56	-	-
167	-	-	-	-	33	-	-
177	-	-	-	-	94	31	-
156, 171	-	-	-	-	18	-	-
200, 157	-	-	-	13	-	-	-
172	-	-	-	-	15	-	-
180	-	-	-	-	119	56	66
201	-	-	-	-	25	19	-
196	-	-	-	-	-	-	-
194	-	-	-	15	17	11	-
209	-	-	-	25	18	15	6

**Table 12. Continued.** The concentration ( $\text{ng.g}^{-1}$  pentane extractable lipid, PEL) of 35 individual polychlorinated biphenyl congeners in the polychaete annelid *Nephtys hombergii* from the North Sea. Numbering of congeners according to IUPAC rules as suggested by Ballschmiter & Zell (1980). The congeners are given in order of elution from the GLC column.

PCB-Congener IUPAC #	Sampling-station / Tyro-ICES #								
	I	II	III	IV	V	VI	VII	VIII	IX
18	-	-	-	-	-	-	-	26	-
28	-	-	-	-	18	-	17	24	23
52	-	-	-	-	-	-	-	28	27
49	-	-	-	-	-	-	-	-	-
75, 47	-	-	-	-	-	-	-	-	-
44	-	-	-	-	-	-	-	21	-
61	-	-	-	-	-	-	-	7	-
70, 98	-	-	-	-	22	59	27	30	25
93, 66, 80, 95	-	-	7	-	18	44	21	25	22
60, 71	-	-	-	-	-	17	8	7	7
92	-	-	-	-	-	-	-	-	-
84	-	-	-	-	-	78	-	-	-
101	-	-	13	19	35	102	43	39	42
83	-	-	-	-	-	68	-	-	-
115, 87, 90, 116	-	-	-	-	-	-	-	11	-
136	-	-	-	-	-	-	-	-	-
107	-	-	-	-	-	-	-	-	-
139, 149, 123	-	-	10	18	20	42	33	27	29
118, 140	-	-	13	31	29	196	51	46	44
153	168	151	33	40	56	224	99	65	82
141, 179	-	-	-	-	-	-	-	8	-
138	119	150	24	31	40	73	64	46	57
187	-	-	11	-	15	52	32	20	31
183	-	-	-	-	-	-	-	-	-
128	-	-	-	-	-	-	-	-	-
167	-	-	-	-	-	-	-	23	-
177	-	-	-	-	-	54	20	17	19
156, 171	-	-	-	-	-	-	-	14	-
200, 157	-	-	-	-	-	-	-	-	-
172	-	-	-	-	-	-	-	-	-
180	-	-	-	20	-	-	44	-	-
201	-	-	-	-	-	-	-	-	15
196	-	-	-	-	-	-	-	-	-
194	-	-	-	-	-	31	-	10	10
209	-	-	-	-	-	40	9	-	-

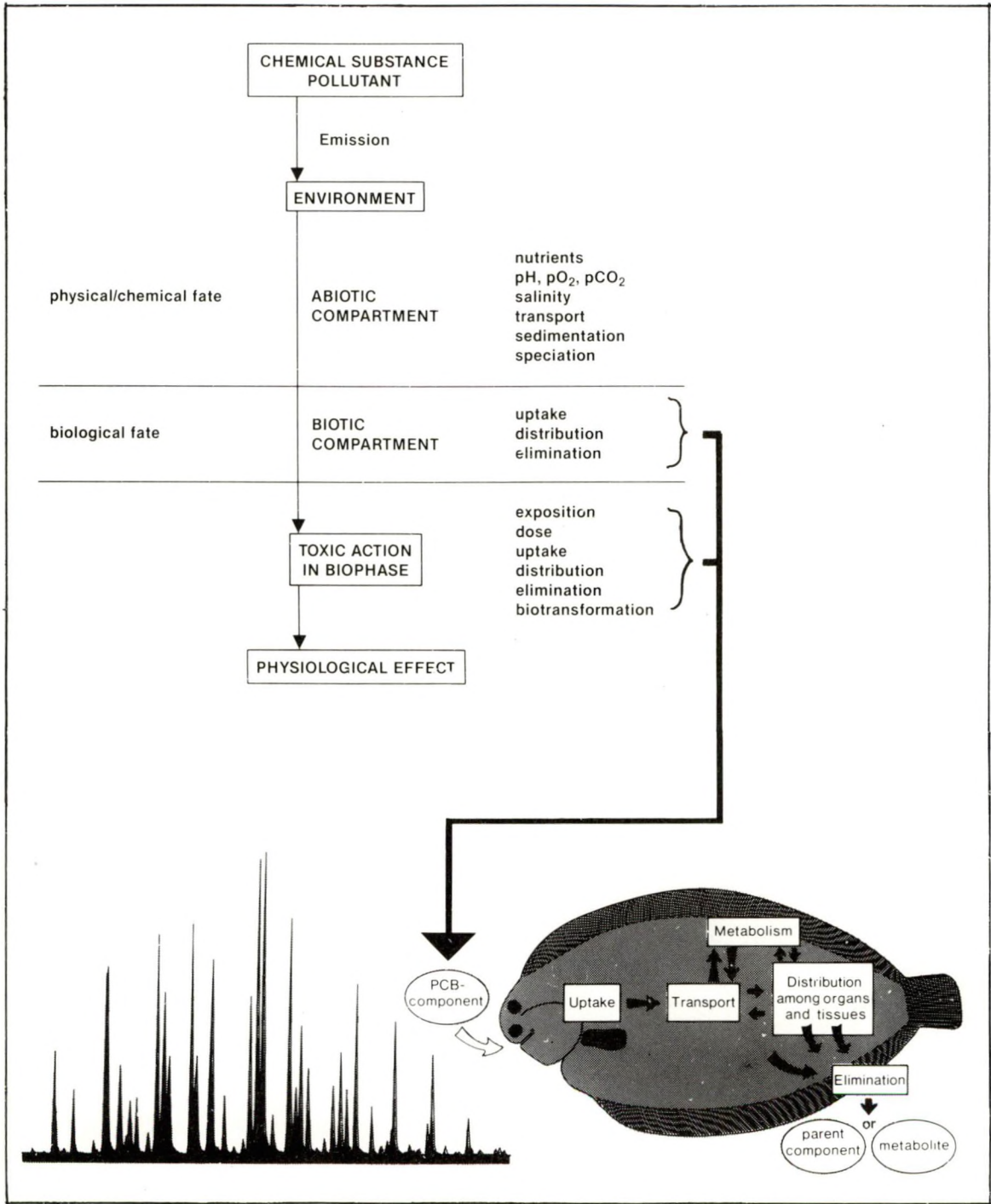


Fig. 1. Pathway of a chemical substance, entering the natural environment onto exerting its physiological effect, including a scheme showing the processes determining the kinetics of a chemical substance (eg. PCB-congeners) in organisms. (Figure combined after BOON, 1986 and EVERAARTS, 1986).

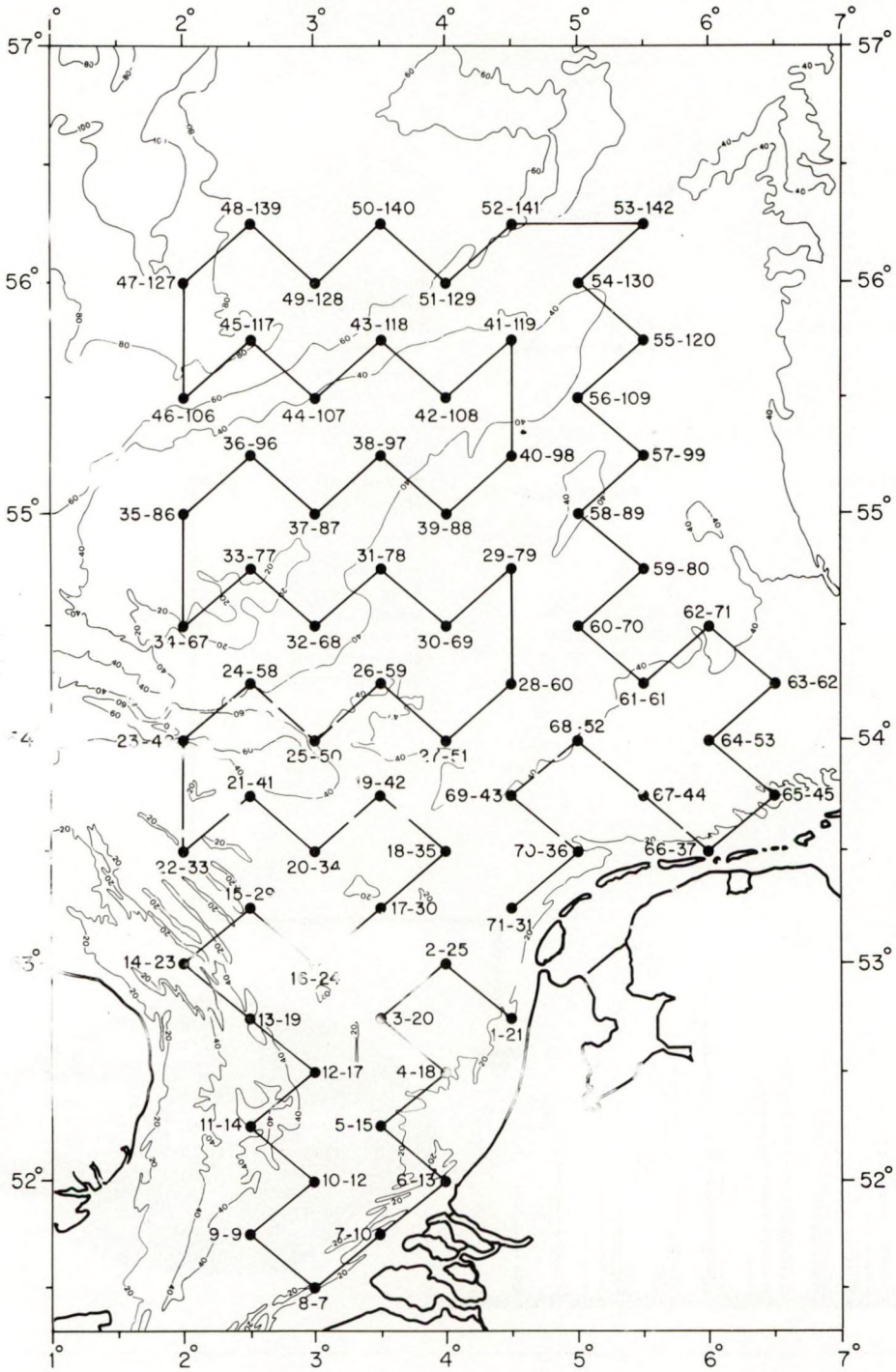


Fig. 2. Position of the sampling station in the Dutch sector of the continental shelf of the North Sea, during the Synoptic Mapping Programme (16 april-2 may, 1986); the sampling sites are identified by two numbers: the first number according to the sampling sequence on board R.V. 'TYRO' and the second number according to the 'Cooperative North Sea Programme 1986' of the Benthos Working Group of the ICES.

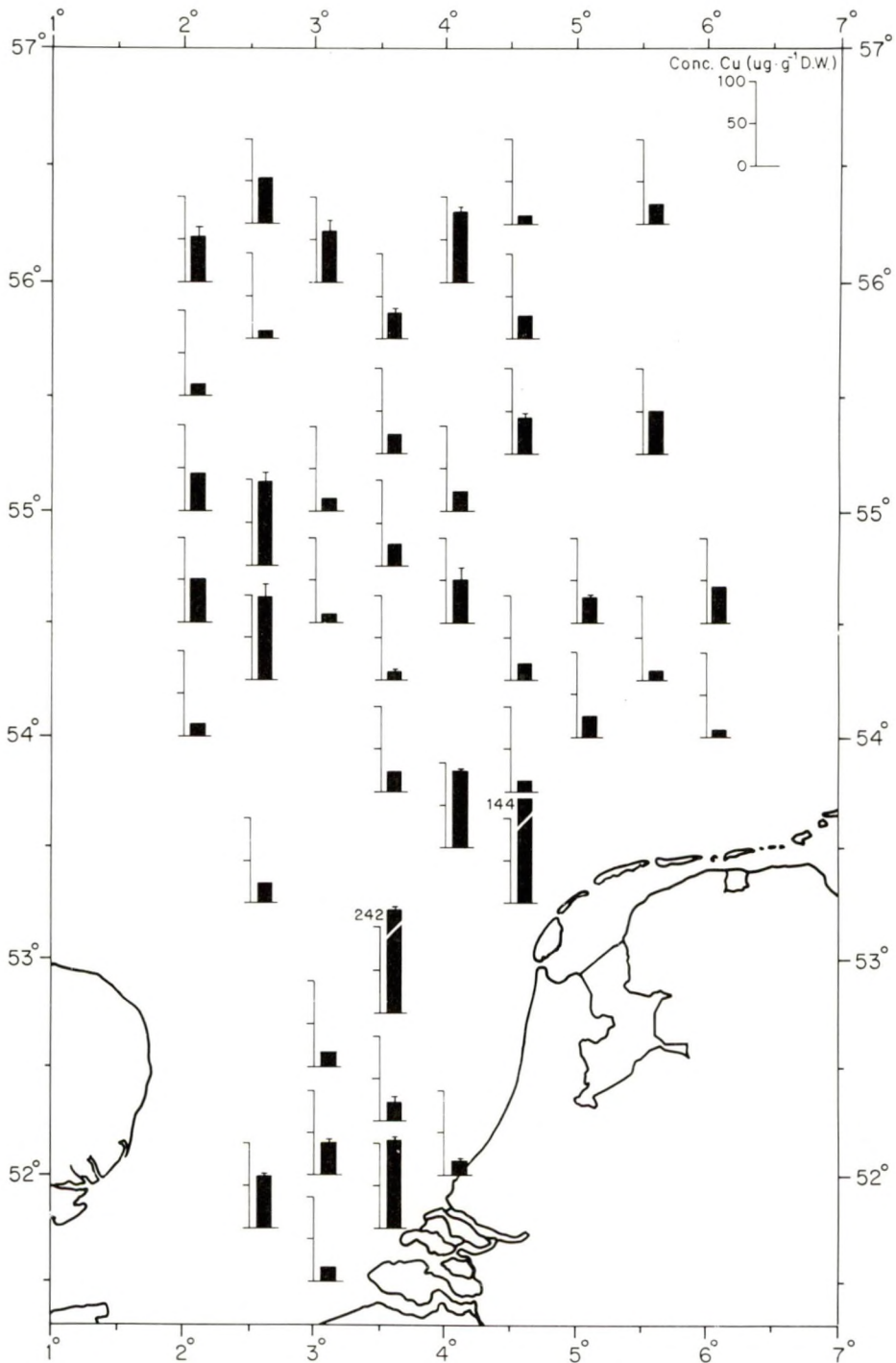


Fig. 3. The mean and duplo values of the concentration of copper ( $\mu\text{g}\cdot\text{g}^{-1}$  dry weight) in the silt fraction (grain size  $< 63 \mu\text{m}$ ) of surface sediment (upper 2 cm) from the North Sea. The Y-axis gives  $100 \mu\text{g}\cdot\text{g}^{-1}$ .

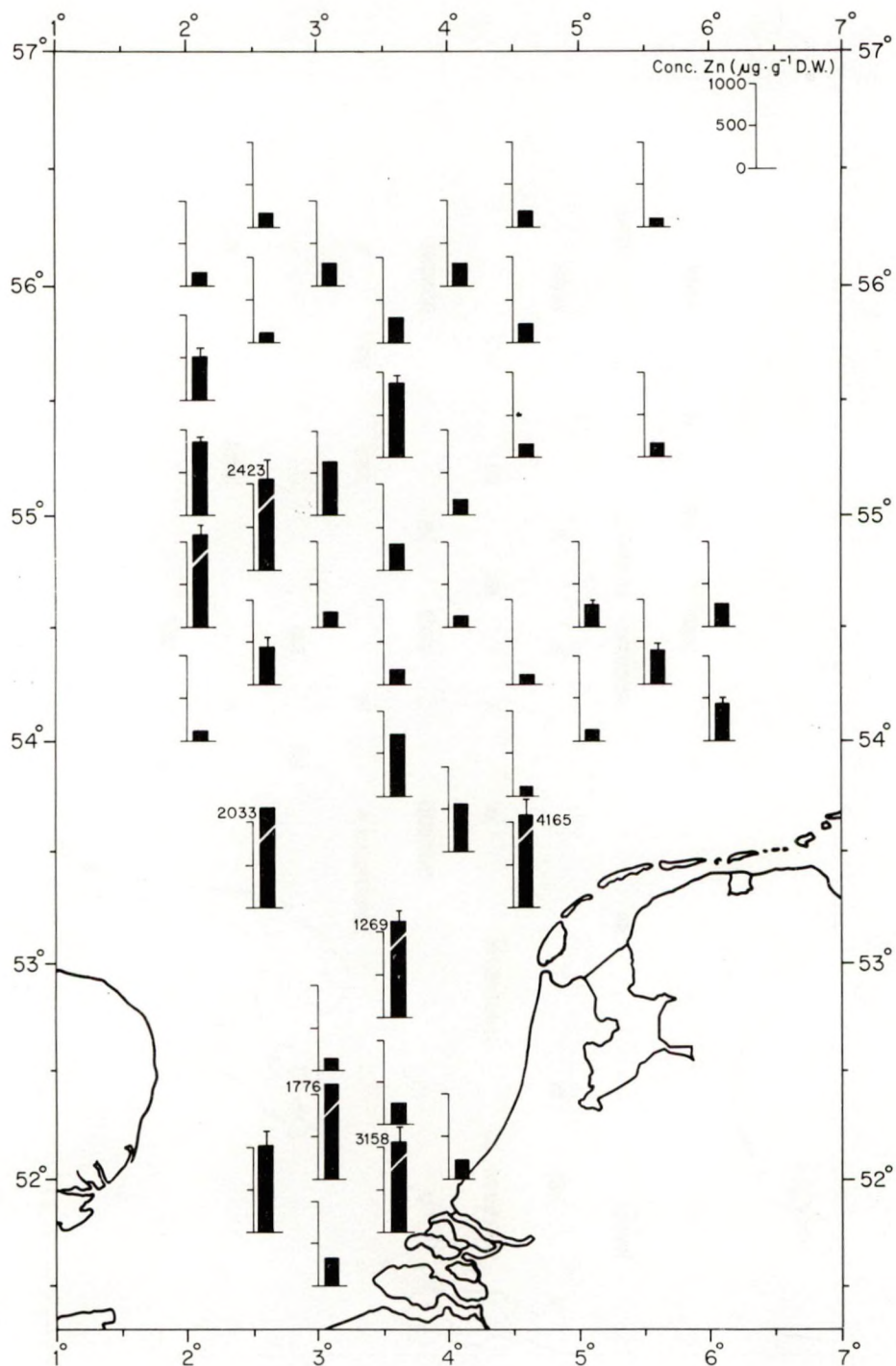


Fig. 4. The mean and duplo values of the concentration of zinc ( $\mu\text{g}\cdot\text{g}^{-1}$  dry weight) in the silt fraction (grain size  $< 63 \mu\text{m}$ ) of surface sediment (upper 2 cm) from the North Sea. The Y-axis gives 2000  $\mu\text{g}\cdot\text{g}^{-1}$ .



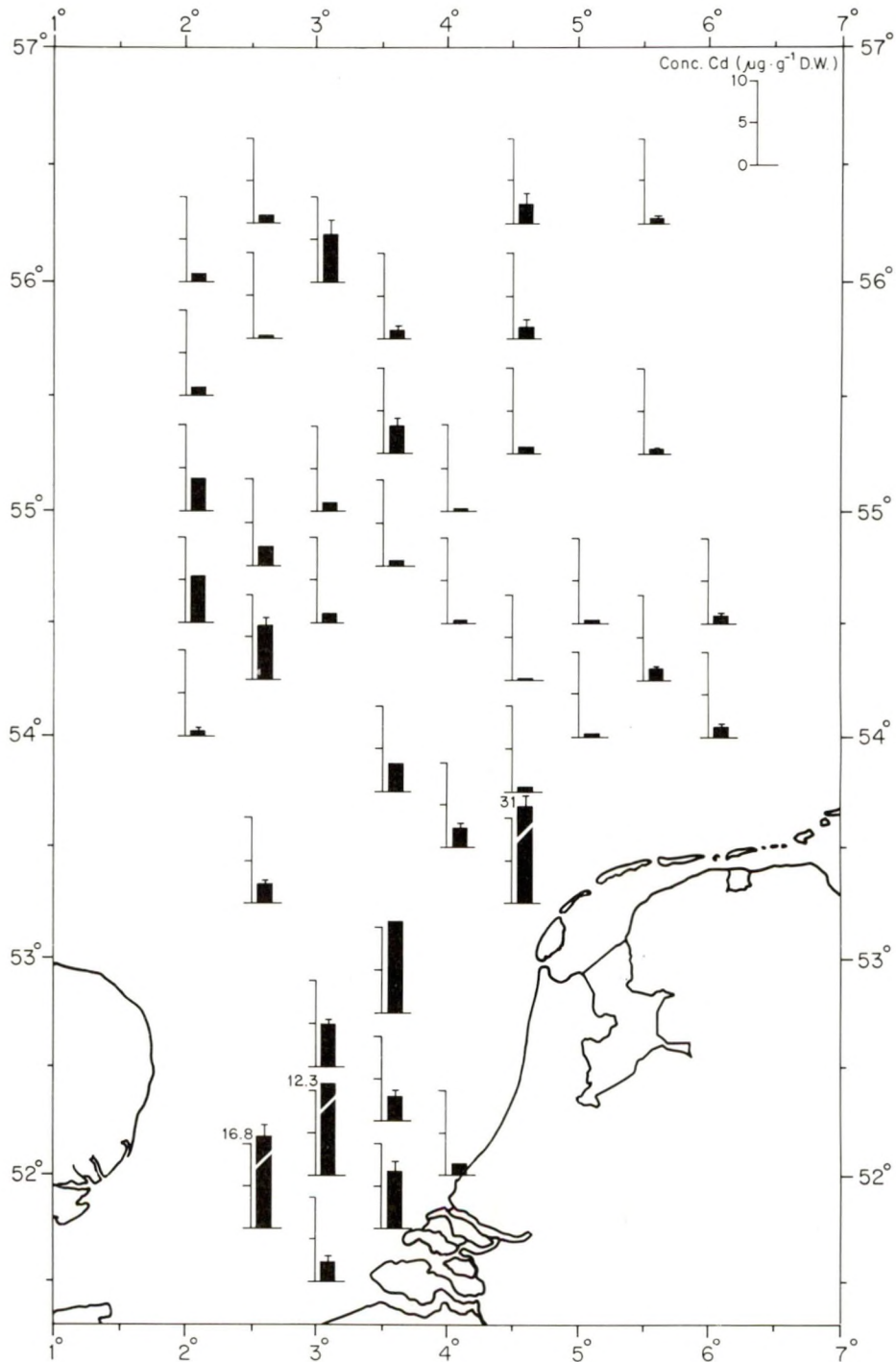


Fig. 5. The mean and duplo values of the concentration of cadmium ( $\mu\text{g}\cdot\text{g}^{-1}$  dry weight) in the silt fraction (grain size  $< 63 \mu\text{m}$ ) of surface sediment (upper 2 cm) from the North Sea. The Y-axis gives 10  $\mu\text{g}\cdot\text{g}^{-1}$ .

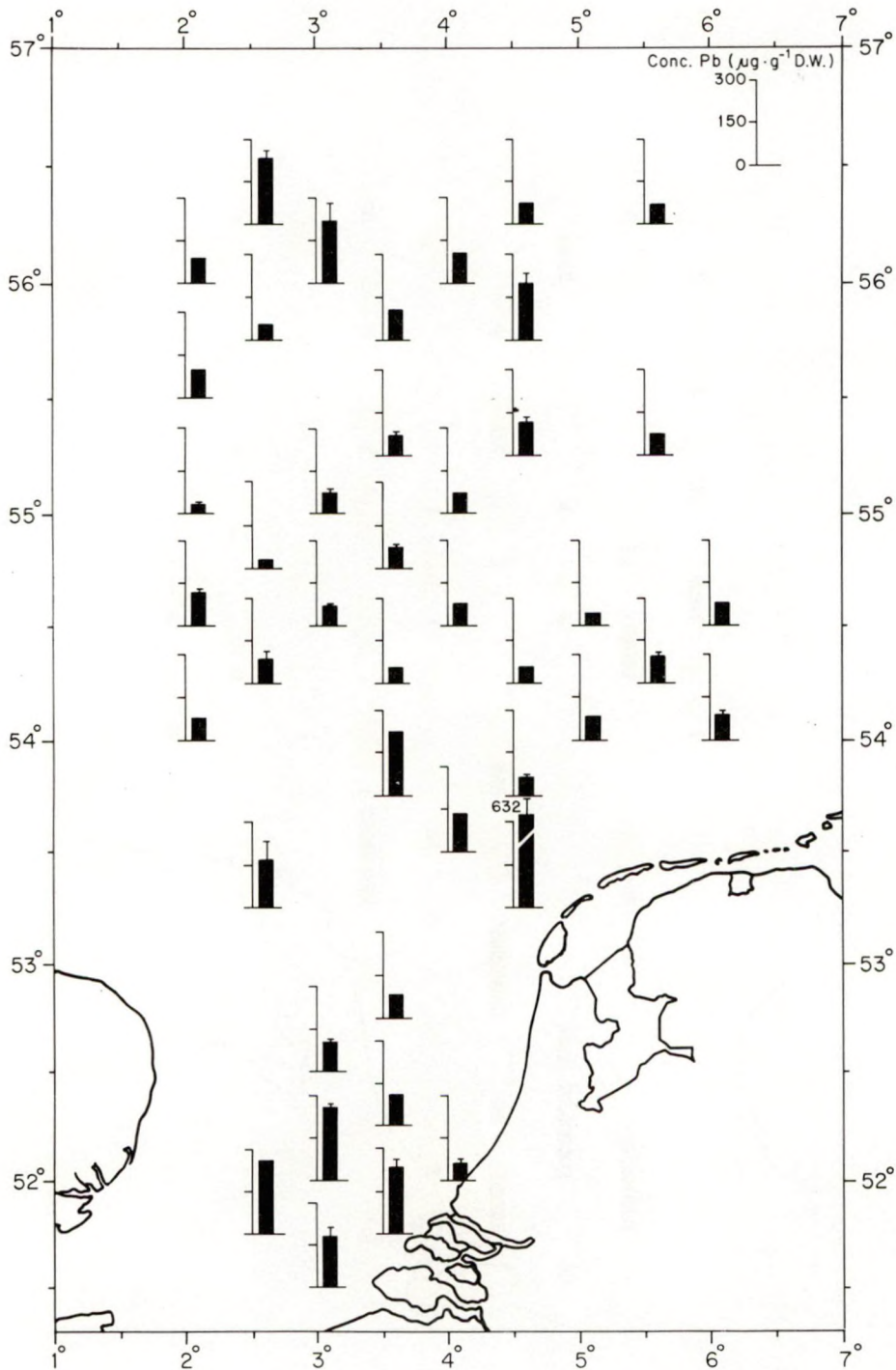


Fig. 6. The mean and duplo values of the concentration of lead ( $\mu\text{g}\cdot\text{g}^{-1}$  dry weight) in the silt fraction (grain size  $< 63 \mu\text{m}$ ) of surface sediment (upper 2 cm) from the North Sea. The Y-axis gives  $300 \mu\text{g}\cdot\text{g}^{-1}$ .

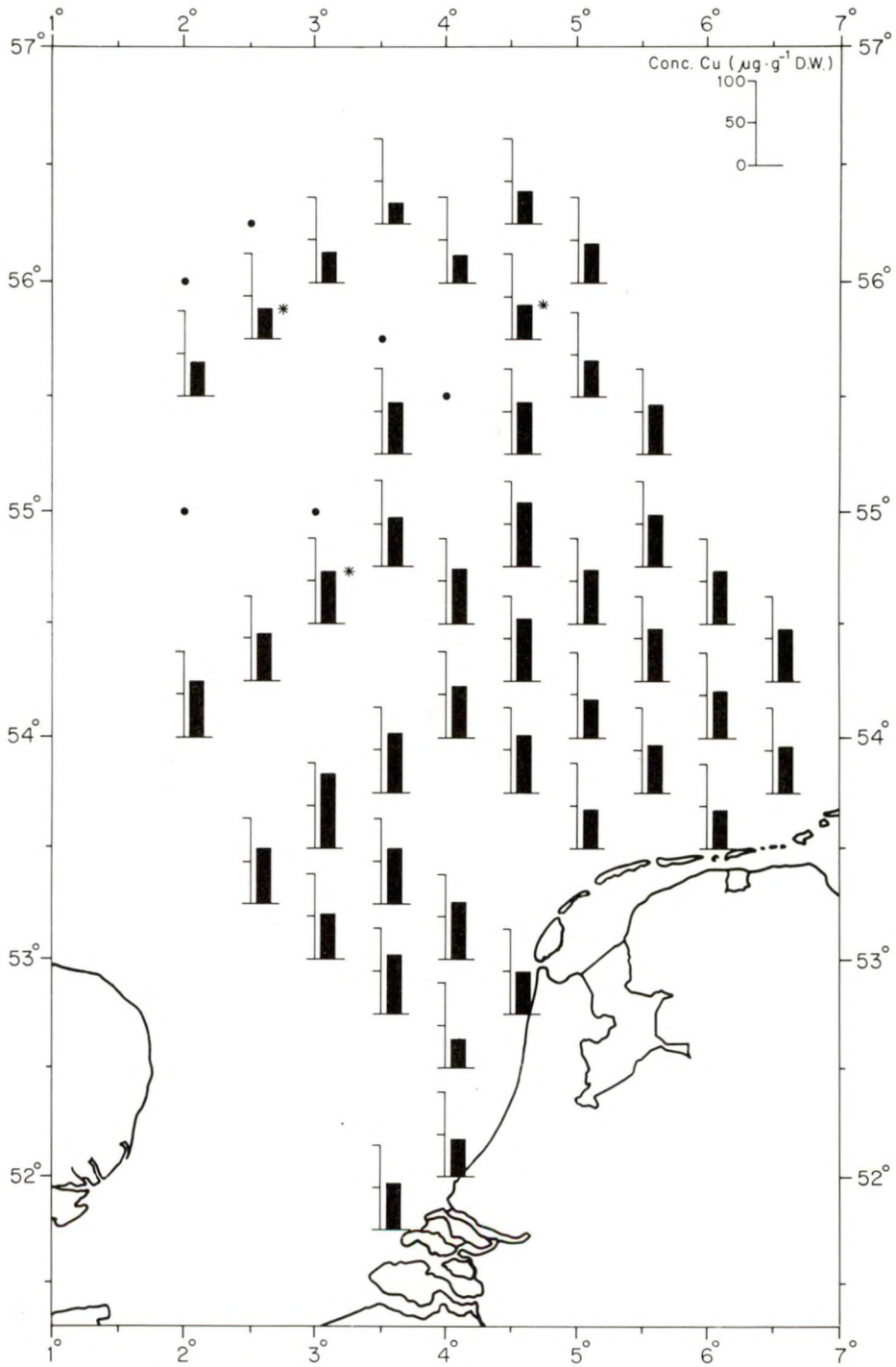


Fig. 7. The concentration of copper in whole body of the shrimp *Crangon allmanni*. The Y-axis gives  $100 \mu\text{g}\cdot\text{g}^{-1}$  dry weight. The sampling sites from which specimens are pooled, together with the concentration to match, are indicated by ● and \*, respectively (cf. Table 4).

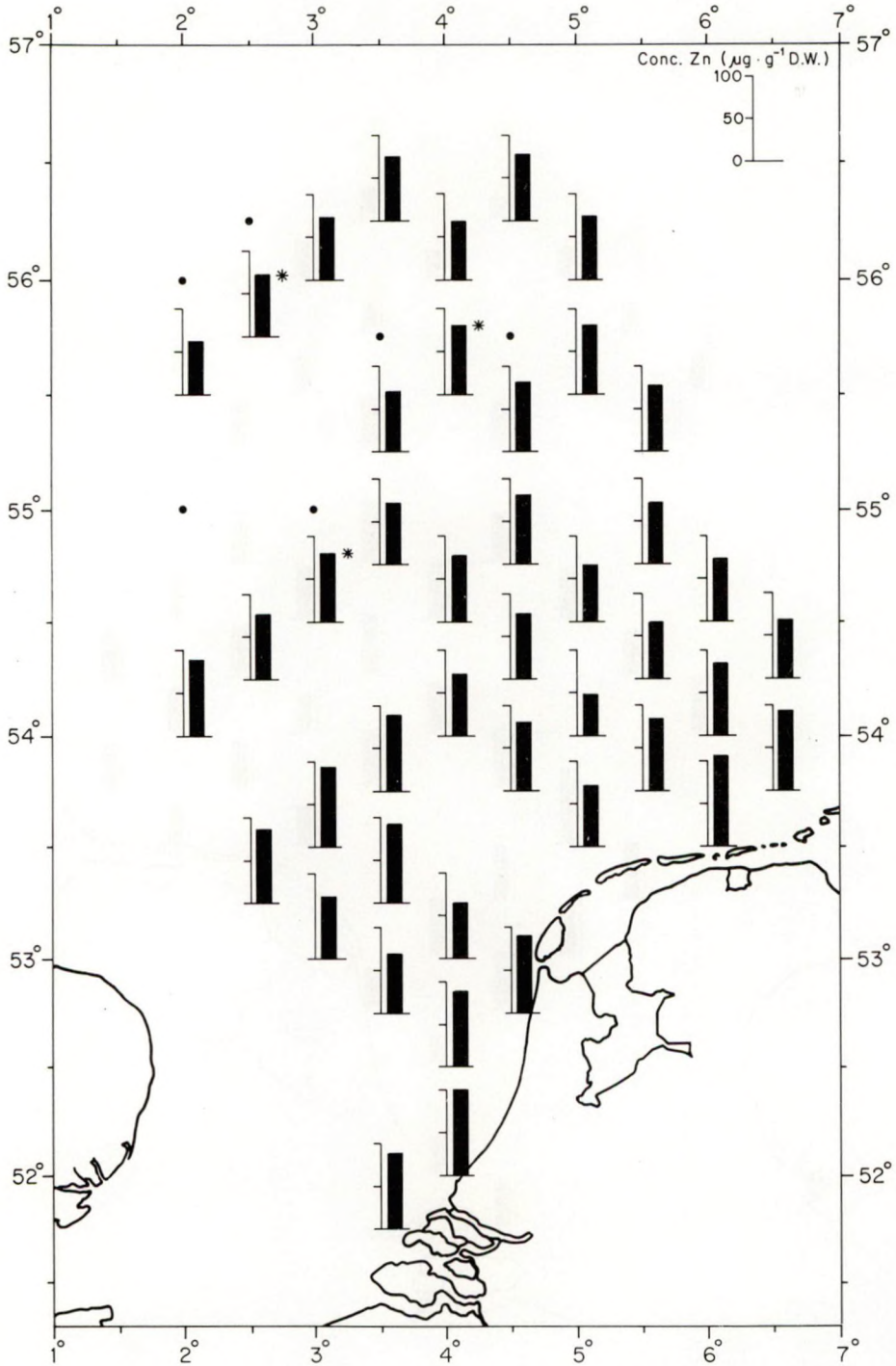


Fig. 8. The concentration of zinc in whole body of the shrimp *Crangon allmanni*. The Y-axis gives  $100 \mu\text{g} \cdot \text{g}^{-1}$  dry weight. The sampling sites from which specimens are pooled, together with the concentration to match, are indicated by ● and \*, respectively (cf. Table 4).

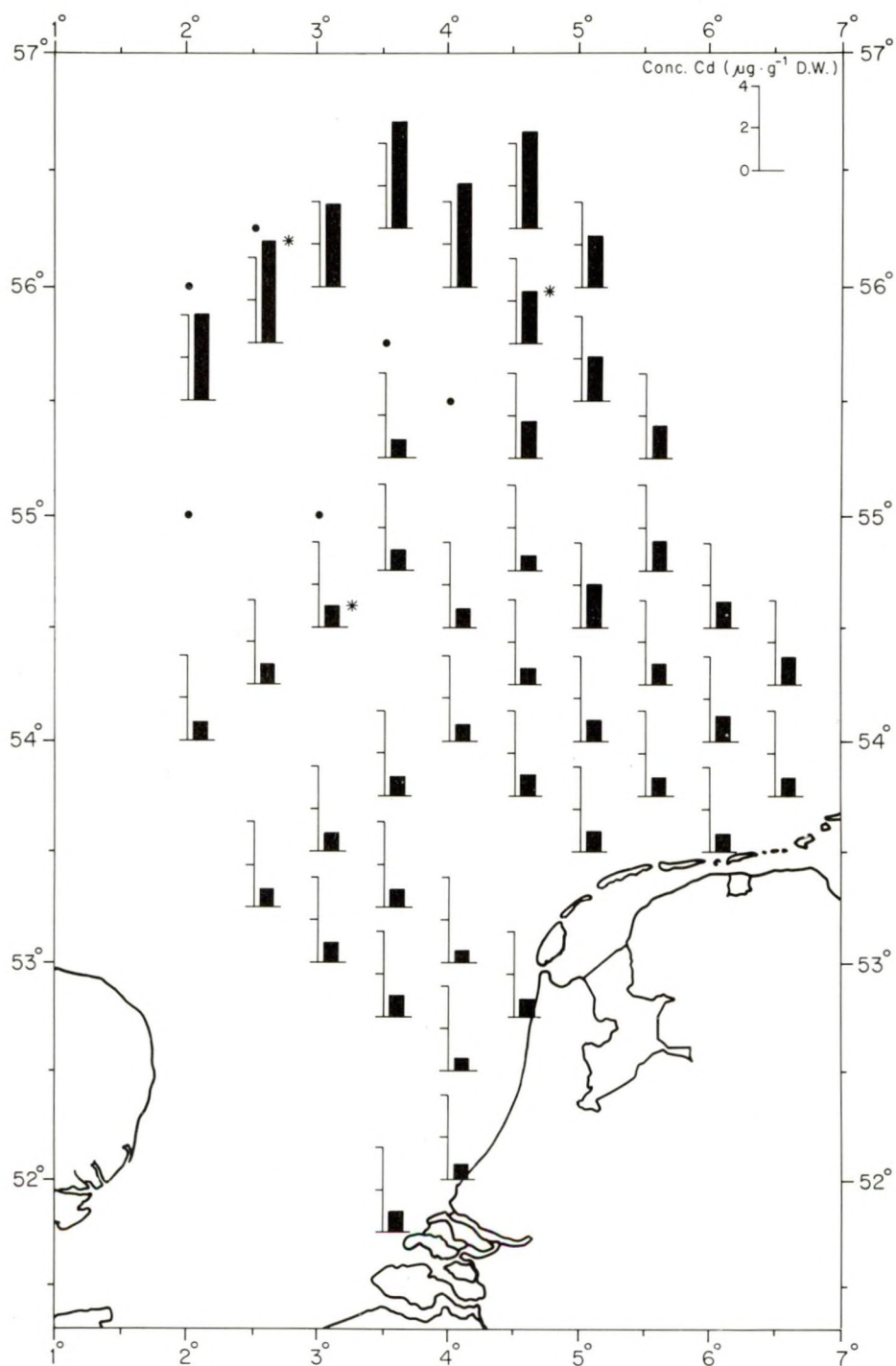


Fig. 9. The concentration of cadmium in whole body of the shrimp *Crangon allmanni*. The Y-axis gives  $4 \mu\text{g}\cdot\text{g}^{-1}$  dry weight. The sampling sites from which specimens are pooled, together with the concentration to match, are indicated by • and \*, respectively (cf. Table 4).

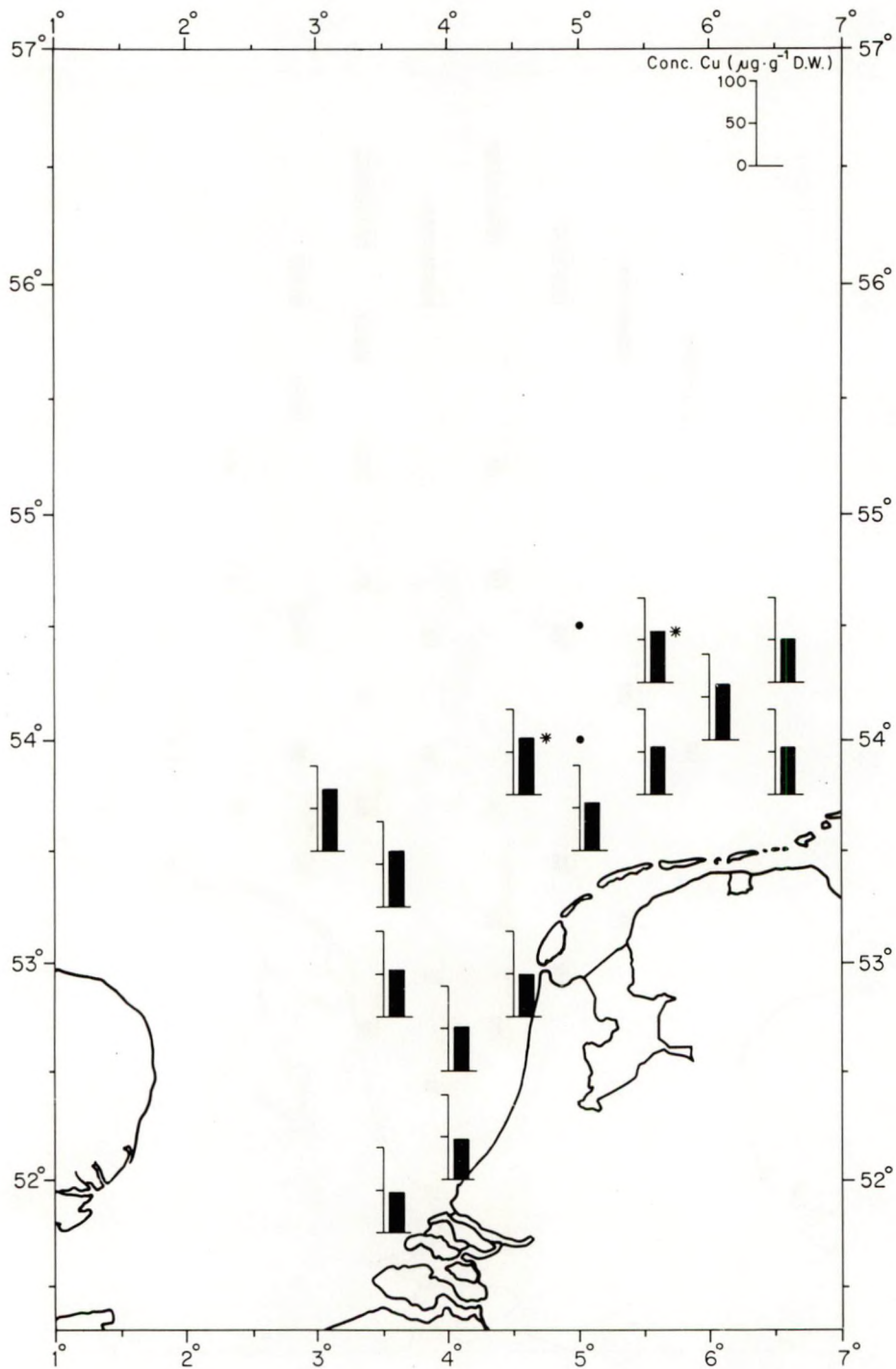


Fig. 10. The concentration of copper in whole body of the brown shrimp *Crangon crangon*. The Y-axis gives  $100 \mu\text{g}\cdot\text{g}^{-1}$  dry weight. The sampling sites from which specimens are pooled, together with the concentration to match, are indicated by • and \*, respectively (cf. Table 5).

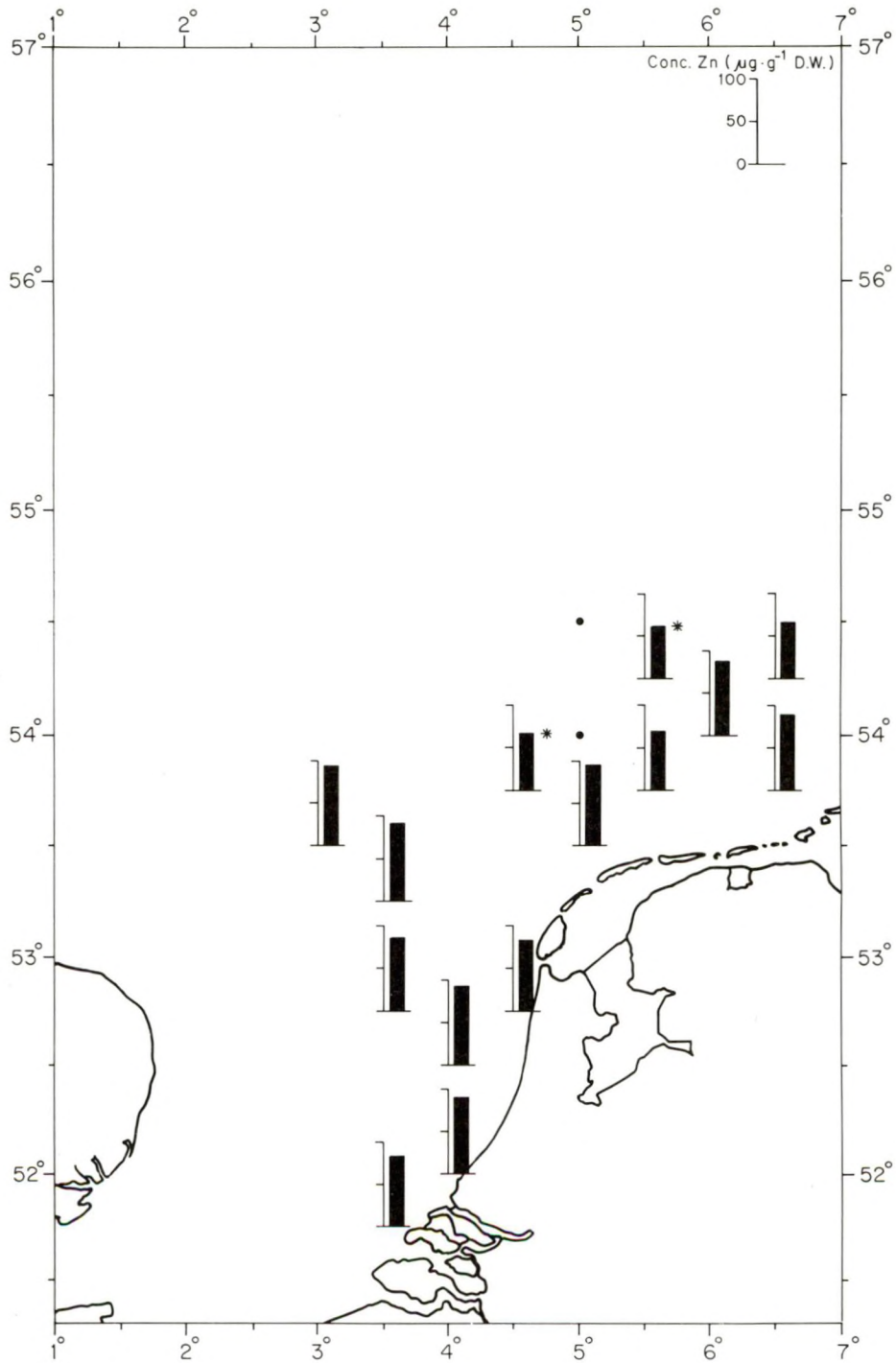


Fig. 11. The concentration of zinc in whole body of the brown shrimp *Crangon crangon*. The Y-axis gives  $100 \mu\text{g}\cdot\text{g}^{-1}$  dry weight. The sampling sites from which specimens are pooled, together with the concentration to match, are indicated by ● and \*, respectively (cf. Table 5).

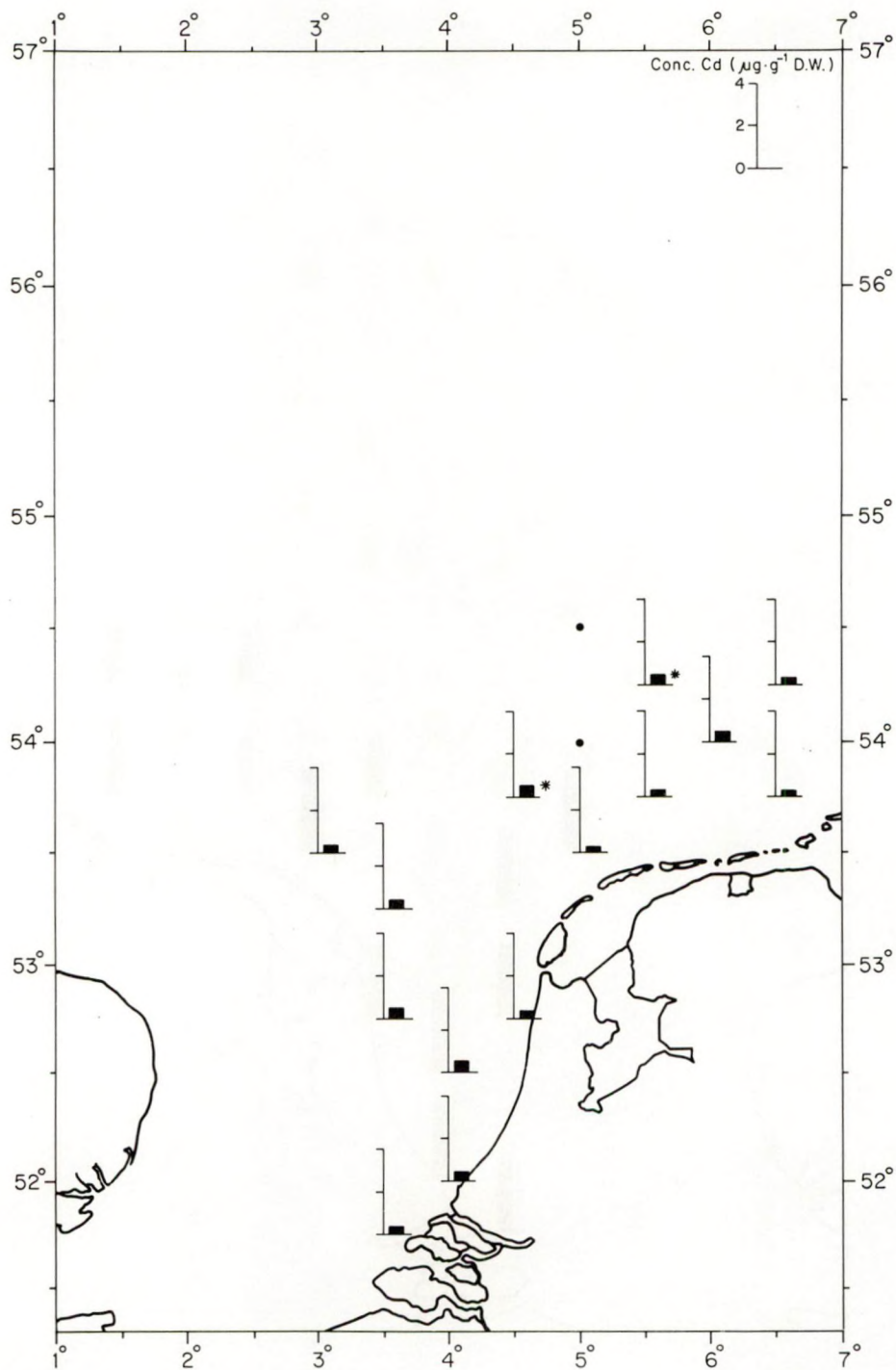


Fig. 12. The concentration of cadmium in whole body of the brown shrimp *Crangon crangon*. The Y-axis gives  $4 \mu\text{g}\cdot\text{g}^{-1}$  dry weight. The sampling sites from which specimens are pooled, together with the concentration to match, are indicated by ● and \*, respectively (cf. Table 5).



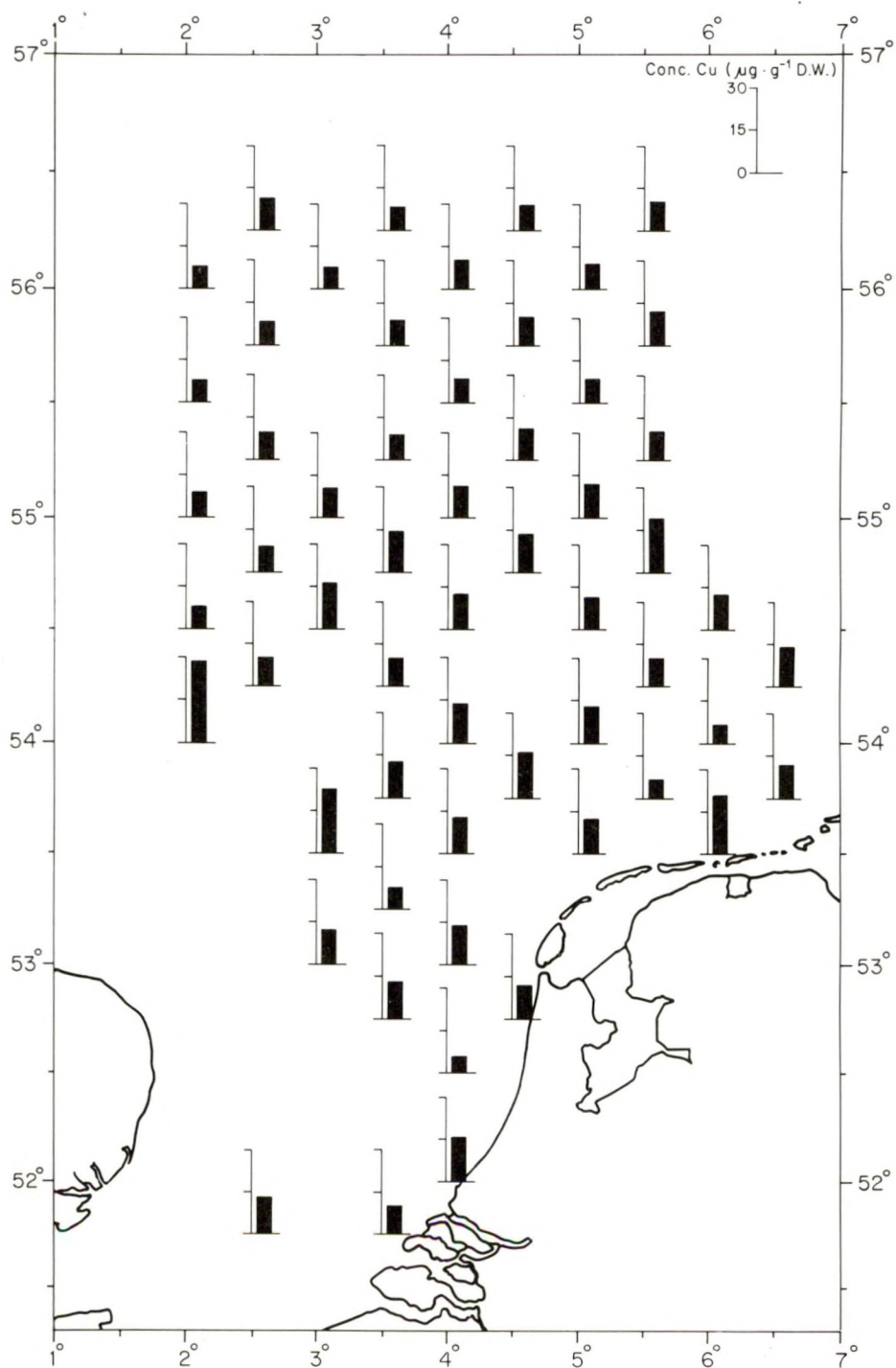


Fig. 13. The concentration of copper in whole body of the starfish *Asterias rubens*. The Y-axis gives  $30 \mu\text{g}\cdot\text{g}^{-1}$  dry weight.

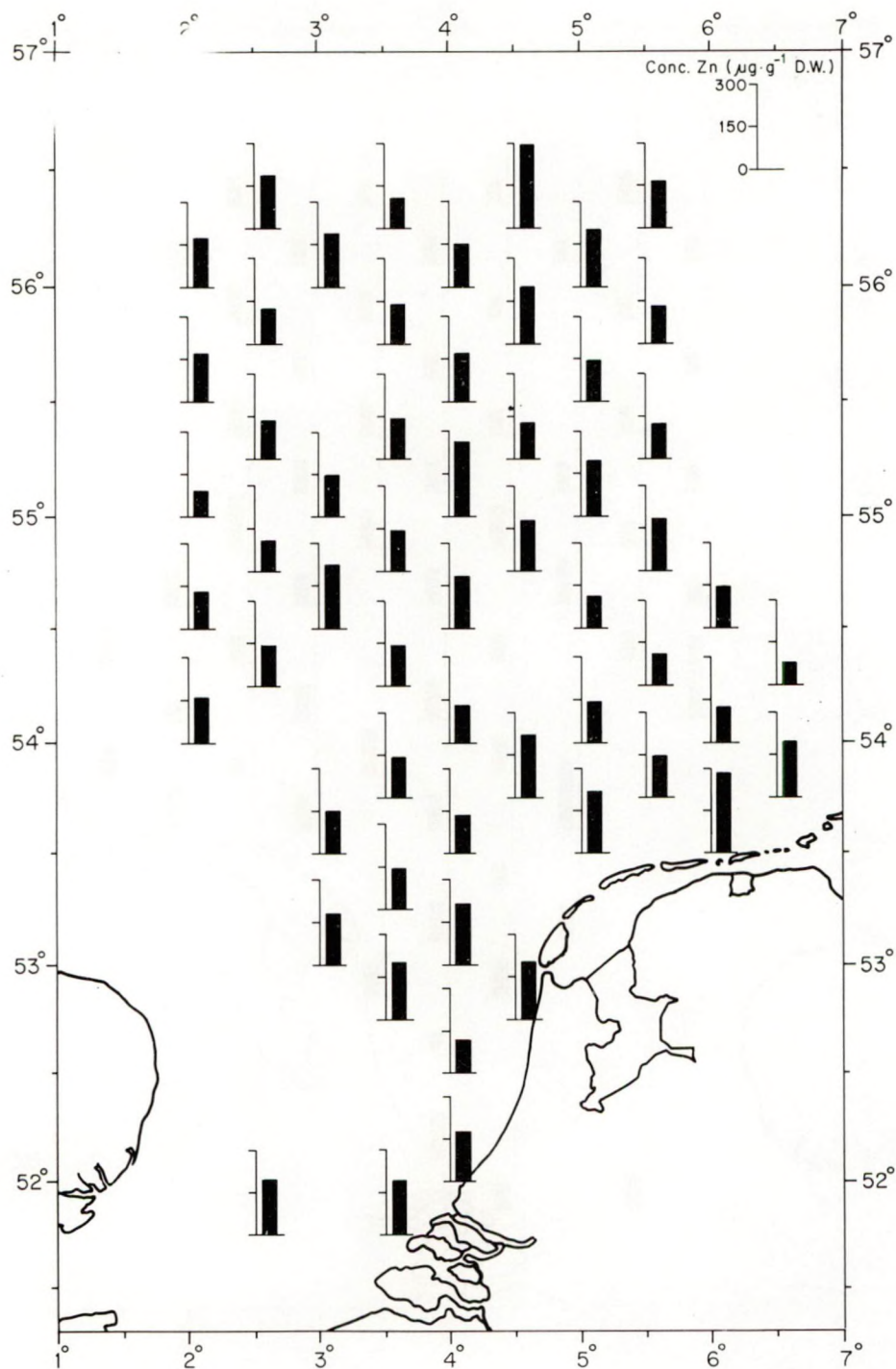


Fig. 14. The concentration of zinc in whole body of the starfish *Asterias rubens*. The Y-axis gives  $300 \mu\text{g}\cdot\text{g}^{-1}$  dry weight.

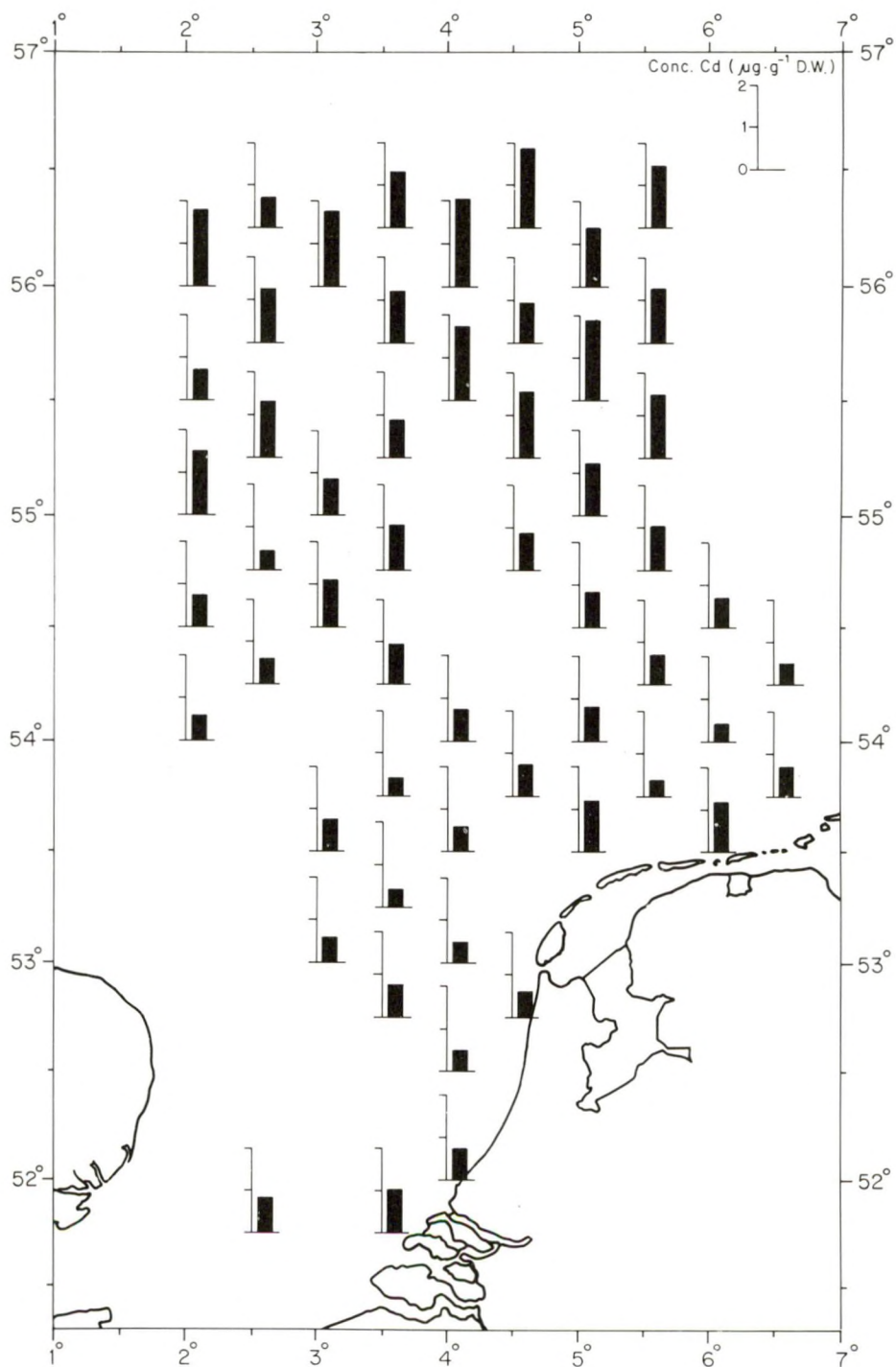


Fig. 15. The concentration of cadmium in whole body of the starfish *Asterias rubens*. The Y-axis gives  $2 \mu\text{g}\cdot\text{g}^{-1}$  dry weight.

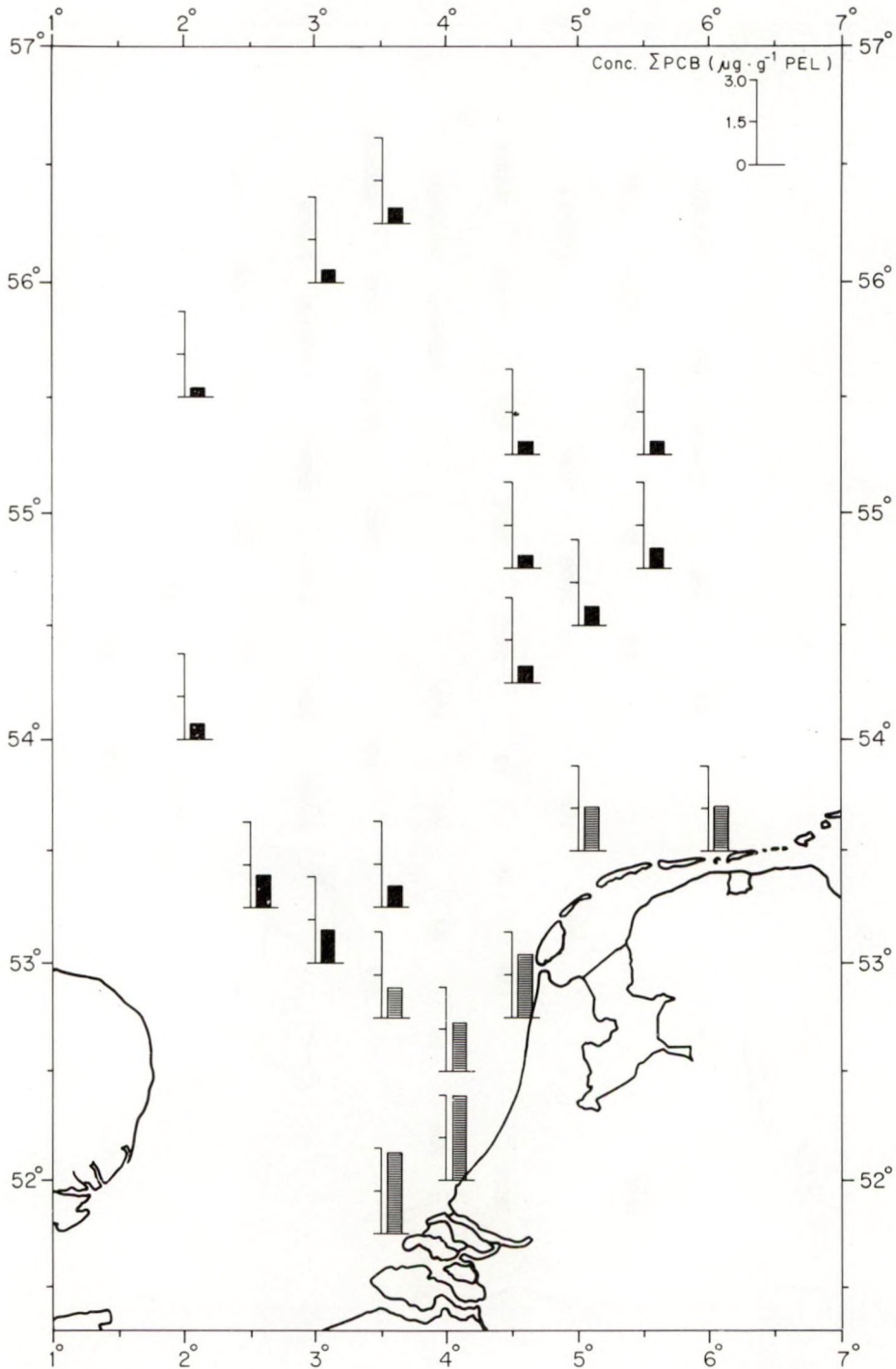


Fig. 16. The concentration of  $\Sigma$ PCB in whole body of the shrimp *Crangon allmanni* (■) and in whole body of the brown shrimp *Crangon crangon* (▨). The Y-axis gives  $3 \mu\text{g}\cdot\text{g}^{-1}$  pentane extractable lipid.

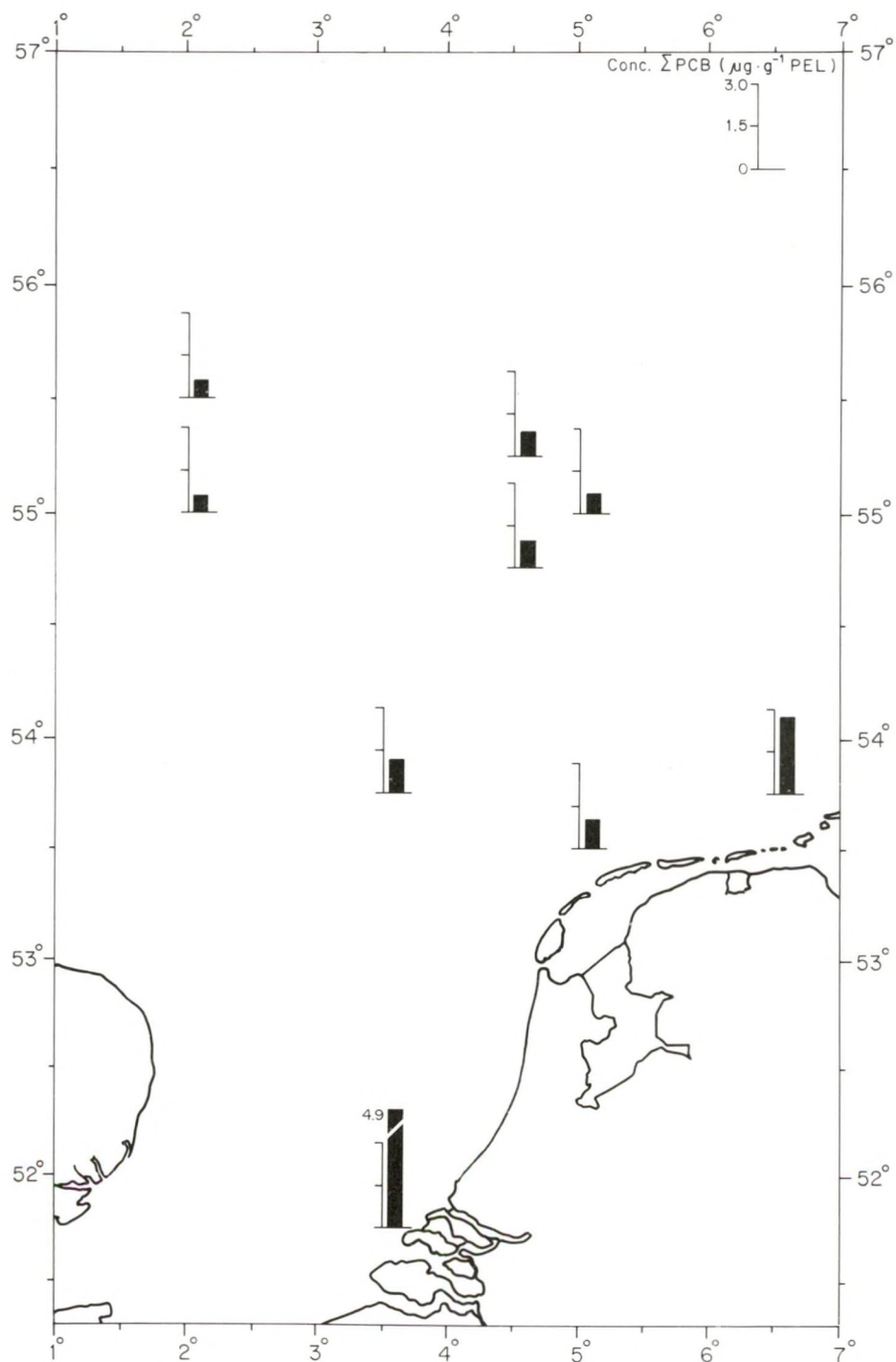


Fig. 17. The concentration of  $\Sigma$ PCB in whole body of the starfish *Asterias rubens*. The Y-axis gives  $3 \mu\text{g}\cdot\text{g}^{-1}$  pentane extractable lipid.

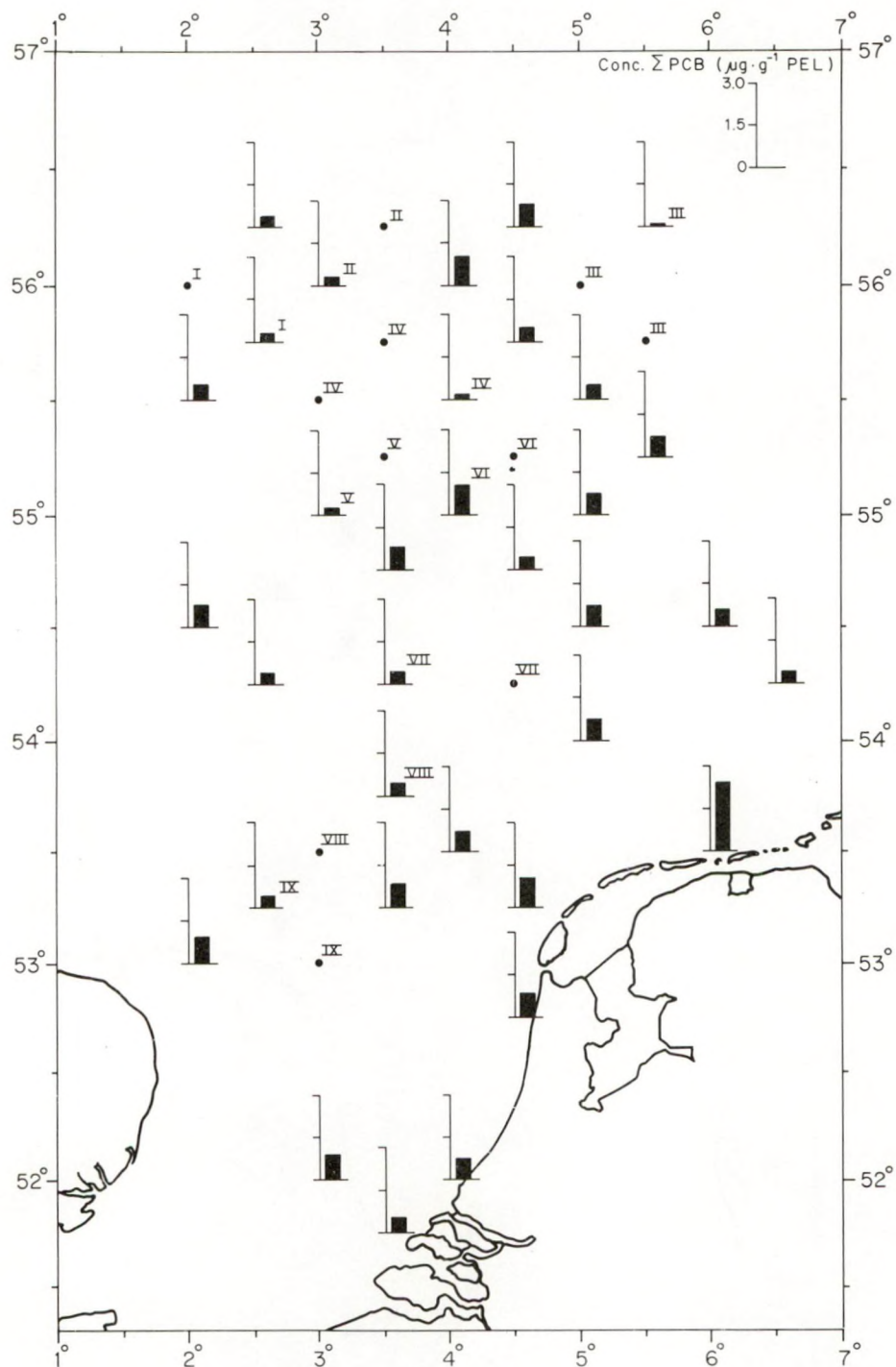


Fig. 18. The concentration of  $\Sigma$ PCB in whole body of the polychaete annelid *Nephtys hombergii*. The Y-axis gives  $3 \mu\text{g}\cdot\text{g}^{-1}$  pentane extractable lipid. The sampling sites from which specimens are pooled, together with the concentration to match, are indicated by I up to and including IX (cf. Table 4).

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