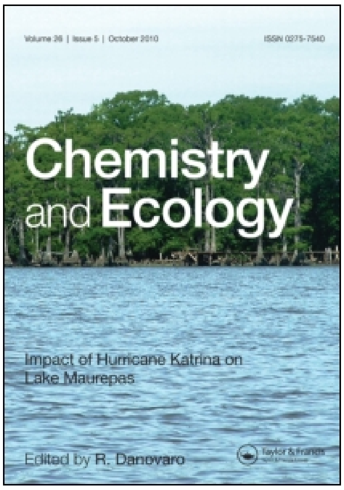

Chemistry and Ecology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713455114

A 4-Years' Analysis of the Meiofauna Community of A Dumping Site for Tio_2-Waste Off the Dutch Coast

N. Smol[a]; R. Huys[a]; M. Vincx[a]
[a] Institute of Zoology, Marine Biology Section, Gent, Belgium

To cite this Article Smol, N. , Huys, R. and Vincx, M.(1991) 'A 4-Years' Analysis of the Meiofauna Community of A Dumping Site for Tio_2-Waste Off the Dutch Coast', Chemistry and Ecology, 5: 4, 197 — 215
To link to this Article: DOI: 10.1080/02757549108035250
URL: http://dx.doi.org/10.1080/02757549108035250

Chemistry and Ecology, 1991, Vol. 5, pp. 197–215 Printed in Singapore

A 4-YEARS' ANALYSIS OF THE MEIOFAUNA COMMUNITY OF A DUMPING SITE FOR TiO_2-WASTE OFF THE DUTCH COAST

N. SMOL, R. HUYS and M. VINCX

Institute of Zoology, Marine Biology Section, K.L. Ledeganckstraat, 35, B-9000 Gent, Belgium

(24 January 1991)

Sublittoral meiofauna of 24 stations was monitored over 4 years (1984–1987) in and around a dumping site for TiO_2-acid waste in the Southern Bight of the North Sea off the Dutch coast.

The meiofauna was examined quantitatively and qualitatively with special reference to the nematode and the copepod community structure down to species level and to the trophic structure of the nematodes.

Biological, sedimentological, geographical parameters and the concentration of several heavy metals were subject to univariate and multivariate statistical analysis and classification techniques to evaluate the impact of the TiO_2-dumping activities.

The meiofauna is dominated by nematodes, copepods, gastrotrichs and turbellarians. There is a difference of 4% between the nematodes and the copepods: the dumping area being characterised by 76% abundance of nematodes and 12% copepods in comparison with 72% nematodes and 16% copepods in the reference area. The meiofauna community, and the nematode and copepod communities in particular, are very diverse in this area. The diversity of the copepod community, described by a k-dominance curve, is distinctly lower in the dumping area than in the reference area.

For several structural community parameters (such as density, diversity, biomass, trophic structure) opposite relationships are found between the years of investigation.

Higher amounts of silt and the concentrations of 8 contaminants in the sediment had a reducing influence on the diversity of the nematodes, while higher amounts of gravel had a reducing effect on the diversity of the copepods. The diversity of the latter was positively correlated with the density of the copepod community and with the diversity of the nematodes.

KEY WORDS Meiofauna, Nematoda, Copepoda, dumping, TiO_2-acid waste, North Sea

INTRODUCTION

Monitoring of the meiofauna community at a dumping site for TiO_2-acid waste started in 1984 and is examined on a yearly basis until dumping at the Dutch grounds is discontinued (end 1989).

Discharges of TiO_2-acid waste take place daily in a restricted area 20 miles off the coast near "Hoek van Holland" (Figure 1). The area is characterised by depths ranging between 28 m and 45 m. The discharge area is restricted within four coordinates: A: 52°27′30″ NL, 3°07′30″ EL; B: 52°15′00″ NL, 3°45′00″ EL; C: 52°08′00″ NL, 3°35′30″ EL; D: 52°16′00″ NL, 2°59′00″ EL.

The design of the monitoring programme is described by Spaans (1987) and Bos (in press).

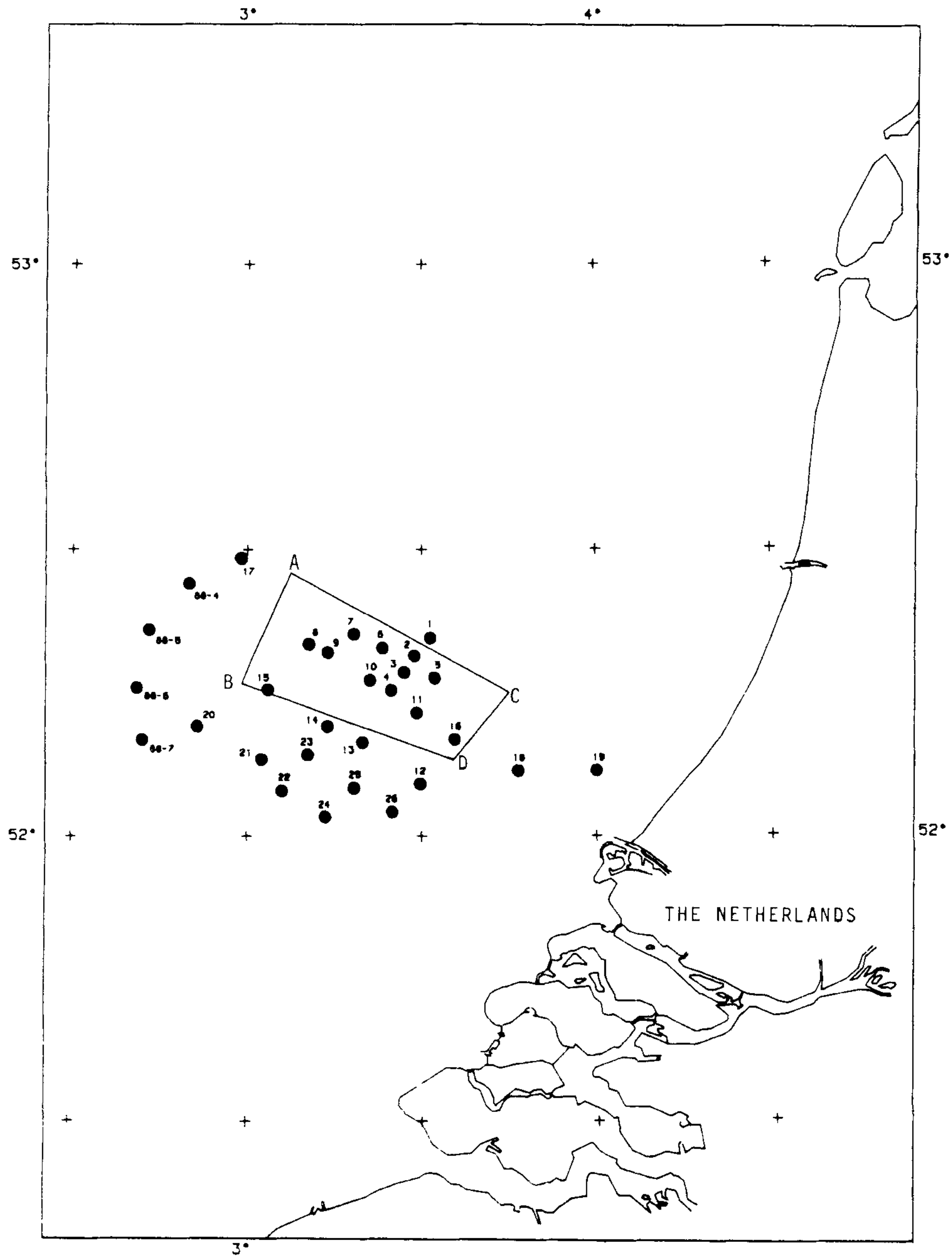

Figure 1 Location of the TiO_2 dumping area (ABCD) and the sampling stations.

The meiobenthos is examined quantitatively and qualitatively on the basis of two samples per station each year taken in early summer (June–July). The community structure of the two dominant taxa, nematodes and copepods, is analysed down to species level and the trophic structure of the nematodes in 1986 and 1987 was determined.

Biological, sedimentological, geographical parameters and the concentration of several heavy metals in the sediment are subject to univariate and multivariate statistical analysis and classification techniques to assess the impact of the TiO_2-acid waste discharges.

Meiofauna taxa are known to be sensitive indicators of environmental perturbations. Community characteristics such as abundance, relatively stationary life habit, short generation time, benthic larvae, intimate association with sediments, and the ease of sampling, make them more suitable as pollution indicators than macrofauna.

Most pollution studies, however, focus on the impact of organic sewage. Information about relationships with inorganic heavy metals are scarce, especially in off-shore regions.

This paper presents a summary of the results of several reports (Huys *et al.*, 1984; Smol *et al.*, 1986; Smol *et al.*, 1989).

MATERIALS AND METHODS

Study Area: Figure 1

A total of 24 stations has been sampled for meiobenthos; 13 stations are within the dumping area ABCD (Figure 1). The number of stations in the reference area has changed: 4 in 1985, 10 in 1985, 11 in 1986 and 10 in 1987.

At the start (1984), 19 stations were sampled (stations 1 to 19), stations 1 to 16 being within or close to the dumping area, and stations 17, 18 and 19, designated as reference stations, situated outside the dumping area.

From 1985, stations 20 to 26 (south-west of the discharge area) were added to increase the number of reference stations and stations 18 and 19 were eliminated as inappropriate (they are too much influenced by coastal activities). In 1988, 4 additional reference stations (88-4, 88-5, 88-6, 88-7) situated further west, were chosen, taking into account a possible influence from the dumping areas located on the Belgian Continental Shelf.

All stations are sampled each year within a three day period at the end of June or the beginning of July. Sediment at each station was sampled with a Reineck box-core, from which five replicate $10\,cm^2$ hand-held core samples of sediment were taken to a depth of at least $15\,cm$. Two replicates were analysed for meiofauna and one for grain size analysis, the others served as reserve.

Sediment Analysis

Sediment grain sizes are analysed according to the dry-sieve method using a set of sieves suited to the intervals of the Wentworth scale.

Faunal Analysis

Meiofauna was extracted by a combination of decantation through a 38 μm sieve and the Ludox centrifugation technique (Heip *et al.*, 1985). After staining with rose bengal, meiofauna was counted to major taxon level (the archiannelids are included within the polychaetes).

For the samples whose fauna was identified to species level, 200 (randomly chosen) nematodes and all of the copepods were picked out and mounted on slides for identification.

Functional grouping of the nematodes into feeding guilds was deduced from the structure of the buccal cavity according to Wieser (1953): 1A being selective deposit feeders (bacterivores), 1B non-selective deposit feeders (bacterivores), 2A epistratum (diatom) feeders, 2B predators/omnivores. The trophic diversity of the nematodes is expressed in a trophic index $\Theta = \varepsilon\theta^2$; θ reflecting the percentage of each feeding type (Heip *et al.*, 1984).

Biomass Analysis

Dry weights of nematodes were determined using a Mettler microbalance after drying in a desiccator for 2 h at 110°C. Dry weights of copepods are calculated by applying an estimated dry weight value to the males, females and juvenile classes for each species. The species are previously divided into biomass classes depending on their body shape and length (Herman *et al.*, 1985).

Diversity Analysis

Diversity is calculated as Brillouin's index (Brillouin, 1962). The *k*-dominance curve, proposed by Lambshead *et al.* (1983) is used to detect differences among the assemblages within and outside the dumping area.

Chemical Analysis

A chemical analysis of the sediment of 17 stations (stations 1 to 17) was undertaken during the survey. The analysis included Fe, Ti, Cr, V, Sr, Ba, Pb, Cd, Co, Mn, Sn, Zn, Cu and Ni. The results are tabulated in the reports of Anten (1985, 1987a, 1987b).

Statistical Analysis

A one-way ANOVA, checked with 'a posteriori' comparisons, using a pooled mean square within sites (Sokal & Rohlf 1981) was used to detect differences between stations in abundance, biomass and diversity of the communities. A two-level nested ANOVA was used to detect differences between all stations within the discharge area and all reference stations outside the discharge area. These stations were (see Figure 1):

Dumping area: stations 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11.

Reference area: stations 12, 13, 14, 17, 20, 21, 22, 23, 24, 25, 26.

Stations 15 and 16, situated at the border of the discharge area, were eliminated from statistical analysis.

The same data were also subjected to the non-parametric Kruskall–Wallis test (Siegel, 1956).

Correlations between abiotic and biotic parameters were analysed by Spearman-rank correlation coefficients (Siegel, 1956).

TWINSPAN classification techniques (Hill, 1979) were applied to the meiofauna (*sensu stricto*), the nematode and copepod data.

RESULTS

Sediment Characteristics

Sedimentological data have been presented as mean values of 6 years (1984–1989) and include the data of stations 88-4, 88-5, 88-6, 88-7.

Sediment analysis for each station over 6 years (Figure 2) shows that all the area during the period 1984–1989 is characterized by a well, to moderately well, sorted ($0.35 > \phi > 0.50$) medium ($250\,\mu m >$ grain size $> 500\,\mu m$) clean sand (>90% sand) (Table 1).

Higher variation (SE) for the stations 9 (silt) and 15 (gravel) (Figure 2) are due to a bias of sampling in 1985: station 9 contains 13.4% silt and 8.7% gravel; station 15: 9.5% silt and 21.4% gravel. The sea-bed consists of sand ridges alternating with steep depressions extending from the Bruine Bank south of the Belgian coast to the north of the dumping area. In the depressions, small patches of silt may occur; station 24 is unusual for its median grain size and degree of sorting, due to exceptional high values found in 1985: a grain size of 643 μm and a degree of sorting of $\phi = 0.727$.

The mean values for the stations situated within the dumping area and of those of the reference area are compared in Table 1 and in Figure 3; little difference is found in the fractions of sand, silt and gravel. The median grain size and the degree of sorting are somewhat higher for samples in the reference area but the differences between the mean values for the dumping area and the reference area are statistically insignificant.

The Meiofauna

A total of 20 meiofauna taxa (including macrofaunal juveniles) was found during the survey: Nematoda, Copepoda, Turbellaria, Gastrotricha, Tardigrada, Halacarida, Hydrozoa, Polychaeta, Oligochaeta, Ostracoda, Kinorhyncha, Rotifera, Scyphozoa, Entoprocta, Amphipoda, Isopoda, Tanaidacea, Cumacea, Bivalvia and Echinodermata. The nauplii larvae of the copepods were also enumerated. Kinorhyncha, Rotifera and Entoprocta were rare.

The meiofauna of the whole area was dominated by nematodes (74%), followed by copepods (13%), gastrotrichs (5%) and turbellarians (4%). These four taxa were present at all stations. The mean density of the common meiofauna taxa over the 4 years are shown in Table 1.

The absolute density values for the whole area are similar each year and are comparable to values for the period 1970–1975 and with data for analogous sublittoral sediments in the literature.

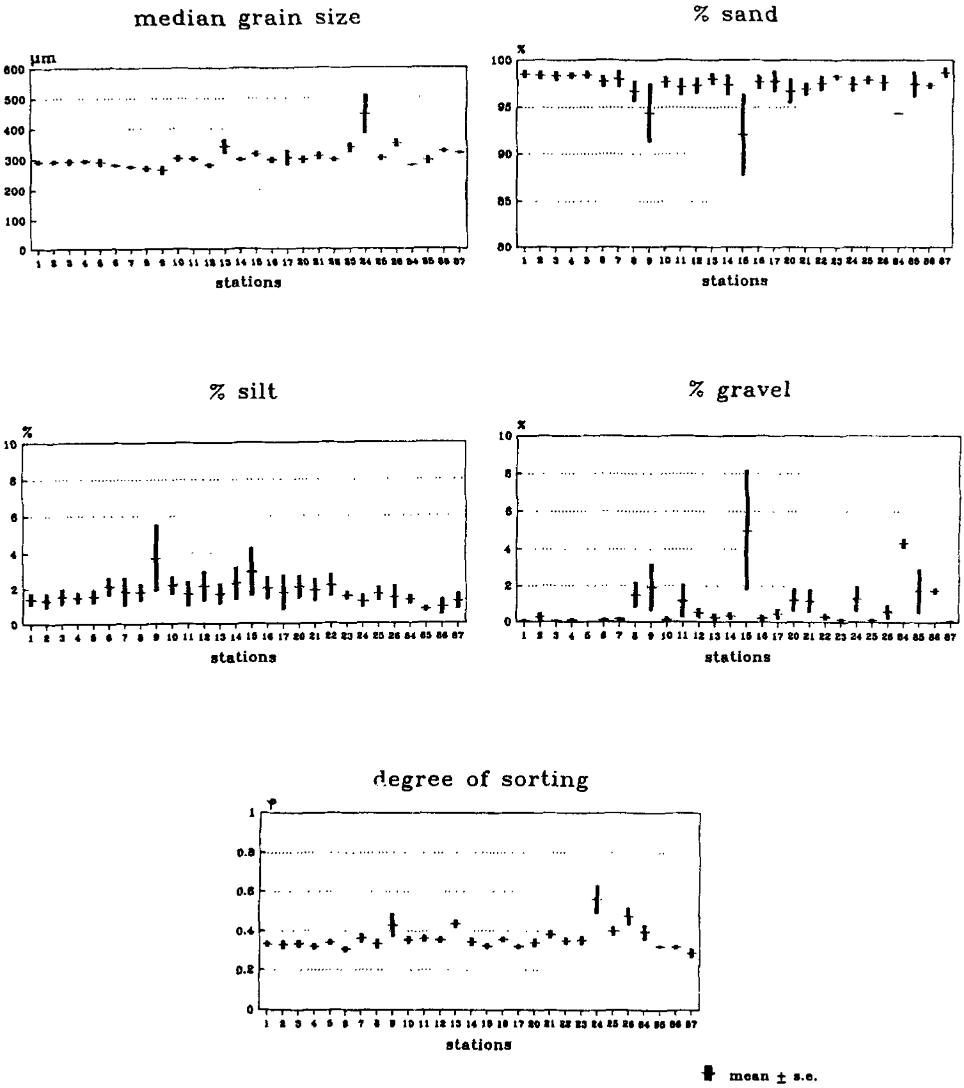

Figure 2 Sediment characteristics: mean values and standard errors over 6 years per station (84, 85, 86, 87 = respectively the stations 88-4, 88-5, 88-6, 88-7 shown in Figure 1).

Density pattern over 4 years (Figure 4) shows no striking difference between the density of stations within the discharge area (stations 1 to 11) and reference stations (stations 12, 13, 14 and 20 to 26), although numbers were higher in 1985, 1986 and 1987. Lower numbers in 1984 were possibly due to lack of data for stations 20 to 26.

Comparison of the samples from the dumping area and the reference area (Table 1 and Figure 5) shows little change in the relative composition of the

Table 1 Sediment and meiofauna characteristics: mean values over 6 (sediment) and 4 years (meiofauna)

	I		*D*		*R*	
	x	*s.e.*	*x*	*s.e.*	*x*	*s.e.*
% sand	97.3	(0.3)	97.6	(0.4)	96.6	(0.2)
% silt	1.9	(0.2)	1.9	(0.2)	1.7	(0.2)
% gravel	0.8	(0.2)	0.5	(0.2)	0.7	(0.1)
median grain size (mm)	0.303	(0.004)	0.286	(0.003)	0.321	(0.007)
degree of sorting (ϕ)	0.361	(0.006)	0.345	(0.008)	0.384	(0.011)
density Meiofauna (ind./10 cm^2)	1328	(62)	1224	(77)	1408	(111)
density Nematoda (ind./10 cm^2)	996	(54)	931	(126)	1038	(170)
density Copepoda (ind./10 cm^2)	175	(18)	147	(20)	208	(36)
density Gastrotricha (ind./10 cm^2)	67	(6)	64	(9)	66	(10)
density Turbellaria (ind./10 cm^2)	56	(5)	57	(8)	55	(7)
% Nematoda	74.4	(1.4)	75.8	(1.8)	72.0	(2.4)
% Copepoda	13.4	(1.2)	12.3	(1.5)	15.5	(2.0)
% Gastrotricha	5.3	(0.5)	5.2	(0.6)	5.3	(0.8)
% Turbellaria	4.2	(0.3)	4.4	(0.5)	4.2	(0.4)
N/C-ratio	5.7	(3.0)	6.3	(5.4)	4.9	(2.6)

I = Whole investigated area, D = dumping area, R = reference area, N = nematodes, C = copepods.

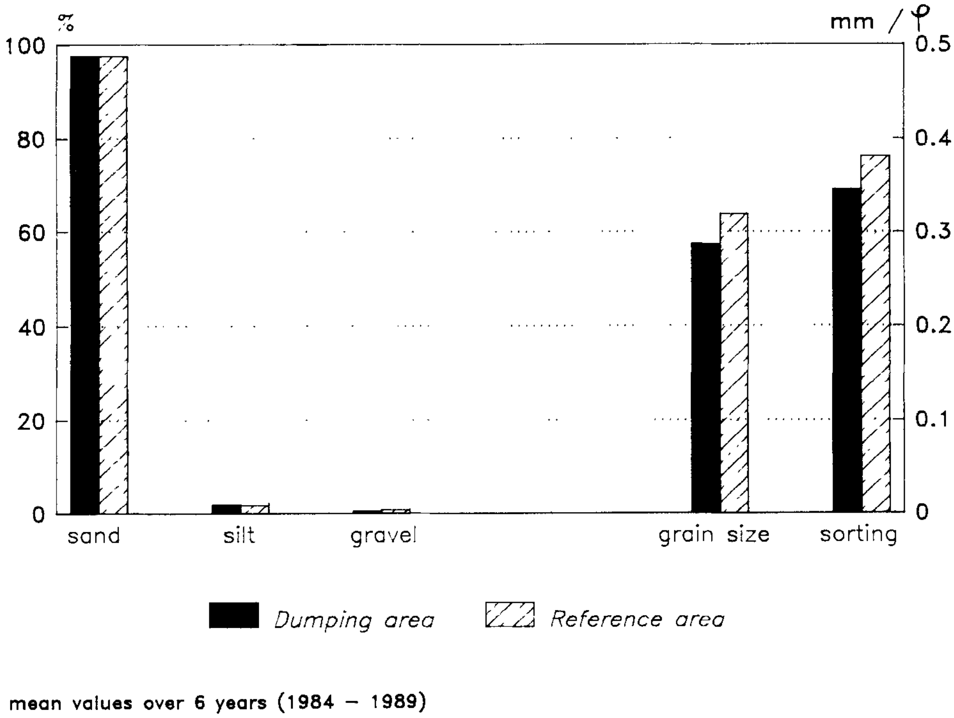

Figure 3 Sediment characteristics: comparison between the dumping area and the reference area (mean value over 6 years).

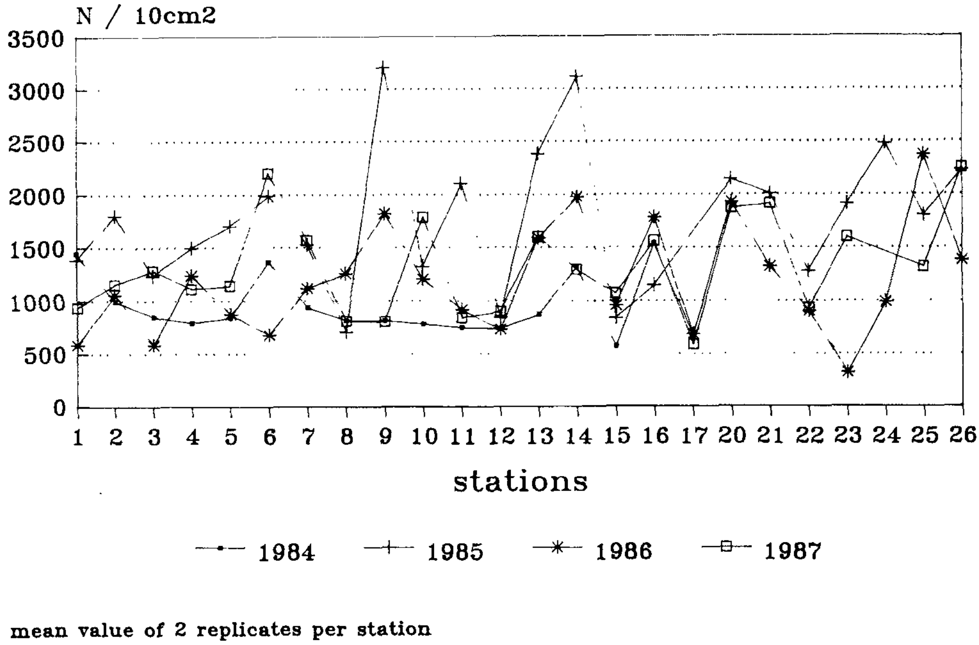

Figure 4 Density of the meiofauna over 4 years at each station.

meiofauna (based on the mean values over 4 years). There is a difference of 4% between nematodes and copepods: the dumping area being characterized by 76% occurrence of nematodes and 12% of copepods instead of respectively 72% and 16% in the reference area.

For the meiofauna as a whole and for the dominant taxa, the mean density in reference stations is higher than that in stations situated within the dumping area (Figure 6), but the differences are statistically not significant ($p = 0.05$). Log transformations of the data did not reveal any significance.

Comparison of the mean percentage abundance of the 4 dominant taxa

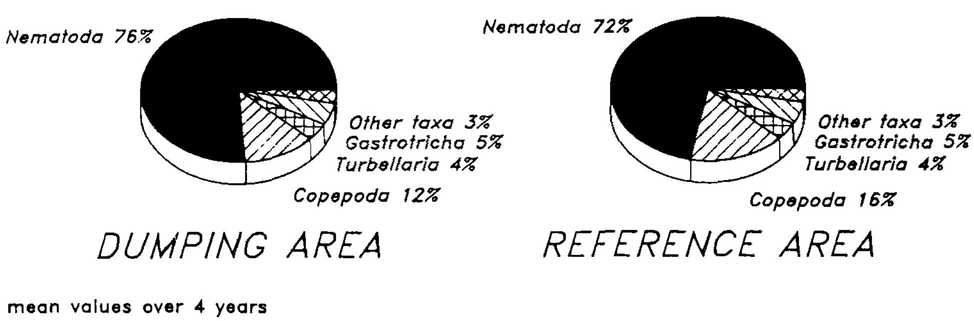

Figure 5 Percentage composition of the meiofauna.

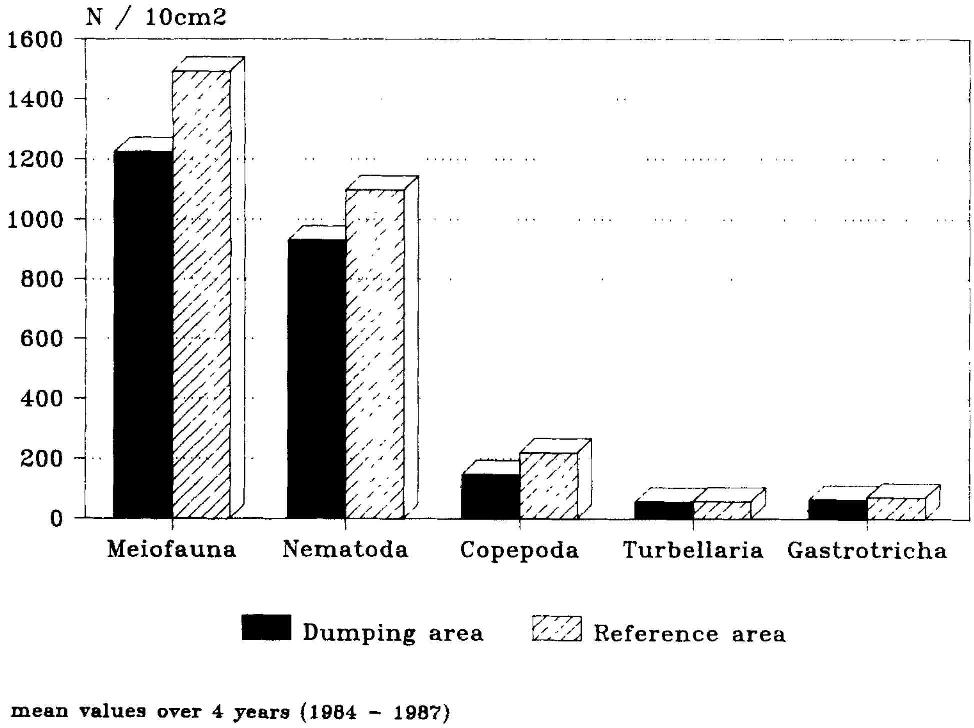

Figure 6 Comparison of the density of the dominant meiofauna taxa between the dumping and the reference area.

(nematodes, copepods, gastrotrichs and turbellarians) within the dumping area with other off-shore areas (with analogous sediment) in the vicinity, shows that nematodes are more abundant in the TiO_2-dumping area than in stations situated to the south on the Belgian Continental Shelf and stations situated more to the north on the Dutch Continental Shelf (Milzon) (Figure 7). This may nevertheless indicate an influence of pollution as nematodes are known to be a most resistant taxon. The data of the Belgian stations and Milzon are reported by Vandenberghe (1987) and Groenewold & van Scheppingen (1988), respectively.

The nematode/copepod ratio, presented by Raffaelli & Mason (1981) as a possible indicator of pollution, showed large variation (0.8 to 215) between stations and time. The mean values for the dumping and the reference area are presented by year in Figure 8. The N/C-ratio is consistently greater within the dumping area, although the difference is not significant (Table 2). For the period 1984–1987 the overall mean ratio $N/C = 16.1$ for the whole area, with values 20.0 and 12.5 for the dumping and the reference area respectively.

The meiofauna group diversity (Brillouin, 1962) was higher each year in the reference area, but the difference with the dumping area was not significant (Table 2).

TWINSPAN classification based on the abundances of meiofauna taxa and on

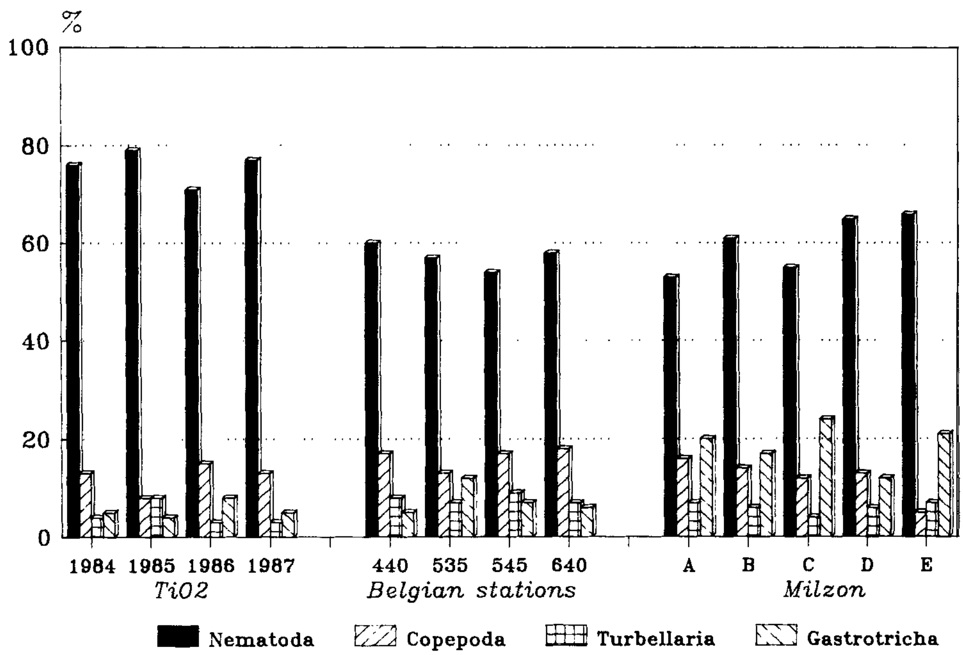

Figure 7 Comparison of the mean percentage of the dominant taxa with other off-shore locations (Belgian stations = stations situated to the south of the TiO_2 dumping site on the Belgian Continental Shelf, investigated by Vandenberghe (1987), Milzon = stations situated to the north of the TiO_2 dumping site on the Dutch Continental Shelf, investigated by Groenewold and van Scheppingen (1988)).

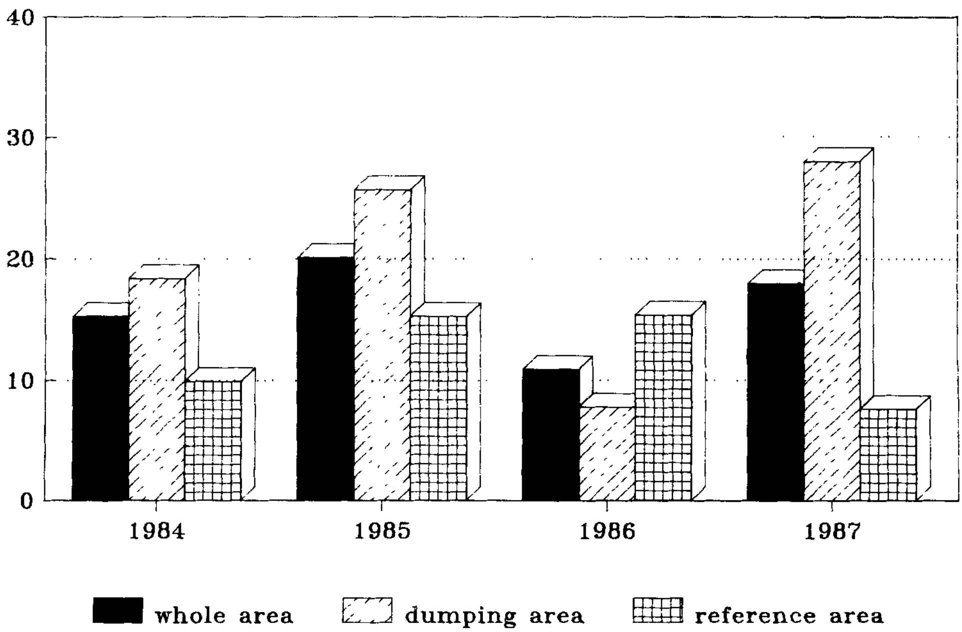

Figure 8 The N/C-ratio over 4 years compared between the dumping and the reference area.

the absence or presence of taxa did not result in any geographical or temporal grouping indicating an effect of the dumping.

Nematoda

A total of 327 species were found during the survey.

The nematode community is dominated by members of the families Chromadoridae, Desmodoridae, Microlaimidae and Cyatholaimidae. The ten most common species are *Karkinochromadora lorenzeni, Dichromadora cucullata, Chromaspirina parapontica, Chromaspirina pellita, Neochromadora munita, Leptonemella granulosa, Microlaimus marinus, Paracanthonchus thaumasius, Paracyatholaimus pentodon, Desmodora schulzii.*

The nematode community for each station is characterized as very diverse; the community has a Brillouin index (*H*) of 4.2 bits/ind. According to this scale, the nematode community was significantly more diverse within the dumping area than outside it in 1986, but in 1987 an opposite trend was manifested (Table 2).

When the data of stations situated within the dumping area are combined and similarly the data of reference stations are combined, the *k*-dominance curve for the 2 areas shows that the nematode communities of both areas were indistinguishable from each other (Figure 9).

Table 2 Comparison of mean values (ANOVA)

	1984 *D R*	1985 *D R*	1986 *D R*	1987 *D R*
DENSITY Meiofauna	▶	◀	◀	◀
Nematoda	▶	◀	◀	◀
Copepoda	◀	◀	◀	◀
N/*C*-ratio	▶	▶	◀	▶
DIVERSITY (*H*)				
Meiofauna	◀	◀	=	◀
Nematoda			*▶	◀
Copepoda			▶	◀
BIOMASS Nematoda (I)			▶	▶
Nematoda (T)			=	▶
Copepoda (I)			◀	◀
Copepoda (T)			◀	◀
NEMATODA				
% sel. dep. feeders			◀	◀
% non sel. dep. f.			▶	▶
% epistratum f.			◀	◀
% pred./omniv.			▶	=
diversity within 1A			*▶	◀
diversity within 1B			=	▶
diversity within 2A			*▶	=
diversity within 2B			▶	◀
trophic index			◀	▶

D = Dumping area, R = reference area, N = nematodes, C = copepods, H = Brillouin-index, I = individual biomass, T = total biomass, * = significant (0.05 level), ◀ = higher value in reference area, ▶ = lower value in reference area, = no difference between reference and dumping areas.

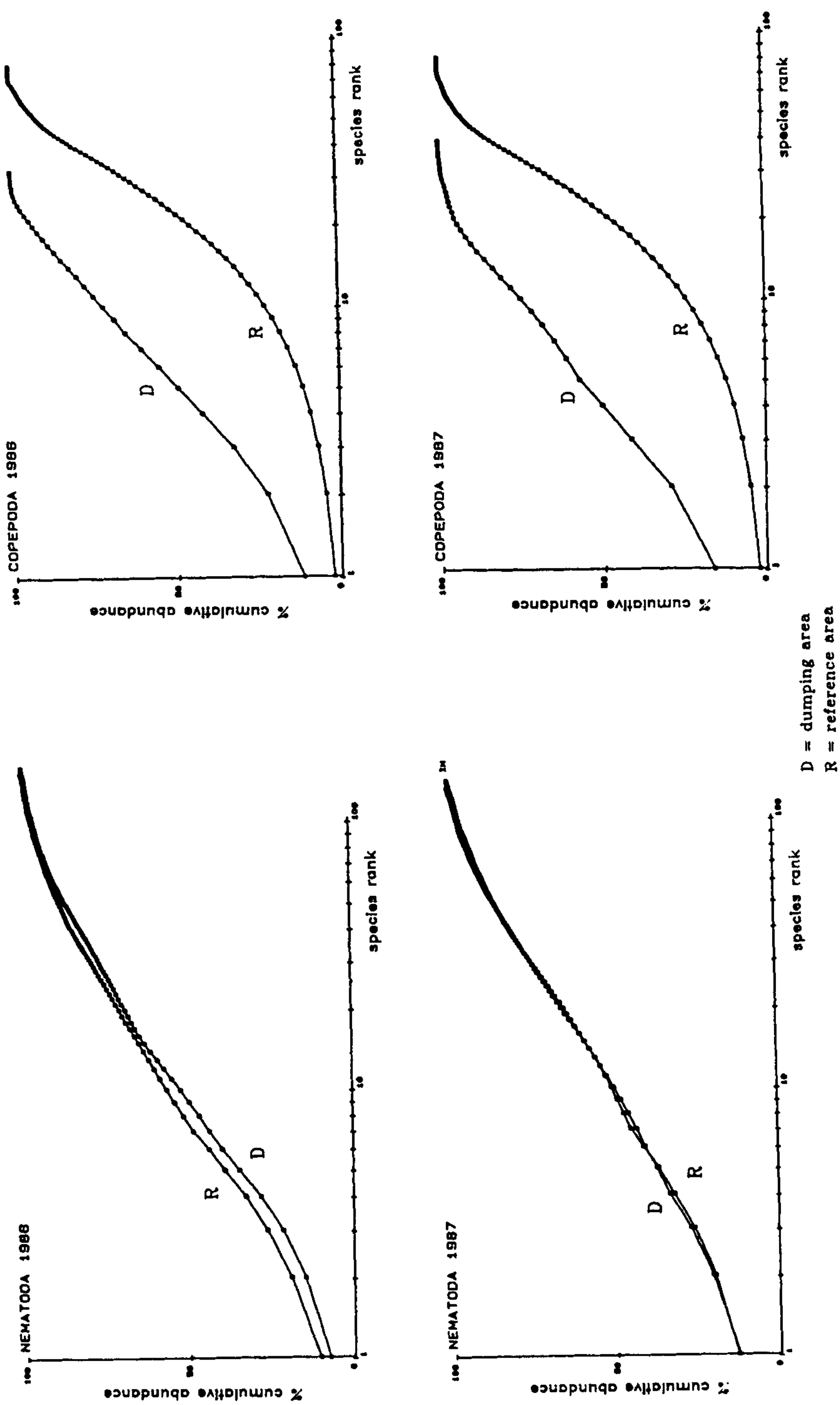

Figure 9 *k*-dominance curves for nematodes and copepods.

The nematode community is dominated by epistratum feeders (2A: 52%); the predators/omnivores (2B) and non-selective deposit feeders (1B) rank second and third, respectively about 19% and 17%; the selective deposit feeders (1A) take up the rest of 12%. The trophic index $\Theta = 0.38$.

Comparison of the trophic characteristics of the dumping and the reference area is given in Table 2. A consistent pattern was found in 1986 and 1987; the percentage of selective deposit feeders (1A) and of epistratum feeders (2A) was higher in the reference area, and the percentage of non-selective deposit feeders (1B) lower. The percentage of predators/omnivores (2B) was higher in the dumping area in 1986 and equal to the reference area in 1987.

Diversity within each feeding type and the trophic index show opposite trends in 1986 and 1987. The mean value of diversity within the group of selective deposit feeders and the group of epistratum feeders was significantly different between both areas in 1986, but this relationship was not repeated in the following year.

The mean individual biomass of a nematode was 0.37 μg dwt. in 1986 and 0.46 μg dwt. in 1987. Taking into account the population density, total biomass was 0.33 mg in 1986 and 0.49 mg dwt. in 1987. No significant difference was observed between the dumping and the reference area (Table 2).

A TWINSPAN analysis of the abundance of the species showed no separation between the two areas for the nematode community.

Copepoda

A total of 77 copepod species were found during the survey, more than 99% belonging to the harpacticoids.

The community is characterised quantitatively and qualitatively by the families Cylindropsyllidae and Paramesochridae (mainly considered as epistratum feeders, cf. 2A-type of nematodes). The ten most common species are: *Kliopsyllus* sp. 1, *K. paraholsaticus, Paraleptastacus espinulatus, Leptastacus laticaudatus, Arenosetella tenuissima, A. germanica, Evansula pygmaea, Scottopsyllus* sp. 2, *Harpacticus tenellus, Paramesochra helgolandica.*

The copepod community is very diverse in the area: $H = 2.7$bits/ind. Comparison between the mean diversity of stations within the dumping area and that of reference stations did not show any significant difference between the two (Table 2) and even showed opposite trends between 1986 and 1987.

The combined species composition at all stations within the dumping area and at all reference stations were also plotted as a k-dominance curve. This showed a more diverse community outside the dumping area than within (Figure 9).

The mean individual biomass of a copepod in that area is 0.15 μg dwt. and the total biomass of the copepod community has a mean value of 29.8 μg in 1986 and 25.0 μg in 1987. Both biomass characteristics (individual and total) are higher in the reference area, but the differences are statistically not significant (Table 2).

TWINSPAN analysis, however, showed no separation of the two areas.

Correlations between Biotic and Abiotic Parameters

The parameters analysed by Spearman-rank correlation coefficients are given in Table 3 and the results of the various correlations are summarised in Table 4.

Table 3 Parameters analysed by Spearman-rank correlation coefficients

Biological parameters:
- density of the meiofauna
  nematodes
  copepods
- biomass of the nematodes and copepods
- diversity of the nematodes and copepods
- nematode/copepod ratio
- parameters of the trophic structure of the nematodes
  % 1A, % 1B, % 2A, % 2B
  1A/2A, 1B/2A, 1A/2B, 1B/2B, 1A + 1B/2A + 2B
  trophic index

Sediment characteristics:
- median grain size
- % sand
- % silt
- % gravel

Geographic position: latitude, longitude, depth
Concentration of contaminants: Fe, Ti, Cr, V, Sr, Ba, Pb
Cd, Co, Mn, Sn, Zn, Cu, Ni

The density of the meiofauna as a whole and of the nematodes was positively correlated with the percent silt and the concentration of 11 heavy metals (Fe, Ti, Cr, V, Pb, Cd, Co, Sn, Zn, Cu and Ni) in the sediment and negatively with the percent sand and the geographic latitudinal position.

The density of copepods is greater with greater median grain size, greater diversity of the copepods and in association with a latitudinal position. No significant correlation exists between the density of the copepods and the levels of associated contaminants.

Higher amounts of silt and of 8 contaminants (Fe, Cr, Pb, Cd, Co, Zn, Sn and Ni) of the sediment had a significant reduced influence on the diversity of the nematodes, and higher percent gravel had a significant negative effect on the diversity of the copepods. The diversity of the latter was positively correlated with its population density and with the diversity of nematodes.

The nematode/copepod-ratio of the whole area was higher with greater percent silt and higher concentrations of 7 heavy metals (Fe, Ti, V, Ba, Cd, Co and Ni) and with lower percent sand and median grain size.

Although the sediment granulometry of the investigated area is homogeneous in general terms, a positive correlation was found between the percent sand and the northerly position of stations and between the percent gravel and the easterly position of stations. Median grain size was greater in the southerly direction. Spearman rank-correlation analysis indicated a north–south and an east–west gradient of sediment, and the analysis was repeated with the stations grouped into rows as follows: row A: stations 6, 10, 14, 23 and 22; row B: stations 1, 2, 3, 4, 13 and 24; row C: stations 20, 21, 23, 25 and 26; row D: stations 8, 9, 10, 4, 11 and 16 to detect which parameters were correlated with geographic position. This showed a positive correlation ($p = 0.036$) between the diversity of copepods and the easterly stations of row C and a positive correlation ($p = 0.028$) between the biomass of nematodes and the easterly stations of row D. Thus, in the case of

Table 4 Significant correlations between biotic and abiotic parameters

	+	−
% sand	position north diversity nematodes	density meiofauna density nematodes N/C-ratio 12 heavy metals
% silt	density meiofauna density nematodes N/C-ratio all heavy metals	diversity nematodes
% gravel	trophic index nematodes	diversity nematodes diversity copepods biomass nematodes position east 1B/2A
median grain size	density copepods trophic index nematodes	position north N/C-ratio 10 heavy metals
density meiofauna	% silt 11 heavy metals	% sand position north diversity nematodes
density nematodes	% silt 11 heavy metals	% sand position north
density copepods	median grain size diversity copepods biomass nematodes	position north
diversity nematodes	% sand diversity copepods biomass nematodes	% silt % gravel position east trophic index nematodes 8 heavy metals
diversity copepods	density copepods diversity nematodes biomass nematodes	% gravel N/C-ratio
N/C-ratio	% silt 7 heavy metals	% sand median grain size biomass nematodes diversity copepods

these two rows, there is some response (diversity of copepods and biomass of nematodes) to the gradient of the gravel fraction of the sediment.

The greater concentration of trace metal contaminants in northerly sites reflects the route of the residual northerly current.

DISCUSSION

Although some stations (stations 9, 15 and 24) show a higher variance for certain sediment characteristics than others, mean values over 6 years are still within the defined ranges to characterize the sediment of the investigated area as a well, to moderately well, sorted medium clean sand. On the basis of these characteristics, the sediment of the region is homogeneous, a condition considered paramount for estimating the impact of pollution in and outside the dumping area.

The density of the meiofauna as a whole and the dominant groups showed temporal and spatial fluctuations which may be due to the aggregated pattern of the groups.

With the exception of 1984, the mean density of the groups tends to be lower in the dumping area, but the differences are not significant. This supports the view that pollution has no great impact on density (Heip *et al.*, 1985). The density of the dominant nematodes does not decrease after contamination with hydrocarbons, especially in sublittoral sands (Elmgren *et al.*, 1980; Elmgren *et al.*, 1983; Boucher, 1980). Neither does raw domestic sewage seem to have an impact on the density and distribution of sublittoral meiofauna (Vidakovič, 1983). The field studies of Lorenzen (1974) and Tietjen (1977) showed that the nematode abundance was not affected by heavy metal contamination.

More remarkable seems to be the mean higher percentage of nematodes in the dumping area than in the reference area (although the difference is not significant). This difference is even more evident if compared with other off-shore locations (Figure 7). A dominance of 90% of nematodes was found in studies undertaken by Renaud-Mornant *et al.* (1981) and Heip *et al.* (1984). The higher percentage of nematodes within the TiO_2-dumping area is totally compensated by a lower percentage of copepods, supporting the hypothesis that copepods are more sensitive to environmental stress than nematodes.

The mean nematode/copepod-ratio is higher every year in the dumping area, but statistically not significant and values showed wide fluctuations. The mean observed ratio of 20.0 for the dumping area as well as the value of 12.5 for the reference area are both beyond the value of >10 for pollution of sand as found by Warwick (1981), taken to indicate that the total area has to be considered as polluted. We conclude that there are still too few data for each specific habitat and type of pollution to reach such broad generalizations.

The whole meiofauna community as well as the nematode and copepod communities are classified as very diverse and are comparable to those of sandbanks (Willems *et al.*, 1982). A general trend that diversity tends to decrease due to heavy metal pollution was indicated during the four years for the meiofauna community (measured by the Brillouin index), but this trend could not be confirmed statistically. However, the diversity of the nematode and the copepod communities showed opposite trends in 1986 and 1987. A more reliable result was obtained by describing the diversity by a *k*-dominance curve as proposed by Lambshead *et al.* (1983). Using this method a clear distinction between the two areas could be made with the copepod community being less diverse in the dumping area.

On the basis of the nematode and the copepod communities as presented by their *k*-dominance curves, the copepods are more affected by the dumping activities. Nematodes as well as copepods are dominated by epistratum feeders, so that they may be in competition for food. Decrease in abundance and diversity of copepods may enable some nematodes to invade the niches of copepods, which benefits the high diversity of nematodes.

The trophic index of the nematodes was not a good indication of the influence of pollution as found by Heip *et al.* (1984). The decrease of the trophic index will only become obvious if different habitats (such as silt and sand) are compared.

Analysis of the trophic structure of the nematode community results in inconsistent findings: even when statistically significant, differences were observed in only one year, as is the case for the species diversity within each feeding type.

The density of nematodes and consequently of the meiofauna as a whole is significantly and positively correlated with the percentage of silt and the concentration of most trace metal contaminants in the sediment. The lower diversity of nematodes is significantly correlated with higher concentrations of 8 different heavy metal contaminants and the amount of silt. Similar observations were found by Tietjen (1980) and Heip *et al.* (1984).

This study advocates the need for long-term monitoring of biological communities in relation to contaminant exposure, as we have found contradictory results in consequent years. Results based on one particular year might lead to incorrect conclusions, favouring or disfavouring discharges or dumping activity.

After 4 years of monitoring, no major effects of the dumping on the density and diversity of the meiofauna could be proven. If we do go down to species level, differences among the copepod assemblages within and outside the dumping area could be detected, the copepod community within the dumping area being less diverse (comparison of the k-dominance species diversity curves). We conclude that knowledge about the species composition of the community is needed to detect possible effects in pollution studies in contradiction to the statements of Heip *et al.* (1988).

We recognize that laboratory experiments could help to resolve causal relationships which are difficult to prove in field studies and may help in interpretation of data.

Monitoring pollution at this site started nearly two decades after the pollution itself. We have no knowledge of the pre-pollution community and it is very hard to find good (clean) reference stations, especially in the North Sea. Because of this we suggest a follow-up of observations in the dumping area for 1991 or later to study whether the fauna has changed after the TiO_2 dumping has ceased. As we missed the pre-pollution situation, it will be a challenge to be able to investigate the possible recovery after 3 decades of dumping.

Acknowledgements

This monitoring study was a project of the Dutch Rijkswaterstaat, North Sea Directorate, financially supported by the German TiO_2-producing industries i.e. Pigment Chemie GmbH and Kronos Titan GmbH. The authors like to thank Prof. Coomans for the facilities in his laboratory and Drs H. Bos and Drs D. Vethaak for their scientific discussions. We are very grateful to D. Van Gansbeke, G. De Smet and W. Gyselinck for technical assistance.

References

Anten, P. G. J. M. (1985). Bepaling van de elementen Fe, Ti, Cr en V in frakties van zeebodems voor onderzoek naar de effekten op het mariene milieu van lozigen van titaandioxide afvalzuur in 1984. Report LAS-84151, Rijkswaterstaat North Sea Directorate, The Netherlands pp. 1–15

Anten, P. G. J. M. (1987a). Bepaling van de elementen Fe, Ti, Cr en V in frakties van zeebodems voor onderzoek naar de effekten op het mariene milieu van lozingen van titaandioxide afvalzuur in de jaren 1985 en 1986. LAS-86214 Rijkswaterstaat, North Sea Directorate, The Netherlands pp. 1–18.

Anten, P. G. J. M. (1987b). Analyse van de elementen Fe, Ti, Cr en V in frakties van zeebodems uit de Noordzee voor onderzoek naar de effekten op het mariene milieu van lozingen titaandioxide afvalzuur in het jaar 1987. Report LAS-87257 Rijkswaterstaat, North Sea Directorate, The Netherlands pp. 1–9.

Bos, H. R. (*Chemistry and Ecology*, in press). Nine years of monitoring titanium dioxide waste discharges in the Netherlands: from field monitoring towards an integrative waste managements.

Boucher, G. (1980). Impact of the Amoco Cadiz oil spill on intertidal and sublittoral meiofauna. *Mar. Pollut. Bull.*, **11**, 95–100.

Brillouin, L. (1962). *Science and Information Theory*. Academic Press, New York, 2nd ed. pp. 1–320

Elmgren, R., Hansson, U. and Sundelin, B. (1980). in, *The "Tsesis" oil spill, Report to the first year scientific study (October 26, 1977 to December 1978)*, ed. Kineman, J. J., Elmgren, R. and Hansson, S., Boulder, Colorado, U.S. Dept of Commerce. Office of Mar. Pollut. Assessment, pp. 97–126.

Elmgren, R., Hansson, S., Larsson, U., Sundelin, B. and Boehm, P. D. (1983). The "Tsesis" oil spill; acute and long-term impact on the Benthos. *Mar. Biol.*, **73**, 51–65.

Groenewold, A. and van Scheppingen, Y. (1988). De ruimtelijke verspreiding van het benthos in de Zuidelijke Noordzee. Milzon-benthos report nr. 2, Rijkswaterstaat, North Sea Directorate, The Netherlands, 1–19.

Heip, C., Herman, R. and Vincx, M. (1984). Variability and productivity of meiobenthos in the Southern Bight of the North Sea. *Rapp. P.-v. Reun. Cons. int. Explor. Mer*, **183**, 51–56.

Heip, C., Warwick, R. M., Carr, M. R., Herman, P. M. J., Huys, R., Smol, N. and Van Holsbeke, K. (1988). Analysis of community attributes of the benthic meiofauna of Frierfjord/Langesundfjord. *Mar. Ecol. Progr. Ser.*, 171–180.

Heip, C., Vincx, M. and Vranken, G. (1985). The ecology of marine nematodes. *Ocean. Mar. Biol. Ann. Rev.*, **23**, 399–489.

Herman, R., Vincx, M. and Heip, C. (1985). Meiofauna of the Belgian coastal waters: spatial and temporal variability and productivity. In: *Concerted Actions Oceanography*. Final Report, vol. 3. Biological Processes and Translocations, C. Heip and Ph. Polk (Eds), Ministry of Scientific Policy, Brussels, Belgium, 2, 65–80.

Hill, M. O. (1979). TWINSPAN—A Fortran program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. *Ecology and Systematics*. Cornell Univ., Ithaca, New York, 1–48.

Huys, R., Vincx, M., Herman, R. and Heip, C. (1984). Het meiobenthos van de dumpingzone van titaandioxide-afval in de Nederlandse kustwateren. Report State University Gent, 1–102.

Lambshead, P. J. D., Platt, H. M. and Shaw, K. M. (1983). The detection of differences among assemblages of marine benthic species based on an assessment of dominance and diversity. *J. nat. Hist.*, **17**, 859–874.

Lorenzen, S. (1974). Die Nematodenfauna der sublittoralen Region der Deutschen Bucht, ins besondere im Titan-abwassergebiet bei Helgoland. *Veröff. Inst. Meeresforsch. Bremerh.*, **14**, 305–327.

Raffaelli, D. G. and Mason, C. F. (1981). Pollution monitoring with meiofauna, using the ratio of nematode to copepods. *Mar. Pollut. Bull.*, **12**, 158–163.

Renaud-Mornant, J., Gourbault, N., de Panafieu, J. B. and Helléouet, M. N. (1981). *Effects de la pollution par hydrocarbures sur la meiofaune de la baie de Morlaix*. In: Amoco Cadiz, CNEXO edn, pp. 551–561.

Siegel, S. (1956). *Non-parametric statistics for the behavioral science*. Tokio, McGraw-Hill & Kogakusha Ltd., 312 pp.

Smol, N., Herman, R. and Heip, C. (1986). Studie van de bodemfauna van een dumpingsgebied van titaandioxide-afval in de Nederlandse kustwateren. Report State University Gent, 1–146.

Smol, N., Huys, R. & Vincx, M. (1989). Studie van het meiobenthos van een dumpingsgebied van titaandioxide-afval in de Nederlandse kustwateren, periode 1986–1987. Report State University Gent, 1–224.

Sokal, R. R. and Rohlf, F. J. (1981). *Biometry*. W. H. Freeman & Co., San Francisco: 859 pp.

Spaans, L. (1987). The Dutch monitoring programme on TiO_2 acid waste discharges. *Mar. Pollut. Bull.*, **18**, 407–412.

Tietjen, J. H. (1977). Population distribution and structure of free-living nematodes of Long Island Sound. *Mar. Biol.*, 123–136.

Tietjen, J. H. (1980). Population structure and species composition of the free-living nematodes inhabiting sands of the New York Bight apex. *Estuar. coast. Mar. Sci.*, **10**, 61–73.

Vandenberghe, R. (1987). Studie van het meiobenthos van een dumpingsgebied in de Zuidelijke Bocht van de Noordzee, met nadruk op de vrijlevende mariene nematoden. Licentiaatsverhandeling, State University of Gent, Belgium, 148 pp.

Vidakovič, J. (1983). The influence of raw domestic sewage on the density and distribution of meiofauna. *Mar. Pollut. Bull.*, **14,** 84–88.

Warwick, R. M. (1981). The nematode/copepod ratio and its use in pollution ecology. *Mar. Pollut. Bull.*, **12,** 329–333.

Wieser, W. (1953). Beziehungen zwischen Mundhohlengestalt, Ernahrungswiese und Vorkommen bei freilebenden marinen Nematoden. *Archives fur Zoology*, **4,** 439–484.

Willems, K. A., Vincx, M., Claeys, D., Vanosmael, C. and Heip, C. (1982). Meiobenthos of a sublittoral sand bank in the Southern Bight of the North Sea. *J. mar. biol. Ass. U.K.*, **62,** 535–548.