ICES 1987 PAPER C.M. 1987/E:33

THE USE OF MEIOBENTHOS IN POLLUTION MONITORING STUDIES. A REVIEW.

by

M. Vincx (+) and C. Heip (++).

(+): Laboratorium voor Morfologie en Systematiek,
Instituut voor Dierkunde, K.L. Ledeganckstraat, 35,
B-9000 Gent, Belgium.
(++): Instituut voor Hydrobiologisch Onderzoek, Vierstraat,
28, N-4401 EA Yerseke, The Netherlands.

ABSTRACT

The aim of many marine pollution monitoring programs is to study what happens with the living organisms when toxic wastes are dumped into the sea.
These programs are often based on the knowledge of baseline natural conditions in order to evaluate the extent of change caused by pollution.
The potential of the meiobenthos (mainly nematodes and copepods) for monitoring is reviewed. Several methods for the detection of pollution induced disturbances have been proposed; they all take into account the changes observed in the structural aspects of the community caused by pollution: 1) taxon diversity of the meiofaunal components; 2) relative abundance of higher taxa of the meiobenthos (ratio nematode to copepod abundance); 3) species diversity of dominant taxa (indices, graphical methods); 4) species distribution patterns.
It is very hard to distinguish pollution induced from natural changes, as in most cases the pre-pollution situation is not well known.
Density in general is not much affected by pollution, whereas diversity generally seems to decrease. Pollution is often accompanied by general changes in sediment characteristics too; both the lethal effect of a pollutant or the change in habitat texture may be responsible for the observed changes. We know that some nematode species are resistant to high levels of pollution and anaerobiosis. The effect of e.g. heavy metals on nematode population dynamics however, can only be studied in the laboratory.
It is however concluded that our knowledge of the ecotoxicology of meiobenthos is still very poor and that much more work remains to be done.

I. INTRODUCTION

The aim of many marine pollution monitoring programs is to study what happens with the living organisms when toxic wastes are dumped into the sea. These programs are often based on the knowledge of baseline natural conditions in order to evaluate the extent of change caused by pollution.

Toxicity can be assessed by effects on the physiology or the behaviour of a single individual, the dynamics or genetics of a population, the ecology of communities or the behaviour of a whole ecosystem.

The bulk of the material which is dumped into the sea, settles down on the sea bottom and the more or less sessile benthic fauna must tolerate pollution or die. The benthos thus integrates effects of pollution over time and is probably the best all-round biotic component to monitor (Gray et al., 1980; Heip ,1980).

Most ecological monitoring and ecotoxicological studies of the benthos have been concentrated on the macrofauna; e.g. a lot of work is done on the histopathology of some widespread macrobenthic organisms, such as *Mytilus edulis* (e.g. Goldberg, 1978). However, it is still impossible to predict the effects of contamination at levels lower than those causing catastrophic destruction; no information is available on ecological consequences at the community level. To this aim, changes in the relative abundance of the species have been advocated as a useful tool to demonstrate sublethal pollution effects. But so far, as Platt et al (1984) noted, 'macrobenthic analysis has failed to provide the answer; it is time to turn the spotlight on the meiofauna'.

The potential of the meiobenthos for pollution monitoring was already mentioned by Marcotte & Coull (1974), Pequegnat (1975), Gray et al. (1980) and Heip (1980).

From a practical point of view, sampling of meiobenthos in intertidal as well as in subtidal areas is relatively simple and is possible on a small-scale: only small amounts of sediment are necessary to elucidate the structure of the meiobenthic communities (using cores). But, on the other hand, because of their small size, meiobenthos species are laborious to sort and to identify; only hard-bodied taxa (especially copepods and nematodes) are recommended in a monitoring context since highly specialized techniques are needed to identify soft-bodied forms such as Turbellaria.

From an ecological point of view, nematodes and copepods are abundant in almost every marine habitat (ranging normally between 500 and 10 000 ind./10 cm^2) making them suitable for ecological and statistical analysis. Especially nematodes are ubiquitious and persistent as a taxon and are found in all environmental conditions that can support metazoans. The high diversity of meiobenthic organisms has been used in the past as an argument against the use of these organisms for biomonitoring purposes, because of the difficulties encountered to identify the numerous species. The use of meiofauna in pollution monitoring studies therefore started at the moment when comprehensive taxonomic works were published, which made taxonomy a lot easier for the ecologist (for copepods : Wells (1976, 1978, 1979, 1981); Bodin (1979); for nematodes : Gerlach & Riemann (1973, 1974), Tarjan (1980), Lorenzen (1981), Platt & Warwick (1983)).

Another advantage of especially nematodes and interstitial copepods is their conservative life cycle (i.e. no highly mobile pelagic life stages), so that local contamination effects are not hidden by immigration. They have a rapid turnover compared to the macrofauna, they have a short life-span and are in intimate contact with pore water. Thus they should demonstrate a fast response to pollution.

Usually, eutrophication and organic pollution will lead to increased food supply and a rise in the total number of benthic organisms. Other types of pollution do not increase the food supply. The difference is important and structural community changes induced by organic pollution and toxic pollution cannot be identical.

II. DETECTION-OF-POLLUTION INDUCED-DISTURBANCE.

Several methods for the detection of pollution induced disturbances have been proposed; they all take into account the changes observed in the structural aspects of the community caused by pollution: 1) taxon diversity of the meiofaunal components; 2) relative abundance of higher taxa of the meiobenthos (ratio nematode to copepod abundance); 3) species diversity of dominant taxa (indices, graphical methods); 4) species distribution patterns.

The impact of pollution on the functional aspects of meiobenthic communities (e.g. respiration, productivity) is not well studied.

II.1. TAXON DIVERSITY

Taxon diversity of the meiofaunal phyla has been proposed as a possible tool for the assesment of pollution effects by Van Damme & Heip (1977) and by Herman et al. (1985). Taxon diversity is lower in pollution conditions; this is caused mainly by the disappearance of the rare taxa (e.g. Ostracoda, Gastrotricha, Halacarida, Hydrozoa, Tardigrada,..). However, sampling techniques are often not adequate (because samples are too small) to get an accurate density estimate of these rare taxa, which occur sometimes between 1 to 10 ind./10 cm^2; the diversity of the meiobenthic community is then much influenced by the presence or absence of these rare taxa. It is well known that sediment composition is also very important in the determination of taxon diversity. Herman et al. (1985) examined taxon diversity of the meiobenthic communities in 18 stations along the Belgian coast; in the sandy stations up to seven different higher taxa are found, while in more than 50 % of the other stations only one or two taxa (i.e. nematodes and copepods) occur.

Amjad & Gray (1983) also found a decrease in the number of meiofaunal taxa along a organic enrichment gradient, which was similar to the gradient in the nematode-copepod ratio (see later).

Aissa & Vitiello (1984) examined the meiofauna of the lagoon of Tunis which is influenced by sewage produced by the urbanized area. Density decreased according to an increasing gradient of organic pollution (and a rise of the RPD layer); especially nematodes and polychaetes are the most resistent meiobenthic organisms; nematodes are the last metazoans which survive in the most extreme sites.

Keller (1984, 1985) described the effect of domestic sewage on the structure of the meiobenthic communities along a transect off Marseille (France). She differentiated three areas: (1) a heavily polluted coastal zone where macrobenthic animals were absent and with a relatively poor meiofauna (nematodes, copepods and acari); the copepods were uncommonly large in size and constituted most of the total benthic biomass; the nematodes were mainly freshwater species; (2) an intermediate zone much richer in meiofauna which was also more diversified; polychaetes increased in number while acari became scarce and copepods decreased in size; 0.4 - 1 km away from the outfall, where the sediment is strongly polluted, the nematode community consisted of large individuals which contributed greatly to the biomass; (3) an off-shore zone, slightly polluted, where meiofauna densities were reduced and individuals decreased in size with increasing depth. Generally an enrichment in the meiofauna was evident from the coastal to the intermediate zone. Enrichments induced by urban pollution had been recorded previously, but not at a distance of more than 1 km away from the outfall, succeeding to a highly impoverished coastal zone.

Huys et al. (1984) found nematodes and copepods more abundant in a dumping area of TiO_2- waste with a significant lower taxon diversity of the meiofaunal groups.

Frithsen et al., (1985) examined in detail the responses of benthic meiofauna to long-term, low-level inputs of fuel oil such as may be present at the heads of urbanized estuaries and bays; they used mesocosms (outdoor tanks) containing sediment and sea water from Narragansett Bay, Rhode Island, USA. The abundances of metazoan meiofauna decreased during oil addition periods; ostracods and harpacticoid copepods were the most sensitive metazoan groups. Abundances of most meiofaunal groups returned to levels similar to the controls within 2 to 7 months after the termination of oil additions. However, the abundances of kinorhynchs and halacarids remained depressed for more than 1 year after the last oil addition, presumably due to residual oil in the sediments.

Coull & Palmer (1984) summarized field experimentation in meiofaunal ecology and mentioned 14 papers in which pollution experiments in the field or in meso- or microcosms were carried out. Controversional results were obtained about the changing of the stuctural parameters of the most important taxa of the meiofauna, depending on the kind of sediment, kind of pollution (oil, sewage, nutrients), sampling techniques and time (references in Coull & Palmer, 1984).

II.2. NEMATODE-COPEPOD RATIO

The use of ratios to observe trends in marine data sets has been suggested by Margalef (1975). He found a number of ratios of planktonic ecosystems which decrease under disturbance (stress, upwelling and pollution). Amongst the ratios were the numbers of dinoflagellates to diatoms, zooplankton biomass to phytoplankton biomass and carnivore biomass to herbivore biomass.

Parker (1975) and more extensively Raffaelli & Mason (1981) proposed the nematode-copepod ratio as a tool for pollution monitoring using benthic organisms. However, these two studies interprete this ratio in an opposite way.

Parker (1975) compared the subtidal meiofaunal composition of two estuaries in N. America; one is polluted by industrial waste of Dow Chemical Company factory (Brazos River Estuary) and the other is the almost completely undisturbed Colorado Estuary. He found that under disturbed conditions 'benthic copepods predominate at their trophic level, while under normal conditions nematodes predominate'. But, only 'surface material from an undisturbed grab sample sufficient to fill a 6-ounce jar' was examined, which may cause overestimation of the copepods, because these animals are mostly restricted to the upper cm of the sediment, while nematodes occur much deeper.

Raffaelli & Mason (1981) compared the response of nematodes and copepods to organic pollution in intertidal areas along the British coast. They sampled to a depth of 35 cm and found that the ratio of nematode to copepod densities was highest where sewage pollution was most obvious. Especially an increase in the abundance of deposit-feeding nematodes (capable of using the high amount of organic material) was noted, while the copepods decrease in number. Organic pollution causes an immediate increase in food supply so that in those areas extremely high densities of meiobenthos (mainly nematodes) can occur.

Especially this last publication in 'Marine Pollution Bulletin' caused a bloom of papers about the use of meiofauna in pollution monitoring studies, because a very easy tool had been proposed.

Most studies had been carried out on organically enriched beaches along the British coasts; in these areas, the nematode to copepod ratio increased in situations with high amounts of organic wastes (Warwick, 1981; Raffaelli, 1982; Lambshead, 1984; Shiells & Anderson, 1985). Similar observations were made in Oslofjord by Amjad & Gray (1983).

The ratio of nematode to copepod increased also with decreasing particle size, but ratios from polluted sites were always extremely high . Ratios from clean beaches were low and always less than 100, even for muddy sites; all intertidal sites (fine as well as coarse) with ratios exceeding 100 were polluted with organic material (sewage). Some sublittoral ratios from unpolluted sites were high, but never approached the very high values characteristic of polluted intertidal areas. The sublittoral ratios also increased with depth. It is obvious that this ratio must be used with caution as the index is also largely affected by sediment granulometry.

Coull et al. (1981) thoroughly discussed the validity of the nem/cop ratio and pointed out that spatial and temporal variation as well as other ecological processes (such as predation,...) could alter the ratio independently. The authors rightly point out that it is not allowed to reduce the complex meiofaunal community structure to a single ratio.

Warwick (1981) proposed a refinement of the ratio based on trophic dynamic aspects of the meiofauna. He assumed that food is the factor which limits energy flow through the nematode and copepod communities; in that case, the total number of copepods should be proportional to the number of type 2A nematodes(epigrowth-feeders) only, as only 2A nematodes are dependent on the same food source as the copepods. If copepods are indeed more sensitive to the effects of pollution than nematodes, then changes in the proportion of copepods relative to type 2A nematodes might be a useful indicator to separate the effects of pollution from any changes or differences in sediment type. Warwick (1981) suggested that pollution might be indicated by nem/cop ratios around 40 for fine sediments and 10 for sands. These values are considerably lower than the values of over 100 proposed by Raffaelli & Mason (1981).

Platt et al., (1984) and Lambshead (1986) suggested that the ratio should be abandoned as a practical pollution indicator, because (1) it oversimplifies a highly complex set of relationships and (2) nematode and copepod populations may react independently to a variety of environmental parameters (of which pollution is only one).

Shiells & Anderson (1985) proposed a possible improvement to the ratio whereby only interstitial forms are included; so, only those animals occupying the same micro-habitat are compared.

An increase in copepods due to pollution (as is found by Parker, 1975) is recorded by Vidakovic (1983), Moore & Pearson (1986), Hodda & Nicholas (1986).

Vidakovic (1983) examined Adriatic sublittoral stations, which are constantly influenced by sewage; in this area, the number of copepods increases more than the number of nematodes.

Moore & Pearson (1986) found also an enhancement of copepod density resulting from sewage pollution. They concluded that the nematode to copepod ratio is mainly determined by the availability of high dissolved oxygen levels to the copepod fauna. In both studies (Vidakovic and Moore & Pearson), the overlying water contains high levels of dissolved oxygen.

Coull & Wells (1981) found no relationship between the ratio of nematodes to copepods and pollution. However, they sampled only till 1-2 cm depth and so up to 90% of the nematodes may be missing (comparing with data from the Southern Bight of the North Sea (unpublished results)).

Hodda & Nicholas (1985) found also that the ratio was not related with pollution; they examined the meiofauna associated with mangroves in South-eastern Australia, which are very much influenced by inorganic pollution; nematode as well as copepod densities decreased as pollution increased.

In mesocosm experiments, with organically enriched sublittoral soft sediments, Gee et al. (1985) found that the nematode to copepod ratio is unreliable as a biomonitoring tool; the authors suggested that the **differential responses in community structure between the** nematode and copepod components of the meiofauna might be a better indication of stress at the community level.

Thus, it is obvious that the ratio of nematode to copepod is not a priori a valid tool for pollution monitoring, because the ratio is much influenced by the sediment, the kind of pollution (organic, inorganic) and the kind of area (intertidal-subtidal).

II.3. OLIGOCHAETA

Although Oligochaetes never dominate in marine meiofaunal communities, the relative abundance of oligochaetes is significantly correlated to levels of pollution in the Mangroves in the Hunter River Estuary (Hodda & Nicholas, 1985).

In some heavily polluted estauries, one oligochaete species (*Limnodrilus* sp.) has an overwhelming dominance (up to 70% of all meiofauna) which is indicative of environmental pollution (Brinkhurst & Jamieson, 1971; Coull & Wells, 1981).

Coates & Ellis (1980) proposed as 'the most practical index for marine pollution' the percentage of total adult enchytraeids represented by *Limnodrilus lineatus*. Unfortunately, in many marine biotopes, this species is completely absent; it occurs mostly in estuarine conditions.

II.4. GASTROTRICHA

One gastrotrich genus, *Turbanella*, is also an indicator of organic enrichment on beaches (Gray, 1971; Hummon & Hummon, 1978; Raffaelli, 1982).

II.5. SPECIES RELATIVE ABUNDANCE

Changes in the relative abundance of species have been advocated as a useful means of demonstrating pollution effects at the community level. This can be done by the simple use of diversity indices or by plotting the distribution of individuals among different species.

Especially the nematode and copepod assemblages are studied at the species level and different ecological analytical techniques have been proposed to detect sublethal pollution effect on the species distribution within these phyla.

A. Diversity indices

The use of a variety of diversity measurements in order to assess the relative complexity of a community in relation to the degree of pollution has increased enormously during the 1970s. Heip et al. (in press) revised the use of the different diversity indices; opinions about the different methods of measuring diversity are almost as numerous as the number of articles discussing them.

The Shannon-Wiener diversity index has been used to indicate long-term changes in community structure (e.g. Heip, 1980) and generally has lower values in polluted situations. The Shannon-Wiener index should preferably be coupled with a measurement of evenness, which, independently of the number of species in the sample, will approach a maximum value when the individuals are divided more evenly among species. Platt et al. (1984) remarked that the Shannon-Wiener information function is currently the most popular diversity index among marine biologists. The index is relatively biased towards the species richness aspect of diversity compared with many other popular indices. Since it is dominance (the reciprocal of evenness) which appears to be more relevant in the context of pollution, the Simpson'sindex is preferred, which weighs species by their abundance (Platt et al., 1984).

Gray (1979) has shown that statistically significant changes in diversity indices are associated with only very gross changes in the community structure; therefore, the value of using a diversity index in a monitoring context must be questioned.

Lambshead et al. (1983) offered a criterion for comparing diversity based on dominance patterns involving all the relative abundance of species; the method is applied by plotting % cumulative abundance curves, the so called k-dominance curves. This method can reveal that some assemblages cannot be compared in terms of diversity or equitability (when the curves intersect) and the intrinsic diversity indices are unreliable under these circumstances. The k-dominance curves provide an easily visualized picture of diversity.

B. Species abundance distributions

Species abundance distributions can only be drawn if the sample is large, and contains many species (S>30)(see Heip et al., in press).

The relative abundances of species can be described in 'statistical models' which make assumptions about the probability distributions of the numbers of the species within the community. Heip et al. (in press) discussed the several models. Especially the logarithmic normal (log normal) and log series statistical models of species frequency distributions have been found to describe data from natural communities of harpacticoid copepods (Gray, 1978; Castel, 1980; Hicks, 1980; Hockin & Ollason, 1981; Hockin, 1982) and nematodes (Shaw et al., 1983; Platt & Lambshead, 1985).

Gray & Mirza (1979) and Gray (1979, 1981) proposed that unperturbed communities can be identified by the fit of the log normal model to the observed species frequency distribution, while perturbed communities suffering from pollution are fitted by the log series model.

However, other authors (Dennis & Patil, 1979; Kempton & Taylor, 1974) suggest a log series for stable communities and log normal for unstable communities.

Caswell (1976) derived the log series species distribution as the result of a neutral model, i.e. a model in which the species abundances are governed entirely by stochastic processes such as immigration, emigration, birth and death, and not by competition, predation or other specific biotic interactions (Heip et al., in press). However, up to now, only the fitting of a model to field data is controlled and examined but the parameter estimates of these models are not used in further analysis. Comparison of different distributions by statistical tests afterwards are the only useful characteristics of these models.

C. Examples

COPEPODA

Marcotte & Coull (1974) examined the changes in species composition, diversity and survival strategy of the subtidal harpacticoid community in response to organic enrichment in the North Adriatic. In winter, the copepods numerically dominated the most polluted stations; copepod diversity decreased in response to increased organic enrichment. The harpacticoids nearest the pollution source were dominated by one species in winter, *Tisbe* sp. and *Bulbamphiascus imus* in summer. The material was collected from the top 10 cm of the bottom and sieved on a 0.125 mm sieve.

Coull & Wells (1981) examined the intertidal meiofauna of muddy substrates in a polluted system, a nearby unpolluted system and a healthy system in Australian waters. They sampled till the redox layer (<1cm) and sieved their material on a 0.044 mm sieve . Copepods dominate nematodes in the first two systems; there was an extremely high percentageof Oligochaetes in the polluted system (up to 78%). Copepod diversity was lowest in the polluted area. The healthy system showed a dominance of nematodes, a high abundance of *Echinoderes* aff. *coulli* (Kinorhyncha), and the highest species diversity of all taxonomic groups.

Hockin (1983) examined by means of field experiments the effects of organic enrichment on a harpacticoid community on an estuarine intertidal beach (Great Britain). The pollutant used was a suitable nutrient source for the sediment-dwelling microfauna upon which many of the copepods feed. The increased supply of organic matter resulted in an increase in the species richness, a decrease in the dominance diversity and no change in the number of individuals and, by inference, the biomass. It was observed that the log series model adequately fitted most data sets, while the log normal model only fitted data drawn from the community inhabiting the organically enriched sediments.

Heip et al. (1984) recorded that *Microarthridion littorale* is the dominant copepod in the polluted area (east coast) of the Belgian coastal waters (on average 94% of all harpacticoids). The impoverishment of the harpacticoid fauna from west to east (from less to more polluted) is also reflected in the average diversity which decreases from H'=0.87 bits/ind. in the west to 0.43 bits/ind. in the east, and in the fact that 14 out of 15 stations in the west yielded harpacticoids against 21 out out of 30 in the east.

Van Damme et al. (1984) examined the influence of pollution on the harpacticoid copepods of two North Sea estuaries, the Westerschelde estuary and the Eems Dollard estuary. The Westerschelde estuary is more loaded with heavy metals (Zn, Cu, Pb) than the Eems Dollard estuary; especially cupper is continuously present in a concentration at which, according to bioassays, egg production and larval development of planktonic copepods are severely affected. The remarkable scarcity of harpacticoid life on nutrient rich mudflats of the

Westerschelde is probably due to heavy metal pollution. In the Westerschelde, two distinct copepod assemblages occur, a mesobenthic assemblage (small, interstitially living grazers; e.g. *Kliopsillus constrictus, Paramesochra* sp.A , *Paraleptastacus espinulatus*) and an endo-epibenthic assemblage (large, burrowing or epibenthic detritus-feeders; e.g. *Canuella perplexa, Pseudobradya* spp. & *Tachidius discipes*). In the Eems Dollard estuary, the copepods all belong to the endo-epibenthic assemblage and are found in the pure as well as in the muddy sands.

Keller (1984, 1985, 1986) described the copapod community which is influenced by a sewage outfall off Marseille (France). The copepod communities (as the nematode communities) can be divided into two main groups : (1) near the outfall, one copepod species, *Darcythompsonia faviliensis*, not yet reported in marine environments,is the dominant species; (2) the second community (from 400 till 4000 m from the outfall) is characterized by the dominance of *Bulbamphiascus imus*, a cosmopolitan species relatively tolerant to pollution. Species diversity and Motomura's constant (calculated from the log linear model) are both seen to increase from the outfall to the off shore zone (the same occurrs for the nematodes, see later).

Gee et al. (1985) studied the effects of organic enrichment on meiofaunal abundance and community structure in mesocosms provided with sublittoral soft sediments. Harpacticoid copepods increased significantly in abundance in the treatment boxes and showed a general trend towards increased dominance and decreased diversity with increasing levels of organic enrichment, although in the low dose treatment, there was also an increase in the number of species present.

Moore & Pearson (1986) examined the impact of sewage sludge dumping on the copepod community of a subtidal muddy deposit off the Scottish coast. Three groups of species are recognized, characteristic of the different levels of sludge loading; in the centre of the dumping ground, only one species is found, e.g. *Bulbamphiascus imus*. The second group includes those species which are virtually absent from the centre of the dumping ground but become dominant in the moderately enriched sediments on either side (e.g. *Amphiascoides debilis, Typhlamphiascus lamellifer, Paramphiascoides hyperborea*). A third group of species only begins to appear towards the ends of the transect *(e.g.Pseudameira furcata, Pseudameira* sp., *Amphiascoides subdebilis*).

With Hockin (1983) we conclude that the use of copepods as indicators of environmental quality is at present problematic. It seems that the response of natural communities will be dependent both upon the load of organic matter and the composition of the community with respect to the ratio of bacterial- and algal feeding species; increased bacterial productivity alone (on organically enriched beaches) may cause increased diversity of the copepod fauna, because of the increase in typically bacterial feeding species (in density as well as in diversity).

NEMATODA

The species distribution of the nematodes has been more extensively studied, since they prove to be sensitive biological indicators of pollution, because they are very diverse taxonomically and occur everywhere, usually in great numbers, often exceeding other taxa by an order of magnitude or more (Platt, 1984; Heip et al., 1985).

A decrease in nematode density after contamination with hydrocarbons, has been demonstrated on several beaches (Wormald, 1976; Giere, 1979; Boucher, 1980) but not on others (Green, et al., 1974) and not in sublittoral sands (Elmgren et al., 1980; Elmgren et al., 1983, Boucher, 1980, 1981). An obvious decrease in nematode abundance after an oil spill has often been followed by explosive development of a few opportunistic species within one year (Wormald, 1976; Giere, 1979). After the Amoco Cadiz oil spill (Boucher, 1980,1981), however, there was no such explosive development on the beaches.

After an oil spill in La Coruna (northern Spain), *Enoplolaimus litoralis* became extremely dominant; many specimens had ingested oil droplets covered with bacteria. In the intestine of *Bathylaimus* sp. and *Tripyloides* sp., oil particles were found surrounded by clouds of bacteria (Giere, 1979).

After the Amoco Cadiz spill, nematode diversity in the sublittoral sands in Morlaix Bay decreased significantly, and most obviously 9 to 12 months after the accident happened (Boucher, 1980). This was due, on the one hand, to an increase of *Anticoma ecotronis, Sabatieria celtica, Paracyatholaimus occultus* and *Calomicrolaimus monstrosus*, species normally abundant in silty sands; and on the other hand, to a decrease of *Ixonema sordidum, Monoposthia mirabilis, Rhynchonema ceramotos, Chromadorita mucrocaudata, Xyala striata, Viscosia franzii* and *Rhynchonema megamphidum*, species normally dominant in clean sands.

Renaud-Mornant et al. (1981) also examined the same polluted area and found that mortality 10 days after the oil input was not important. After one month, density decreased; mortality was especially important in the surface sand layers while in the deeper layers meiofauna was found in the process of spring reproduction. After six months, nematodes became extremely dominant and accounted for 90% of the meiofauna.

Gourbault (1984) examined the nematodes from the Bay of Morlaix Channel during two years after the Amoco Cadiz oil spill. A change of species composition (typical for two years after the spill are: *Sabatieria pulchra, Terschellingia longicaudata & Aponema torosus*) is observed with diversity decreasing in the upper part of the Channel.

Gourbault & Lecordier (1984) found that the nematode assemblage data from the Bay of Morlaix Channel cannot be fitted with the usual abundance distribution models(log normal, log series, log linear). The Pareto law ($y=ax^{-\alpha}$, Pareto, 1897) used in some economic studies, dealing with partitioning of resources, is found to be more meaningful in this case.

The effects of heavy metal pollution have been studied by Lorenzen (1974), Tietjen (1977, 1980) and by Heip et al. (1984) in monitoring field studies and in the laboratory by Howell (1982, 1983, 1984).

Lorenzen (1974) found no short term effects on the nematode fauna in a region of the German Bight of the North Sea subjected to industrial waste disposal (containing 10% H.SO. and 14% FeSO.).

Tietjen (1977) found that heavy metals did not affect nematode populations in Long Island sublittoral muds, although a slight decrease in diversity was obvious. Tietjen (1980) examined the nematodes from the New York Bight Apex, a sandy sediment area with high heavy metal content and organic carbon loads. High concentrations of the contaminants in medium sands result in lowered abundance of the nematode families which normally live in this kind of sediment: Chromadoridae, Desmodoridae and Monoposthiidae. Other species, such as *Sabatieria pulchra*, which are normally associated with finer sediments, increase in abundance. This species is already adapted for living under low dissolved oxygen concentration and/or high organic content.

In the Belgian coastal waters, influenced by the impact of the polluted Western Scheldt estuary, Heip et al. (1984) found that nematode species richness is significantly correlated with the heavy metal content. Most close to the mouth of the Western Scheldt, only non-selective deposit-feeding nematodes are the meiofaunal component which survive in high density, but with few species per station : *Sabatieria punctata, Daptonema tenuispiculum, Metalinhomoeus* n.sp. and *Ascolaimus elongatus*. A combination of trophic diversity (expressed in a trophic index $\Sigma\theta^2$, θ= percentage of each feeding type) and species richness, provides for the highly polluted Belgian coast a good indication of the influence of pollution. The impoverishment of the nematode community along the Belgian coast following a west to east increase in pollution, can be explained by the gradual elimination of species as stress increases. The same can be found for harpacticoid copepods.

Huys et al. (1984) and Smol et al. (1986) examined the effect of TiO_2-waste on the meiofauna in the Southern Bight of the North Sea. The copepod communities are most diverse outside the dumping area; the samples from the dumping area are characterized by low diversities and high densities of nematodes. Comparison of the nematode communities with a 10 years interval (before and during the dumping) reveals that a change of the nematode composition occurred. However, the seasonal variability of the communities in this type of sediment is not known; therefore, further research is necessary for the interpretation of the different results.

Shaw et al. (1983) and Lambshead et al. (1983) discussed several monitoring methods and used the littoral nematode assemblages of the Strangfors Lough, N. Ireland, discussed in Platt (1977). They found that the abundance of the most common species as a percentage of the total sample (i.e. the dominance index), is a good indicator of stress-conditions. However, they didn't really measure any chemical pollution parameter. The use of the dominance index is not suitable in every case study (Platt & Lambshead, 1985; Lambshead, 1986). Platt & Lambshead (1986) found that disagreement with the neutral model predictions (Caswell, 1976) is a method of detecting disturbance or stress. They subjected 98 samples of marine benthic organisms to the neutral model analysis. They found some conflicting results. Assemblages of marine organisms may be more (nematodes) or less (macrofauna) diverse when influenced by contaminants, compared with the normal situation. Where disturbance was known to have occurred, spatial or temporal variations in the degree of deviation from the predicted diversity were in accordance with a hypothesis of diversity based on a combination of the 'intermediate disturbance hypothesis' (Connell, 1978) and the 'general hypothesis of diversity' (Huston, 1979); these theories say that an undisturbed assemblage of organisms would have a low diversity due to competitive exclusion while disturbance initially raises diversity by preventing competitive exclusion. Further increases in the scale of disturbance, however, lower diversity again due to catastrophic effects on certain species.

Vitiello & Aissa (1985) described the nematode communities in polluted sediments of the lagoon of Tunesia; only three nematode species are characteristic for the organically polluted communities there: *Terschellingia* n.sp., *Sabatieria pulchra* and *Penzencia flevensis*. The mean length of the nematodes is longer in the polluted area, where the predators among the nematodes are almost absent, while they provide for 15% of the communities in the non-polluted region.

The nematode communities nearby the sewage outfall off Marseille (France) are, as the copepod communities, divided in two assemblages (Keller, 1986) : (1) near the outfall nematodes of the ordo Rhabditida occur, generally abundant in polluted rivers and which seem to come from both the sewage and a polluted stream diverted into the sewer. Some marine nematodes known for their affinity for polluted sediments such as *Metoncholaimus pristiurus, Sabatieria pulchra* and *Terschellingia* n.sp., are also present; (2) the stations of this area (400-4000 m from the outfall), have different nematode assemblages, consisting mainly of deposit feeders because of the presence of important amounts of organic matter in the sediments. Moreover, two heavily influenced nematode associations were detected at the two most distant stations (1.8 km and 4 km from the outfall), one of them being composed of only mud-dwelling deposit-feeders. This shows that the whole area studied is perturbed by the presence of the outfall. In general, Keller (1986) concluded that species diversity and Motomura's constant are both seen to increase from the outfall to the off shore zone; this indicates a rise in the number of ecological niches available.

Hodda & Nicholas (1986) studied nematode diversity in mangrove mud-flats adjacent to the steel works and chemical factories in the Hunter River Estuary in Australia. Their results suggest that diversity may not be a good universal indicator of pollution that can be applied to all marine nematode communities in any case. The polluted areas were more diverse taxonomically, though seasonal variations in population density and other environmental factors complicate the comparison.

The most recent example of the problems with this approach to pollution monitoring is givenby Lambshead (1986). He reports an investigation on the effects of contamination at a subcatastrophic level on some marine nematode assemblages of beaches in the Clyde Inland Sea area, Scotland. All stations were sampled once (Sep 1978) and the median of the sand fraction varies from less than 150 um for the contaminated stations to more than 150 um for the uncontaminated stations. Diversity, density and feeding type ratio are consistent with the assumption that in uncontaminated sites diversity is higher, density is lower and feeding type ratio is in favour of the epistratum feeders. k-dominance curves however, do not show significant differences between the uncontaminated and the contaminated stations.

Therefore, Lambshead (1986) and Lambshead & Paterson (1986) proposed a new method for the detection of sub-catastrophic contamination at the community level: they introduce the use of numerical cladistics in ecological analysis. The presence of a species is coded as the derived character state while absence is coded as primitive; this means that the outgroup consists of a theoretical station containing no species. All the species used in the analysis must be potentially capable of reaching (if not surviving in) any of the stations examined. This kind of cladistic analysis can only be applied to stations drawn from the same potential species pool. However, reduction in diversity and survival of only the most tolerant species is the only obvious effect of pollution so far detected; therefore, it is difficult to agree that species presence is a derived character, especially when we are interested in pollution effects. The establishment of 'homology' in ecological studies has also some problematic features,i.e. the ontogenetic method as well as the outgroup comparison are highly speculative.

III. CONCLUSION

This review of marine pollution monitoring studies using meiobenthos shows the difficulties and controversies in the interpretation of observed changes. It is very hard to distinguish pollution induced from natural changes, as in most cases the pre-pollution situation is not well known. A posteriori studies on the effects of pollutanta often involve the use of 'natural experiments' in which the density or species diversity of benthic organisms of a polluted area is compared with a similar nearby area, usually referred to as a comparison or reference area (see Eskin & Coull, 1984, for a review). Eskin & Coull (1984) warned that great caution should be taken when control sites are selected and compared with 'disturbed' areas; in this case, a single factor (e.g. pollution) should not be interpreted as causative of observed densities or distribution of abundance. Regardless of the mechanisms controlling distribution, small and medium scale (mm-cm) spatial distribution of meiofauna appears to be so variable and unpredictable that no a priori assumption about the similarity of meiofaunal populations at the two comparison sites could be made, regardless of the apparent visual similarity of the sediment sites. Therefore, larger samples, which obscure the patchy distribution of the meiofauna, are necessary for the examination of the meiofauna for biomonitoring purposes.

Density in general is not much affected by pollution, whereas diversity generally seems to decrease. Pollution is often accompanied by general changes in sediment characteristics too; both the lethal effect of a pollutant or the change in habitat texture may be responsible for the observed changes. We know that some nematode species are resistant to high levels of pollution and anaerobiosis. The effect of e.g. heavy metals on nematode population dynamics, however, can only be studied in the laboratory. Despite their ecological importance, and their significant role in all marine sediments, only a few experimental pollution studies exists; for a review we refer to Heip et al. (1985). It is however concluded that our knowledge of the ecotoxicology of meiobenthos is still very poor and that much more work remains to be done.

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