Rapp. P.-v. Réun. Cons. int. Explor. Mer, 179: 182–187. 1980.

MEIOBENTHOS AS A TOOL IN THE ASSESSMENT OF MARINE ENVIRONMENTAL QUALITY

Carlo Heip
Institute of Zoology
Ledeganckstraat 35, B-9000 Gent, Belgium

The assessment of the impact of pollution on the marine environment depends on the possibility of prediction either by comparison or more ideally by the analysis of time series which are long enough. Obtaining data for the construction of these time series should be one of the principal goals of monitoring. Parameters which are measured should have a low variability in time and in space or low frequency. The analysis of meiobenthic communities in the North Sea and the adjacent estuaries shows that harpacticoid copepods are especially suitable as the number and the nature of the species are stable and density, biomass, and diversity are characterized by the absence of variance in the high frequencies. Nematodes, though overwhelmingly abundant, are more variable and less easily determined, but their overall density is probably a quite stable parameter.

INTRODUCTION

Management of the marine environment is profoundly hindered by the fact that it is impossible to predict changes in marine communities in terms of changes in the values of the state variables used to describe the system, when only the present state of the system is known. The poor development of ecological theory does not permit quantitative or even qualitative predictions about the consequences of, for instance, the increase of nutrients or the introduction of a new species other than very general statements which are unsuitable for management purposes. Moreover, the fundamental importance of ecological processes operating in communities, such as competition and predation, in determining the structural and functional characteristics of these communities is well recognized, but the outcome of these processes is, even in very simple situations, unpredictable. This is not so because of artifacts introduced through the construction of a particular model but may be a fundamental ecological fact; the role of history and chance is probably much greater than was anticipated only a decade ago.

The realization that ecological processes in communities lead to changes which are unpredictable from a knowledge of the present state of the system only, is of fundamental importance in the development of strategies designed to study the impact of human activities on the marine environment. If there is reason to believe that such activities will have adverse effects, not only in the short run, and if political and legislative actions are likely to follow when these effects can be demonstrated, then monitoring studies will be worthwhile if they are designed properly because the only way to "predict" what will happen in the future is through knowledge of what has happened in the past. An understanding of the dynamics of a process is not essential for prediction and although some believe that unless the biological interactions determining the fluctuations of populations are understood these fluctuations cannot be predicted, this is not true. Prediction can be based on regularity as well as on its explanation: the prediction that the sun will come up every morning has been made with remarkable accuracy by people knowing nothing, and in fact having completely wrong ideas, about the dynamics of the phenomenon (I owe this analogy to Poole).

Ecology has a tradition of biologically based modelling techniques drawn largely from the physical sciences, and this tradition may hinder the acceptance of statistical models as forecasting and control tools in ecology. However, as biological models until now have not been able to satisfy the stochastic and pragmatic characteristics of forecasting, it is preferable to use the statistical models at present (Poole, 1978). The acceptance of this idea will force us to review drastically our approach to monitoring and management of the marine environment. The identification and estimation of a model requires a large number of observations, possibly at least 30 to 50 depending on the type of model one uses, and such long time series are only rarely available in ecology. There are few ongoing census programmes even for important or key species; this is clearly a matter of policy and, as it is probably unattractive for young research workers to devote their time to such routine work, it is more a matter for government than academic institutes, and these should be convinced of the necessity of gathering this kind of data.

THE CHOICE OF PARAMETERS

When one accepts the idea that time series of relevant parameters are adequate tools for management purposes then the choice of these parameters has to depend on the statistical considerations associated with time series analysis. Two sets of criteria come to mind immediately; criteria concerning the variability of the parameters or the accuracy of measurement and criteria concerning the frequency of the phenomenon which the parameter is supposed to measure. This is related to variance in space and in time. As the sea is heterogeneous both in space and in time, samples taken to study some statistical target populations must be distributed in space and in time so that they cover all significant scales on which variability characterizing the phenomenon exists. Time series analysis has provided us with the Nyquist criterion which states that the minimum sampling interval must be twice the highest frequency of the phenomenon which is studied. When short periodicity is expected then the sampling interval must also be short, both in time and space. One method to estimate this is spectral analysis (Platt and Denman, 1975) which allows one to break down the variance according to frequency, but again a rather large number of samples is needed. It is clear that when a large part of the variance is found in the high frequencies of time and/or space a parameter is not fit for monitoring purposes, aiming at detecting phenomena on large spatial and temporal scales. It is in fact not worthwhile to monitor biologically the impact of human activities with only a limited spatial extent (some square metres of the sea bottom) or when the impact is immediate and drastic but has a limited temporal extent (some tonnes of oil in the open ocean).

From the point of view of monitoring, benthic systems are without doubt much more efficient as a source of measurable parameters than the planktonic ones. The benthic system is essentially two dimensional and for sampling purposes this has a considerable advantage when one considers the large amount of extra samples needed to include a third dimension. But also horizontal patchiness is much greater in the plankton than in the benthos. Moreover, the location of the benthos is nearly constant, the system is a sink and it integrates the conditions under which populations live over a relatively long time, which is an important advantage for monitoring purposes.

Samples of heterogeneous phenomena require a partitioning of the samples so that all significant scales of variability are represented. One has to identify the highest frequency of this variability in the four dimensions and sample with twice this frequency. If this is not possible there is a risk of aliasing, with strange results when sampling is at harmonic frequency. This is one of the main arguments against using functional parameters for monitoring purposes. Although methods have been developed to measure many of these parameters quickly, their much larger variability both in time and in space requires that many more samples must be taken than the number needed to estimate most structural parameters accurately. Moreover, their frequency is much higher (e.g., feeding, respiration, and primary production, all have strong daily periodicity). Structural parameters are much less variable and some of them are quite narrowly related with functional parameters (consider the use of P/B ratios). Another advantage is trivial: functioning of living beings can only be measured when they are alive and is only representative when they are well; the first condition being obvious, the second implies the necessity of measurement in conditions at least approaching those under which the animals or plants normally live. This necessity does not exist for the measurement of most structural parameters which can be performed a long time after the samples have been taken.

THE VARIABILITY OF MEIOFAUNA COMMUNITIES: THE QUALITATIVE APPROACH

The advantage of benthic systems as sources of parameters for monitoring purposes has been stressed. I will now turn to meiofauna as one of the components of these systems which has been studied rather extensively in our laboratory in the last years, and will describe some of the results of this research which are largely unpublished because work is still going on. This paper will thus contain some bias and should be read with caution.

Meiofauna may be defined as "the small things that crawl in the sand" (Coull, personal communication), as every other definition is disputed by someone and a recent trial at the Third International Meiofauna Conference in Hamburg in 1977 failed to arrive at a generally accepted definition. For those who prefer a more sophisticated definition it may be said that when the animal is multicellular and passes through a sieve which retains macrofauna (and this sieve may vary in mesh size, but is mostly 0·5 or 1 mm) it may be considered to belong to the meiofauna.

From the many meiofauna taxa the soft-bodied forms are less suited for monitoring when individual species have to be recognized, but this need not always be the case. Diversity of taxa itself may be a parameter which is useful; Van Damme and Heip (1977) found a gradual decrease in the number of taxa in the Southern Bight of the North Sea in regions under the influence of the western Scheldt estuary, and a richer community in sand than in mud. Most taxa can be distinguished even by technicians, and as general patterns in the relative abundance of taxa probably exist as well as in species, this parameter deserves further study. From what we know it is clear that nematodes are nearly always overwhelmingly dominant and that harpacticoid copepods are mostly second, though this position is sometimes taken by other groups such as oligochaetes, interstitial polychaetes, ostracods or kinorhynchs when circumstances are not truly marine. However, as this dominance of nematodes and harpacticoids is true in most situations and as both are hard-bodied taxa in which individual species are recognizable after fixation, I will restrict the discussion to them.

Changes in the structure of communities are important indications and can be validly used in monitoring when it can be shown that these communities are normally stable in that their species composition either does not change or changes cyclically, in which case the sampling programme has to take this into account.

Meiofauna communities have been recognized from the time of Remane onwards. Wieser (1960) described two communities from the continental shelf off Massachusetts based on nematode species. Por (1964) was the first to distinguish parallel communities based on harpacticoid copepods. Soyer (1970) described the *Halectinosoma herdmani* — *Harpacticus flexus* community from the western Mediterranean which is of very widespread occurrence, though some species may be replaced by others locally. In the shallow waters of the Southern Bight, Van Damme and Heip (1977) found a variant of this (which they called the *Halectinosoma herdmani* — *Microarthridion littorale* community as *Harpacticus flexus* is absent) present over large areas of muddy sediments in turbid waters. The presence of this community is not closely associated with sediment characteristics, and thus not as variable as nematode communities appear to be. One reason for this is that interstitial harpacticoids require clean sands and are completely absent when rather low mud content is present, whereas nematodes will penetrate to a considerable depth even in pure mud. However, nematode communities in muds are nearly always dominated by Comesomatidae, especially the genus *Sabatieria* and by species of *Theristus* and *Cylindrotheristus,* and only the subdominant species differ widely from sample to sample. Spatial variability on a small scale is also much higher in nematodes than in harpacticoids (Heip and Engels, 1977; Heip, Smol and Delmotte, unpublished), and this is probably associated with the extremely high number of species in this group, in which it is not uncommon to find more than 100 species at one station. This large diversity may be an advantage also when changes in community composition are to be detected, but much work remains to be done and the systematic problems associated with work on nematodes will probably prohibit routine investigations. Whether nematodes are good indicators of environmental conditions has been questioned by Tietjen (1977) who found no relationship between nematode diversity and the concentration of heavy metals in sediments of Long Island Sound. Indeed, nematodes appear to be more tolerant of detrimental conditions than most other groups and have been found to survive as the only group of higher animals in very polluted waters, but again there may be specific differences and some patterns such as the gradual increase of Desmodorida and Chromadorida rather than the Comesomatidae with increasing grain size are commonly found. There is one feature of nematodes that could play an important role in the study of areas undergoing gross pollution and in danger of periodic anoxic conditions from time to time: some species of nematodes have been shown to tolerate anoxic conditions for a long time and one species (*Paramonhystera* sp.) appears to be even an obligate anaerobic species (Wieser et al., 1974). As even short periods of anoxia will wipe out most of the bottom fauna, a quick inspection of such sediments will reveal the occurrence of these.

However, on the whole harpacticoid taxocenes appear to be more suitable for community analysis in a monitoring context, because the number of species is smaller, they are more easily determined, and the species assemblages are more constant in space and have a smaller spatial variability. Investigations of estuarine harpacticoids (e.g. Noodt, 1957; Heip, 1973; Coull and Vernberg, 1975; Castel and Lasserre, 1977) have shown that very similar assemblages exist in estuarine or lagoonal situations on both sides of the Atlantic. The study of the harpacticoids in the delta region of the Netherlands again showed the same species to occur everywhere and these communities can in fact be considered as being an impoverished version of the *Halectinosoma herdmani* — *Harpacticus flexus* community of coastal waters. In the Dollart estuary species of *Asellopsis, Tachidius, Canuella, Halectinosoma, Harpacticus* and *Microarthridion* dominate, but they are replaced in conditions of heavy organic pollution by two species, *Stenhelia pallustris* and *Nannopus pallustris.* In the landlocked Lake Grevelingen *Canuella perplexa* is dominant whereas it is absent in the open estuary of the eastern Scheldt but otherwise the communities are quite similar. *Canuella perplexa* and *Halectinosoma herdmani* are sometimes the only species found in samples from heavily polluted areas of the Southern Bight, and as these are large, easily recognizable species they can be used with profit in monitoring studies.

In deeper waters offshore the clean sands of the Southern Bight are characterized by the predominance of small interstitial species belonging mainly to the Ectinosomidae, Cylindropsillidae and Paramesochridae, and the large epibenthic forms of coastal waters are absent. This community has been named the *Leptastacus laticaudatus — Psammotopa phyllosetosa* community by Van Damme and Heip (1977). In these substrata the nematodes are dominated by species of the Chromadorida which are epistratum feeders, but again the genera at least are not typical for this kind of sediment.

THE VARIABILITY OF MEIOBENTHIC COMMUNITIES: THE QUANTITATIVE APPROACH

Changes in communities in terms of the presence or absence of species or higher taxa may be very useful indications but in most situations these changes will be less pronounced and involve only the relative abundances of the taxa. Measurement involves the use of diversity indices which are subject to sometimes violent criticism but have remained in general use. I have examined the statistical properties of some of these indices in an earlier paper where their small-scale spatial distribution was examined (Heip and Engels, 1974) and will now turn to their behaviour in the time domain. In view of the bewildering multitude of indices used I have chosen to follow the approach of Hill (1973) who has shown that at least three of the more commonly used indices are related in a coherent way, i.e., the number of species S, Shannon-Wiener diversity H', measured as exp H, and Simpson's index $\mathrm{SI} = \Sigma p_i^2$, in which p_i is the relative abundance of the ith species. These and other calculations are based on a time series of copepods from a brackish water pond in Belgium started in 1968 and still being continued with a sampling interval of fourteen days. The analysis concerns 205 data points from 1968 to 1976 inclusive. When yearly averages are compared the correlation between the three indices is nearly perfect but this no longer holds for the number of species and the other indices when the samples are compared. Incidentally, this also holds for evenness indices and as there appears to be a relationship between diversity and evenness on purely statistical grounds, the use of evenness indices should not be recommended. All diversity and evenness indices are very highly correlated and tell us the same thing, and for a number of reasons the Shannon-Wiener index H (which for samples should be calculated by Brillouin's formula (Pielou, 1975)) is probably best suited. Those people feeling uncomfortable about the use of information theory statistics must bear in mind that H is calculated solely from the relative abundance of species, a perfectly valid parameter from a biological point of view. In the taxocene I studied, diversity and species richness show a distinct temporal behaviour with very long periodicities predominant in the second parameter whereas the first has a distinct yearly component (Heip, 1979). Diversity measures something different from the number of species, and this is intuitively reasonable: a change in the number of species in a taxocene is a dramatic event and it is not likely that extinction or invasion are phenomena with time scales shorter than a few years say. The relative abundance of species is a reflection of the subtle and probably unmeasurable interactions between them, and changes continuously. If this parameter is to be fit for monitoring the frequency of changes has to be within the limits set by logistics of sampling. A spectral analysis of my data shows that even when the data are detrended for the long trends there is no variance which is explained by the high frequencies. The autocorrelation for a lag of up to 600 days is highest at a lag of one year. The number of species S also has no variance at high frequencies, but the autocorrelation has a peculiar pattern, steadily decreasing with the lag. Both parameters therefore have desirable statistical properties. To demonstrate this I calculated H and S using only four single samples from different months of every year and using only six such samples. An analysis of variance shows that even with this extremely small number of samples there is no significant influence of time on the yearly average. The predominance of periodicities with a long period in both these parameters makes them valuable tools for monitoring but extrapolation in time requires the existence of long time series or the possibility to compare with similar communities; the latter is a sometimes dangerous procedure but in many instances will be the only way to proceed, unless long-term baseline studies of the particular community will be undertaken.

Besides diversity and species number the other parameters of particular interest in monitoring are density and biomass, which are easier to measure than the two previous ones and require no great taxonomical skills. Spectral analysis of the data shows peaks in the power spectrum for periods of one year and a smaller one for a period of the order of magnitude of the generation time of most of the species (2—4 weeks). After detrending, the spectra show no longer

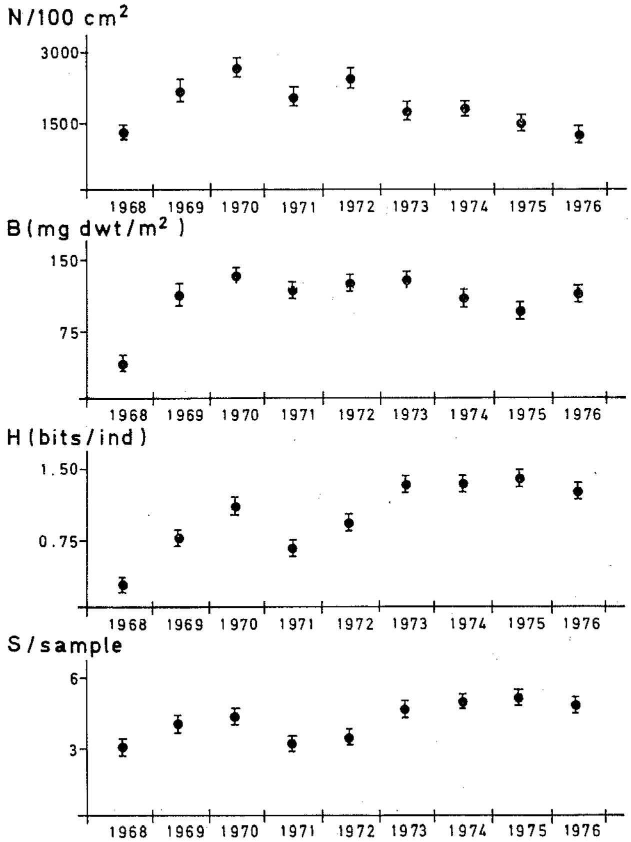

Figure 1. Mean annual values and standard errors of four community parameters; density, biomass, diversity and species richness.

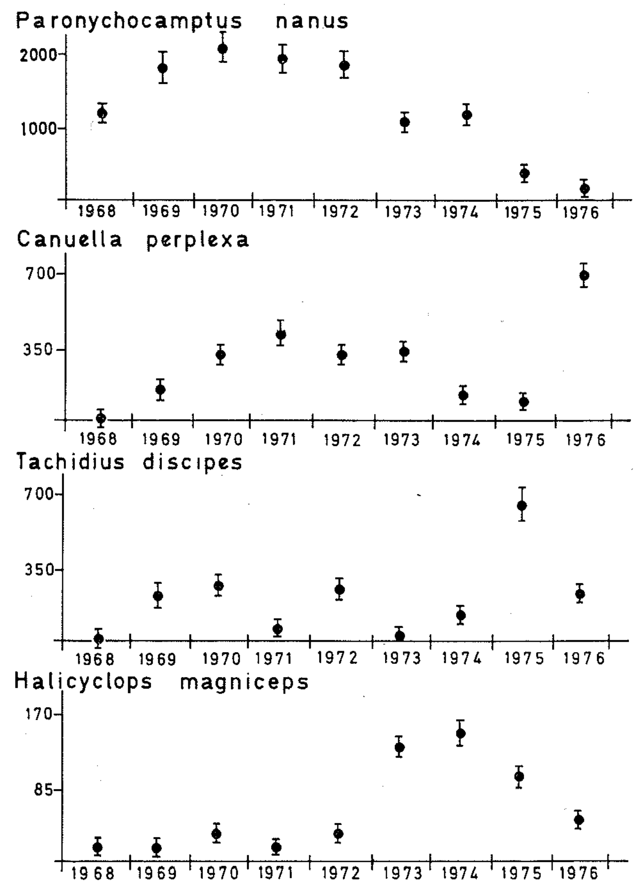

Figure 2. Mean annual density of the four most abundant copepods in the Dievengat, Belgium. (N/100 cm²).

any variance at the higher frequencies. Most of the variance is thus introduced by long periodicities, somewhat contrary to what is expected *a priori,* but this makes those two parameters again valuable in a monitoring context. A similar procedure as was followed for diversity and species number again yielded the result that time is a very significant source of variance while even with only four single samples per year the mean average value is not significantly affected. A similar analysis on nematode density at eighteen stations of the Southern Bight in three different months gave an effect of time which was exactly on the limit of significance but no effect of station. It appears indeed that nematode density is fairly constant and numbers between one and five million individuals per square metre are found in most habitats. If this is confirmed this parameter could also be of use.

Table 1. Mean x and variation $s/\bar{x}$ of different community and population parameters (n = 205)

	$\bar{x}$	$s/\bar{x}$
Density (n/sample)	128	1·39
Biomass (g dry wt./m²)	112	0·52
Diversity (bits/ind)	1·06	0·49
Number of species	4·2	0·27
Paronychocamptus nanus (n/sample)	76	1·46
Canuella perplexa (n/sample)	18	1·46
Tachidius discipes (n/sample)	22	6·46
Halicyclops magniceps (n/sample)	5	2·07
Amphiascoides debilis (n/sample)	3	2·32
Nitocra typica (n/sample)	1	2·72
Mesochra lilljeborgi (n/sample)	1	4·97

FINAL CONSIDERATIONS

Meiofaunal animals are small and benthic, and this makes them potentially valuable indicators in the assessment of environmental quality. With the aid of spectral analysis it has been shown that the variance of such community parameters as density, biomass, diversity, and number of species of the harpacticoid copepods (Fig. 1) that I studied is explained by phenomena having a low frequency. This is particularly important because it implies that sampling can be performed with a low frequency as well, and I showed that even only four samples a year yield quite acceptable estimates of these four parameters. The variability of community parameters is less than the variability of population parameters as number of individuals. This is compared in Table 1.

Fluctuations of the individual species are larger than overall density, which in turn fluctuates more than overall biomass; as this parameter is closely related to the functional characteristics of ecosystems it might be concluded that the system tends to stabilize its functional behaviour. Though wild differences exist in the yearly mean densities of the different species (Fig. 2) and the order of dominance, overall diversity does not change that much and the number of species even less. The slight increase in diversity may be explained by the fact that this pond has shown an increasing salinity over the years, turning from mesohaline to polyhaline brackish water. This change, if continued, may cause the immigration of new species and in fact this has been observed: in December 1976 two females, one of them carrying eggs, of *Pseudobradya* sp. were found in two consecutive samples (Herman, personal communication).

Stability in the number of species and in the nature of these species is a character of harpacticoid copepod taxocenes which makes them particularly suitable for monitoring purposes. The much larger diversity of nematodes and their much higher spatial heterogeneity make them probably less suited, but their density may be a good parameter for monitoring purposes. Much study remains to be done on this group, and the taxonomical problems associated with nematodes are unlikely to be solved quickly.

REFERENCES

Castel, J., and Lasserre, P. 1977. Colonisation et distribution spatiale des copepodes dans des lagunes semi-artificielles. *In* Biology of benthic organisms, pp. 129–146. Ed. by B. F. Keegan, P. O. Ceidigh and J. S. Boaden. Pergamon Press, New York.

Coull, B. C., and Vernberg, W. B. 1975. Reproductive periodicity of meiobenthic copepods: seasonal or continuous? Mar. Biol., 32: 289–297.

Heip, C. 1973. Partitioning of a brackish water habitat by copepod species. Hydrobiol., 41 (2): 189–198.

Heip, C. 1979. Density and diversity of meiobenthic copepods: the oscillatory behaviour of population and community parameters. *In* Cyclic phenomena in marine plants and animals, pp. 43–48. Ed. by E. Naylor and R. G. Hartnoll. Pergamon Press, New York.

Heip, C., and Engels, P. 1974. Comparing species diversity and evenness indices. J. mar. biol. Ass. U.K., 54: 559–563.

Heip, C., and Engels, P. 1977. Spatial segregation in copepod species from a brackish water habitat. J. exp. mar. Biol. Ecol., 26: 77–96.

Hill, M. D. 1973. Diversity and evenness: a unifying notation and its consequences. Ecology, 54 (2): 427–432.

Noodt, W. 1957. Zur Ökologie der Harpacticoidea (Crust. Cop.) des Eulitorals der deutschen Meeresküste und der angrenzenden Brackgewässer. Z. Morph. Ökol. Tiere, 46: 149–242.

Pielou, E. C. 1975. Ecological diversity. Wiley-Interscience, New York. 165 pp.

Platt, T., and Denman, K. L. 1975. Spectral analysis in ecology. Ann. Rev. Ecol. Syst., 6: 189–210.

Poole, R. W. 1978. The statistical prediction of population fluctuations. Ann. Rev. Ecol. Syst., 9: 427–448.

Por, F. D. 1964. A study of the Levantine and Pontic Harpacticoida (Crustacea, Copepoda). Zool. Verh., Leiden, 64: 1–128.

Soyer, J. 1970. Bionomie bentique du plateau continental de la côte Catalane Française III. Les peuplements de Copépodes Harpacticoides (Crustacea). Vie Milieu, Ser. B., 21 (28): 337–511.

Tietjen, J. H. 1977. Population distribution and structure of the free-living nematodes of Long Island Sound. Mar. Biol., 43: 123–136.

Van Damme, D., and Heip, C. 1977. Het meiobenthos in de zuidelijke Noordzee. Final Report Project Sea. Ministry of Scientific Policy, 165 pp.

Wieser, W. 1960. Benthic studies in Buzards Bay II. The meiofauna. Limnol. Oceanogr., 5: 121–137.

Wieser, W., Ott, J., Schiemer, F., and Gnaiger, E. 1974. An ecophysiological study of some meiofauna species inhabiting a sandy beach at Bermuda. Mar. Biol., 26: 235–248.

Printed in Denmark by Bianco Luno A/S