

Changes in softbottom macrofauna communities along environmental gradients

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A comparison is made between three study areas on the Finnish and Norwegian coasts with differing environmental gradients in order to determine the macrozoobenthic community structure. Regression analysis is used to find the environmental parameters that correlate with the two most important principal component axes obtained in the Principal Component Analysis (PCA). It is concluded that depth is the most important factor determining the community structure. However, areas with no external disturbance show a more obvious correlation to depth than polluted areas. To avoid problems in interpreting the data when several environmental gradients are overlapping, one should have a sample design that includes as many environmental gradients as possible.

1. Introduction

Single macrozoobenthic species show a characteristic distribution pattern along environmental gradients, including depth, sediment quality, salinity and pollution. When several gradients coexist, a complex community pattern is created in which characteristic community types are found as groups of related stations. Pollution studies and monitoring programs are often confronted with the problem of how to identify the environmental factors determining the community structure. The community changes within a study area become even more complex when several pollution sources are present, and the gradients are thus diffuse. The use of methods that can clarify the relations between environmental factors and faunal communities will be demonstrated.

2. Study areas

The results are based on data from three soft bottom macrozoobenthos studies, carried out in the Tvärminne area (a northern Baltic Sea archipelago, SW Finland) in 1982, the Vestfjorden, inner Oslofjord (SE Norway) in 1985 and Frierfjord (SE Norway) in 1986. The study area near Tvärminne reaches 50 m depth and is in the unpolluted archipelago where the salinity is low (6‰).

The Frierfjord is connected to the Langesund fjord and opens to Skagerrak. The salinity of the bottom water varies between 33 and 34‰ (Follum & Moe 1988). The Frierfjord is affected by many sources of pollution, such as heavy industry and waste from the surrounding dense population (Rygg 1985). Although some industries in the

area have reduced their waste discharge during the last decade, there is still a considerable pollution input.

The Inner Oslofjord has been a recipient for sewage during the last 100 years. The sewage was discharged at several localities almost untreated until 1982 when a new sewage treatment plant was established 20 km south of Oslo city. The Vestfjord, inner Oslofjord, is still characterized as polluted but the pollution gradient has become more distinct due to the reduced number of point discharges (Aschan & Skullerud 1990).

3. Material and methods

In the Tvärminne area, 5 replicate samples were taken from 41 stations with a tube-core (56.7 cm²) while 4 replicates were taken with a grab (0.1 m²) from 19 and 6 stations in Oslofjord and Frierfjord respectively. The samples were sieved through a 1.0 mm sieve with the exception of the samples from Tvärminne which were sieved with 0.5 mm sieves. The animals were conserved in a buffered 4% formaldehyde solution and identified to the species level, or, when the identification was difficult, to family or genera.

Species numbers, abundance, diversity (Shannon & Weaver 1963) and evenness (Pielou 1969) were calculated and compared. Principal Component Analysis (PCA) (eg. Harris 1975, Seber 1984) was used to place the stations in each area in relation to each other. Here only the 9 dominating species in each data set were used since the reduced data matrix gave as good a result as when

the whole data matrix was used. This was also concluded by Gray et al. (1988) who used 19 randomly selected species.

Regression analysis was used to find the environmental parameters, such as depth, distance from sewage discharge, carbon content and grain size of the sediment, that correlated with the two most important principal component axes (PCOM 1 and PCOM 2) received in the PCA analysis.

4. Results

The samples from the Tvärminne area have a fauna consisting of 11 species characteristic for the soft bottoms of the northern Baltic Sea. The Frierfjord samples have 110 species characteristic for the Skagerrak area, while 130 species, of which several dominating species were characteristic for moderately polluted areas, were found in the Vestfjord, inner Oslofjord. The numbers of stations, depths, salinities, species numbers, abundance, biomass, diversity H' and evenness J' for the three areas are given in Table 1.

In the Tvärminne area it is obvious that each species has its own optimal depth range (Fig. 1). A pattern along the depth gradient was clear in the Oslo data set when the most polluted stations were excluded. In the Frierfjord data the 10 dominating species showed an increase or a decrease in abundance with increasing depth. In Fig. 2 the density of *Nuculoma tenuis* along the depth gradient is given for the Oslo and Frierfjorden stations.

The PCA analysis was based on a data matrix including only the 9 dominating species of the

Table 1. Number of stations, depth, salinity, species number, abundance (mean \pm SE), biomass, diversity and evenness in the studied areas.

	Tvärminne	Frierfjord	Oslofjord
Number of stations	41	6	19
Depth (m)	15–47	22–113	37–132
Salinity (‰)	6	33–34	30–33
Number of species	9	110	130
Abundance (ind./m ²)	9156 \pm 313	3084 \pm 696	3262 \pm 779
Biomass (g/m ²)	69.1	91.7	47.2 ^a
Diversity (H')	0.69–2.30	1.48–4.70	1.76–4.21
Evenness (J')	0.34–0.89	0.46–0.73	0.37–0.73

^aThe biomass value for the stations in Oslofjord are from 1980 (Skullerud 1985).

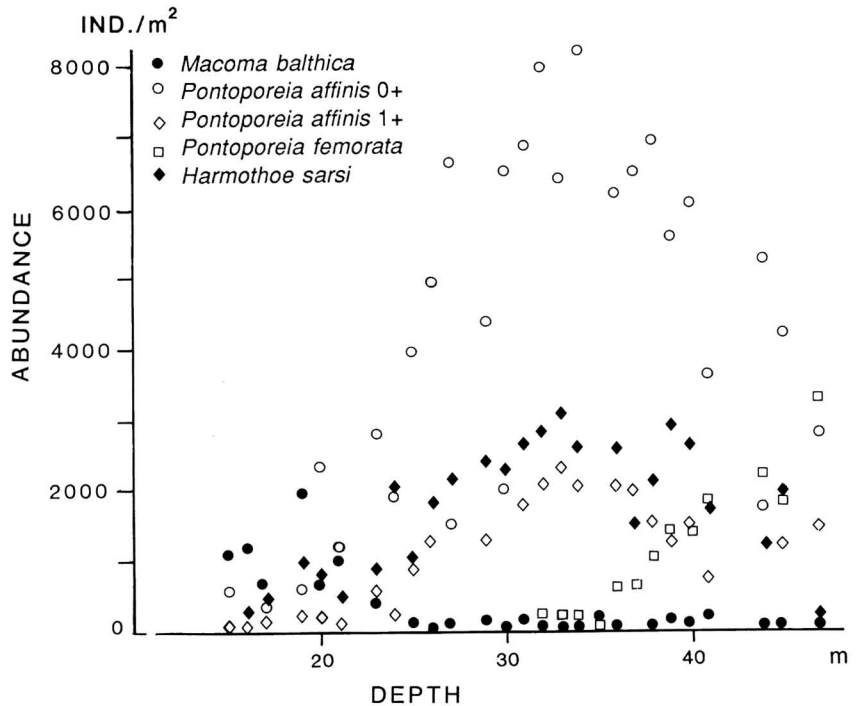


Fig. 1. The abundance along the depth gradient for *Macoma balthica*, *Pontoporeia affinis* age group 0+, *P. affinis* age group 1+, *P. femorata* and *Harmerothoe sarsi* in the Tvärminne area.

total number of species in each study area (Table 2). The Tvärminne area had no species in common with the two other areas, which had over 70 species in common, when the whole data matrixes were compared.

The PCOM 1 explains 30 to 40% of the observed faunal variations and when the PCOM 2 is added, the variance explained in the 2-dimensional field represents over 50% of the total variance observed in the benthos community. In a typical community study, the first three eigenvalues may account for 40 to 90% of the total variance (Gauch 1982).

The distribution of stations in the two dimensional fields received from the PCA analysis are given in Fig. 3. In the Tvärminne area and the Frierfjord area the stations show a "horseshoe distribution" and are located according to depth. The "horseshoe effect" is caused by a discrepancy between the underlying model of the PCA and the mathematical properties of communities (Gauch 1982). The "horseshoe effect" was eliminated in

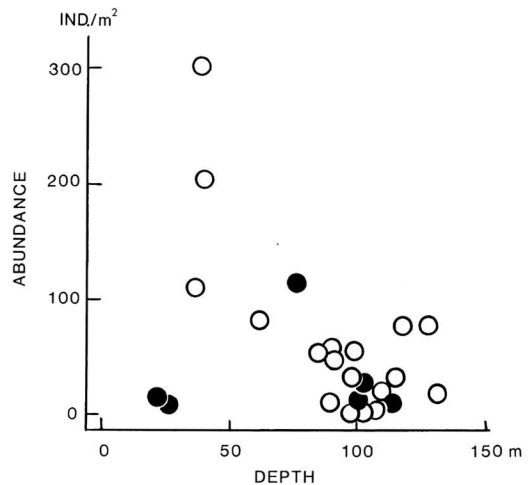


Fig. 2. The abundance along the depth gradient for *Nuculoma tenuis* in the Frierfjord (black) and Vestfjord, inner Oslofjord (white).

Table 2. The nine dominating species in each study area.

Tvärminne	Frierfjord	Oslofjord
<i>Pontoporeia affinis</i> Lindström	<i>Thyasira</i> spp.	<i>Scalibregma inflatum</i> (Rathke)
<i>Harmothoe sarsi</i> (Malmgren)	<i>Amphiura filiformis</i> (Müller)	<i>Mediomastus fragilis</i> Rasmussen
<i>Pontoporeia femorata</i> Kröyer	<i>Cossura longocirratu</i> s Webst. & Bened.	<i>Heteromastus filiformis</i> Clap.
<i>Macoma balthica</i> (L.)	<i>Paraonis lyra</i> Southern	<i>Chaetozone setosa</i> Malmgren
<i>Mysis mixta</i> Lilljeborg	<i>Nuculoma tenuis</i> Montagu	<i>Thyasira</i> spp.
<i>Halicryptus spinulosus</i> Siebold	<i>Abra nitida</i> (Müller)	<i>Polyphysia crassa</i> Oersted
Chironomidae spp.	<i>Echinocardium cordatum</i> (Pennant)	<i>Polydora caulleryi</i> Mesnil
<i>Saduria entomon</i> (L.)	<i>Proclea graffii</i> (Langerhans)	<i>Polydora</i> spp.
<i>Oligochaeta</i> sp.	<i>Paramphinoe jeffreysii</i> (McIntosh)	<i>Nuculoma tenuis</i> Montagu

the Tvärminne (Aschan 1988) and the Frierfjord data (Gray et al. 1988) when the Detrended Correspondance Analysis (Hill & Gauch 1980) was used.

In Table 3 the eigenvalues, their percentage share of the total variance and the correlation with depth, is given for PCOM 1 and PCOM 2. In the Tvärminne area, PCOM 1, which represents 36% of the total variation in the community, correlates well with the depth as is the case in the Frierfjord data.

In the Vestfjord data there is no obvious parameter correlation with PCOM 1. However, the PCOM 1 shows the highest correlation with depth (see Table 3 and 4). Aschan & Skallerud (1990) used a classification analysis, based on Bray-Curtis dissimilarity index (Bray & Curtis 1957), which grouped the 19 stations into four groups that were different according to depth and distance to pollution source. The area close to the sewage outlet had clear pollution effects and was grouped into a shallow area and a deeper area. The area further away from the sewage outlet was divided into a deep and moderately polluted area and a deeper area showing little pollution effects. Only the deep area close to the sewage outlet is indicated in Fig. 3c as the three striped stations in the upper left corner.

Neither is there any significant correlation between environmental parameters such as depth and particle size distribution in the sediment or carbon content of the sediment and distance to sewage discharge (Table 4).

The PCA and the regression analysis show that the depth seems to be the main environmental factor determining the fauna composition at

Table 3. The eigenvalues of the principal components 1 and 2 expressed as percentage of total variance, and correlation (r^2) between principal component values and station depth in the three study areas.

	Tvärminne	Frierfjord	Oslofjord
PCOMP1	36 %	40 %	32 %
r^2	0.73	0.77	0.29
PCOMP2	16 %	21 %	27 %
r^2	0.09	0.13	0.00

Table 4. The correlation (r^2) between principal component (PCOM1, PCOM2) values and particle size distribution and carbon content in the sediment and distance to the sewage discharge in the Vestfjord, inner Oslofjord.

	particle size	carbon	distance
PCOMP1 r^2	0.00	0.02	0.01
PCOMP2 r^2	0.07	0.22	0.17

each site in all three data sets. However, it is clear that areas with no external disturbance show a more obvious relation to depth than areas that are polluted.

5. Discussion

Several parameters are connected to depth either directly, such as pressure and light, or indirectly,

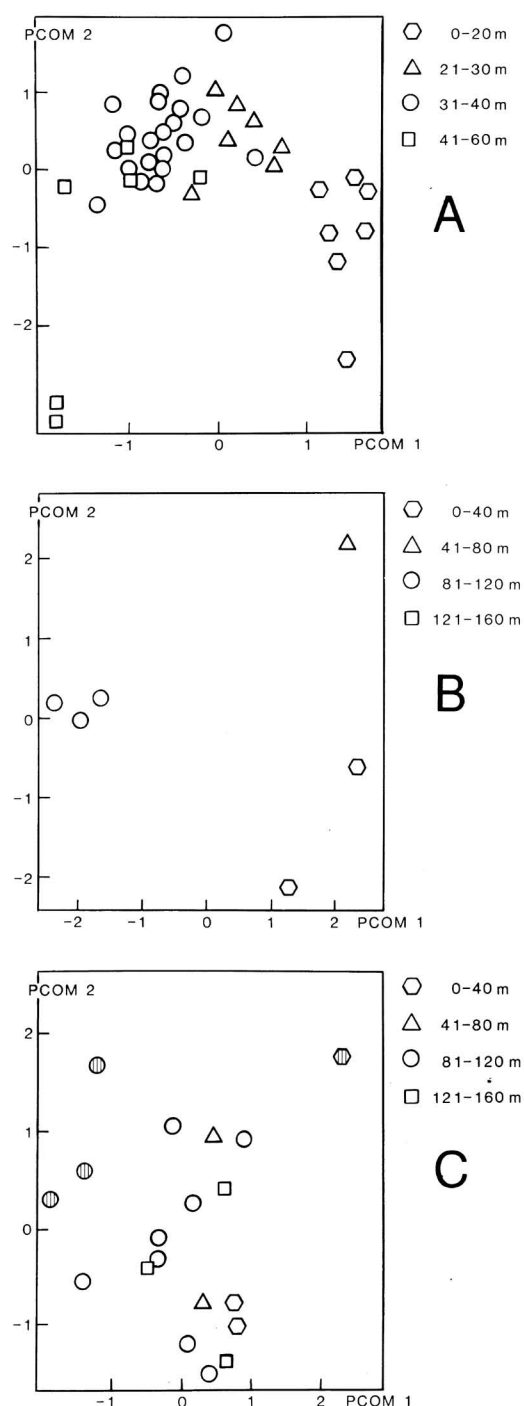


Fig. 3. The twodimensional plot from the PCA analysis for the Tvärminne (A), Frierfjord (B), and Vestfjord (C) area where stations close to the sewage discharge are striped.

for example temperature, salinity, oxygen concentration and sediment qualities. However, these parameters can be measured separately and a distinction between their effects can often be made.

Gage (1974) concluded that in shallow water (<5m) the faunal distribution was determined primarily by tidal and wave exposure together with salinity and temperature, whereas in deeper water sediment composition became more important. Coleman & al. (1978) described two faunal assemblages characterized as a "clean medium sand" assemblage, distributed in the deeper (>5.5 m) sublittoral areas, and a "fine sand and mud" assemblage distributed over the tidal flats in shallow (≤ 5.5 m) sublittoral areas.

The sediment character which varies most obviously is the grain size. The type of grain size deposit found depends on current speed, the roughness of the sediment and the length of time when conditions are calm and particles can sediment. Mixtures of grain sizes are the rule and usually poorly sorted sediments are heterogeneous and are typical where the current is low and the sediment is soft (Gray 1981).

Chardy & Clavier (1988) concluded that differences in the macrobenthic trophic structure between the muddy-bottom, grey sand and white sand communities of the SW lagoon of New Caledonia reflected the functional characteristics of each bottom type. However, grain size showed correlation with neither depth nor PCA axis in the Vestfjord (Table 4) area and Frierfjord area (Gray et al. 1988).

The bulk of organic material in sediments is derived from sedimentation from the overlaying water column. Calculations indicate in general that between 30 and 40% (eg. Smetacek 1980, Forsskål et al. 1982) but even up to 50% of the primary production settles to the sea floor (eg. Nixon & Pilson 1983, Wassmann 1986).

Josefson (1987) argues that the major cause of the common variability pattern is some factor related to production in the sea such as sedimentation of organic matter, which affects either one or a combination of the following: settlement, somatic growth and survival on the bottom. He also observed that increased abundances were accompanied by increased organic content. Recipients enriched with sewage usually show in-

creased primary production followed by an increase in organic content of the sediment and increased abundances to a certain pollution limit.

In the Vestfjord, inner Oslofjord, one would assume the sediment carbon content to decrease with increasing distance to the sewage outlet. However, there was no correlation between the two parameters (Table 4). One explanation is that the titration method (Gaudatte et al. 1974) used is inexact. Processing sediment samples through a CHN analyser could have given better results. Still these two analyses can give a false impression since a part of the carbon is present as coal particles which cannot be utilized by bacteria (Gray 1981). To overcome this problem a method estimating the organic matter occurring as protein can be used (Buchanan & Longbottom 1970).

Depth, sometimes together with sediment parameters, has been shown to be the determining parameter for several macrobenthic communities. As seen in Fig. 1 and Fig. 2, the species show a regular abundance pattern along the depth gradient. The number of species increased with increasing depth in the Tvärminne area, the Southern Baltic (Persson 1983) and also among less polluted stations in the Vestfjord and Frierfjord area. In the three data sets the depth is the main environmental factor determining the fauna composition at each site (Fig 3, Table 3). It is however demonstrated that areas with no external disturbance show a more obvious correlation to depth than polluted areas (see Table 3).

Studies of the effects of pollutants on marine benthic communities use a variety of techniques aimed at separating the pollutant effect from natural environmental variability. Pollution gradients are usually characterized by increasing enrichment towards the pollution discharge (eg. sewage outlet, dumping ground, oil rig). When the pollution gradient is distinct, characteristic community changes such as changes in species number, abundance and biomass, occur along the gradient. This is described in the so called SAB diagram introduced by Pearson & Rosenberg (1978). The relation between species biomass and species abundance changes along the pollution gradient and is presented in a ABC plot by Warwick (1987).

Classical methods used in pollution studies include the Shannon-Wiener index (Shannon &

Weaver 1963), Sanders rarefaction method (Sanders 1968, Hulbert 1971), evenness (Pielou 1969) and the log-normal distribution (Ugland & Gray 1982). However it becomes difficult to apply these methods in an area that is influenced by several point sources or that has been subjected to enrichment for several years, as is the case in the inner Oslofjord (Aschan & Skullerud 1990). In such an area the benthic community has established a "second stage" equilibrium where deposit feeders dominate and distinct pollution effects are hard to detect (Gray 1981).

Gray & Pearson (1982) introduced a modification of the log-normal distribution of individuals among species and created a new method which can be used to objectively isolate groups of species sensitive to pollution effects. However, these species do not necessarily give any better indication than randomly selected species, as was the case in the Frierfjord (Gray et al. 1988). In the Oslo area, two of the three species selected by this method (*Lumbrineris* spp. and *Pholoe minuta*) were carnivores and probably do not show as direct an indication of pollution changes as filter feeders would (Aschan & Skullerud 1990).

In a comparison, the Frierfjord area has a distinct pollution gradient and the above mentioned methods are easy to apply and give interpretable results (Gray et al. 1988). By using several methods and by including classification and several types of ordination analysis, the problem of diffuse gradients was solved (Aschan & Skullerud 1990).

The pollution gradient often follows the depth gradient from the shore to the open sea and it gets problematic to separate these two parameters. However, the problem can be avoided by having a good sampling design where shallow stations further away from the pollution discharge are also sampled.

A low diversity is not necessarily a sign of pollution effects. As we have seen, it can also be caused by natural parameters such as low salinity, as in the Tvärminne area, or periods of poor oxygen conditions caused by insufficient water exchange. It is, therefore, important that we try to separate the effects caused by natural conditions from the pollution effects.

The marked decrease in the number of marine species from the Skagerrak towards the inner parts

of the Baltic Sea may be caused not only by the decreasing salinity but also by unfavourable temperature conditions (Voipio 1981). Still the salinity plays a major role for the faunal composition as it determines limits for several marine species. Because of this, a gradual change in species composition in the macrozoobenthic communities follows along the salinity gradient. The same effect of salinity conditions is found on a smaller scale in estuaries (Green 1968). Roger & Hughes (1971) conducted a benthic survey of the Bideford River estuary in NW Prince Edward Island, Canada. Sublittoral stations were influenced by several factors correlated with distance from shore. The extent of sea-ice in winter and the influx of fresh water during the spring were probably important.

6. Conclusions

Natural environmental parameters often influence the community structure to such a degree that any possible pollution effects are not to be discerned. One reason is that the pollution gradient, when present, often follows the depth gradient and the salinity gradient, especially in estuaries. If the pollution has continued for some time, the carbon content in the sediment and the particle size distribution have been influenced and it is difficult to ascertain the original or "natural" condition. However, the depth gradient determines the community structure though pollution seems to diminish this effect.

To avoid problems in interpreting the data when several environmental gradients are overlapping, it is important to have a sample design that includes as many environmental gradients as possible. Here a single transect, for example from shore to sea or from dumping ground to clean water areas, is insufficient.

It is important to make exact measurements of several environmental parameters. Special attention should be paid to environmental gradients found during pilot studies or in data received earlier.

The use of several statistical and mathematical methods is important. In particular, classification methods and ordination methods in combination with simple regression analysis are likely to give

interpretable results, while usually at least one of the measured environmental parameters correlate with the ordination axes.

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