

Benthic studies: summary and conclusions*

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INTRODUCTION

The analysis of benthic community structure is a good tool for describing changes in space (with application in point source pollution monitoring) and time (with application in the description of changes in the state of marine systems). A whole battery of simple to very sophisticated statistical techniques is now available to describe and compare the structure of benthic communities. These methods are based on the analysis of abundance and biomass of the species present complemented with information from life-history traits of selected species. Both univariate and multivariate methods are now standard technology in environmental impact assessments. Univariate methods concern statistical analyses of primary (abundance biomass) and derived variables such as the many different diversity indices (e.g. the Hill numbers which form a coherent family of indices covering species richness, the traditional Shannon-Wiener and Simpson indices, and the abundance of the most dominant species; see Soetaert & Heip 1990). They are under certain conditions amenable to the very powerful classical statistical tests. Multivariate methods are also based on species abundances or derived variables at different stations and depending on the choice of similarity or distance measures can take one of many different forms. Some of the more popular in benthic ecology are TWINSpan (Two-way species indicator analysis), CANOCO (Canonical Correspondence Analysis) and MDS (Multi-dimensional Scaling).

Classical benthic community studies covering both the meiofauna (Gee et al. 1992) and the macrofauna (Kröncke & Rachor 1992, Kröncke et al. 1992) were

made in the 2 contrasting situations covered by the sea-going workshop: the area around the former drilling site and the German Bight from the Elbe mouth to the Dogger Bank. The data were supplemented with pictures from a REMOTS camera system (Rumohr & Schomann 1992).

RESULTS

Drilling site

The drilling site (Site F-18-9 in Daan et al. 1992 and Stn A in Kröncke et al. 1992) was used in 1987 but not replaced by a drilling platform. The effects of the drilling on the macrofauna shortly after operation were studied by Daan et al. (1990).

Meiofauna. Separate analyses were performed on the major taxa, copepod and nematode species. Univariate measures that were calculated were species richness, diversity and evenness, and total number of individuals. The significance of differences in univariate measures was tested with ANOVA. Furthermore *k*-dominance curves were constructed. Multivariate methods were also used including classification and multi-dimensional scaling. Only one of the univariate indices showed a trend that could be related to the supposed pollution gradient: the abundance of nematodes in the deeper sediment layers (2 to 10 cm) was reduced. The *k*-dominance curves for the nematodes (and therefore total meiofauna), but not the copepods, are remarkably similar between stations. The difference for the copepods is however not statistically significant. There was no relationship between the form of the curves and the supposed pollution gradient.

The MDS ordinations show no clear discrimination for any of the faunal components. However, for the major taxa and total nematodes and nematodes in the deeper layers, there is a tendency for the 3 stations

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nearest to the drilling site to separate from the rest. The dendrograms are very flat with all dichotomies occurring at approximately the same relatively high similarity level. Again there is no discrimination between sites or clear sequencing with respect to the supposed pollution gradient.

In conclusion it can be said that it proved impossible to detect any statistically significant difference between stations in any except one of the meiobenthic components studied that could be related to a gradient of contamination or disturbance which decreased in intensity away from the drilling site. Meiobenthic community structure along the gradient and at the reference site was extraordinarily uniform, to an extent that has never been observed before. Possible explanations for this are:

(1) The meiobenthos was insensitive to oil drilling and community structure was not affected. This is considered unlikely in view of data in the literature.

(2) The cessation of the drilling activities and the removal of the installations some 18 mo prior to sampling provided sufficient time for rapid and complete recovery of the meiofauna. From the literature it appears that this may be the case for the copepods but that particularly deeper living nematodes tend to recover over longer periods.

(3) The occurrence of 2 extremely strong gales in January and February 1989 displaced large quantities of sediments and disrupted and homogenized meiofauna community structure over large areas. The REMOTS-pictures taken by Rumohr & Schomann (1992) clearly show fresh deposition of several centimetres of clean sandy sediment on top of the oiled old sediment. This would explain the high degree of uniformity of the surface communities (and of the chemical parameters) over the whole area covered.

Macrofauna. The univariate measures abundance, biomass and diversity all show unclear trends with a minimum value at the drilling site. Although there is much overlap in comparison intervals, stations within 1000 m of the drilling site separate from the others with regard to these variables. A striking feature is the continued absence of deep burrowing species such as *Calliannassa subterranea*, *Echinocardium cordatum* and the polychaete *Notomastus latericeus* at the drilling site. A clear trend exists for the sipunculid *Golfingia elongata*. In 3 species (*Amphiura filiformis*, *Mysella bidentata* and *Corbula gibba*) length-frequency distributions compared along the gradient did not show any difference; it therefore does not appear that recent recruitment has taken place close to the drilling site in these species.

Classification of the stations resulted in a cluster of the 3 outermost stations (F, 2 km; G, 5 km; R, 15 km) being separated from the others. Also the drilling site

itself tends to cluster out. The replicates are frequently clustered in the MDS ordination. It thus appears that community structure in the macrofauna has been retained to some extent, even after the storms.

A comparison with an older investigation of Daan et al. (1990) showed that for some species the initially existing gradient had disappeared (*Amphiura filiformis* and *Diastylis bradyi*) whereas it still existed for others. Species with large reproductive and dispersal potentials (*Mysella bidentata* and *Montacuta ferruginosa*) which were absent in 1987 had reappeared near the drilling site.

In conclusion, macrofauna community analysis was capable of showing differences along the gradient that could be related to the drilling activities 3 yr earlier. These differences were most striking in long-lived and deep burrowing species.

German Bight transect

Meiofauna. All univariate measures for copepods and nematodes were significantly different along the transect, except nematode abundance. Based on copepod species, the stations can be grouped into 3 distinct groups. The innermost Stns 1 to 3 are characterized by the species *Longipedia helgolandica* and several Ectinosomatidae. Abundance and diversity are very low. Stns 5 to 8 are characterized by the presence of *Longipedia coronata*, several other Ectinosomatidae and *Pseudameira crassicornis*. Stns 5 & 6 have the highest abundance and diversity and are almost similar to the drilling site stations. At Stations 7 & 8 some species from 5 & 6 are absent and abundance and diversity are lower. Stn 4 is intermediate between the 2 groups. Stn 9 on the Dogger Bank is entirely different from the others and is characterized by the species *Rhizothrix minuta* and members of the Paramesochridae and Cyliindropsillidae. The pattern for the nematodes is somewhat different as there is a gradual increase in species richness and equitability from Stn 1 to 9. Stns 6 to 8 have the highest diversity and are indistinguishable from each other.

Meiofauna density in general is much lower at Stns 1 & 2 than at the other stations. The number of higher taxa is also much lower here and tends to increase along the transect. The Dogger Bank station is characterized by the abundance of Gastrotrichs.

In the MDS ordination the replicates for copepods cluster reasonably well and there is a general trend in the sequence from Stn 1 to 9. For the nematodes, Stns 1 & 9 are clearly separated at either end of the plot.

An analysis with copepods, nematodes and environmental variables showed a best fit between copepods and the percentage of silt/clay. The fit is significantly improved with the addition of water depth and zinc

(and/or mercury). For the surface nematodes the correlations are very similar. For total sediments mercury gave the best fit. This is a clear indication that the change in sediment grain size is the main factor responsible for the change in the fauna.

In conclusion most univariate and multivariate measures of meiofauna community structure showed significant differences along the transect but it is difficult to determine whether these differences are due to pollution. Physical factors such as sediment granulometry, water depth and salinity strongly affect species composition and structure of meiofauna communities. Sediment granulometry is the single most important factor. However, zinc (and/or mercury) appear to be important, especially for the copepods.

Macrofauna. Along the transect abundance and species number showed an increase towards the outer stations. As in the copepods 3 community types are found:

(1) The *Nucula nitidosa* community in the inner German Bight on mud (Stns 1 to 3).

(2) The *Amphiura filiformis* community in the fossil valley of the Elbe on muddy sands (Stns 4 to 8).

(3) A transitional *Amphiura filiformis*-*Tellina fabula* community at the border of the Dogger Bank on fine sands with a low mud content.

Again sediment characteristics are largely responsible for the changes in community structure, but the ABC-curves show stressed communities with a shift towards higher numbers of short living species with low biomass. Comparison of these data with earlier investigations indicates that biomass has increased both in the *Nucula nitidosa* and the *Amphiura filiformis* community from the 1920's to the 1970's. This increase has stopped in the *N. nitidosa* community due to the occurrence of oxygen depletion events from the early 1980's onwards.

DISCUSSION

Both meio- and macrofauna data show differences between stations along the German Bight transect, with a group of coastal stations (Stns 1 to 3) and the Dogger Bank (Stn 9) clearly delineated from the other stations. These differences are mainly correlated with differences in sediment composition.

The benthic fauna did not clearly reflect the supposed pollution gradient around the former drilling site. The meiofauna generally did not show trends along this gradient, concordant with the absence of trends in the sediments and the measured pollutants. The fauna is remarkably uniform over a large area, reflecting the passage of 2 storms, important physical disturbance events acting over a very large spatial scale, which destroy small-scale patchiness due to bio-

logical processes. However, trends do exist in the macrofauna and are especially striking in long-lived and deep-burrowing macrofauna, not affected by the storms. This shows that some memory of the pollution event is retained in the macrofauna even after several years. Macro- and meiofaunal communities thus give different and strongly complementary types of information, indicating that both should be used for monitoring.

Constancy in space and time is such that the description of benthic community structure has predictive power (an example is the evolution of the macrofauna at the drilling site since 1987) but to improve this predictive power more effort should be devoted to the mathematical description of structure as a function of temporal and spatial scale and to multivariate statistical techniques in which significance testing is possible.

The use of benthic communities in monitoring is based on the size distribution and the abundance of the species present in a certain delimited environment. To increase predictive power, the causal mechanisms leading to changes in size and abundance should therefore be better understood at several levels of organisation. Basic information is needed on genetics, biochemistry and physiology for most benthic species. Data on energy flow (food uptake, growth and reproduction, respiration and excretion) and life-cycle strategies, as determined by natural selection, do not exist for even the dominant macrofauna species and for nearly all marine meiofauna.

Ecological models investigating the role of disturbance in explaining diversity of benthic communities should be elaborated. The role of competition and predation in subtidal benthic communities is only poorly known and has not been quantified. Ecological models should include the planktonic (larval) phase of benthic macroinvertebrates and recruitment processes. Models of carbon flow through complete marine systems should take the diversity of benthic structure and functioning into account.

Much more effort should be put into the study of relationships between benthic animals and their aquatic and sedimentary environment. Processes such as bioturbation, the role of feeding processes, tube building and burrowing activities, the production of mucus etc. in regulating the geochemical properties of the sedimentary environment and its physical characteristics are nearly unstudied. Only when a good description of the physical, chemical and biological processes and their interrelationships, which govern the mass transfer from pelagic to benthic systems, and early diagenesis are available, will it be possible to relate results from chemical behaviour of pollutants, ecotoxicological tests and hydrodynamic or atmospheric dispersal models.

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