Examples of responses of benthic communities to environmental stress (Dover Strait, France)

Stress
Rank-frequency diagrams
Diversity
Benthos

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Diagrammes rang-fréquence
Diversité
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ABSTRACT

Rank-Frequency Diagrams (RFD) permit the determination and visualization of the coenotic strategy used by benthic communities in temporarily or permanently disturbed environments.

Examples of structures, dynamic stability and strategies of benthic communities according to environmental variations are given and discussed. Both spatial and temporal variations have been analyzed by means of RFD.

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RÉSUMÉ

Exemples de réponse des communautés benthiques au stress de l'environnement

Les diagrammes Rangs-Fréquence (DRF) permettent de déterminer et de visualiser la stratégie coenotique adoptée par les peuplements benthiques en fonction des perturbations, permanentes ou temporaires, de l'environnement.

Différentes structures de peuplements benthiques, leur stabilité dynamique et leurs réponses aux changements de milieu, sont présentées. Les variations, tant spatiales que temporelles, peuvent être analysées à l'aide des DRF.

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INTRODUCTION

In disturbed natural environments, communities are adapted to persist using coenotic strategies (Blandin *et al.*, 1976). The latter include demographic strategies of species, and interactive connections between them, resulting in their actual numerical ratio as well as the sharing of time and space. Two extreme types of community exist: a) communities with few species, among which a very small number are strongly dominant. These communities, which show large fluctuations of biomass but tend to recover quickly after a perturbation, are observed in most unstable or stressed environments; and b) communities with numerous species, having a great number of inter-specific interactions. Consequently, their demographic distributions are mutually controlled and are more stable, but also more vulnerable to environmental perturbations. Such populations exist in relatively stable or little-stressed environments.

The Dover Strait shows several gradients of stress such as that produced in anthropogenic actions, tidal currents or silt content of the sediment. These stresses directly act on the bionomical structure of the benthic communities. Benthic communities from the Dover Strait provide examples of both types described above, whilst others oscillate between them according to the permanence and the strength of the stress.

In order to describe the partition of space and/or resources among the various species of a community, use was made of several models of species distribution (*i.e.* distribution of individuals among species) which differ from each other by the method of generating probabilities of occurrence of species and by the hypothesis adopted in modelling the sharing of resources among them: they include the Motomura model (1932); the McArthur model (1957); the Preston (log-normal) model (1948); and the Zipf-Mandelbrot model (1953) which was applied to ecological data by Margalef (1958) and Frontier (1976 and 1985).

All these methods permit direct visualization of multispecific distributions on Rank Frequency Diagrams (RFD). The comparison of several RFD describe the species distribution more accurately than a mere numerical index.

Some other methods used to determine the impact of stress can be found in the litterature. They use models derived from those named above. Gray and Mirza (1979) and Gray (1980 and 1981) use log-normal plots for the detection of pollution-induced disturbance. Recent developments of pollution studies use combined k-dominance curves (Warwick, 1986; Warwick and Ruswhayuni, 1987) to separate unpolluted, moderately polluted and grossly polluted conditions. They assume that the distribution of numbers of individuals should be different from the distribution of biomass when the community is stressed by pollution.

In this paper, some examples of use of RFD are provided from benthic communities of the Dover Strait area. The "pebbles community with sessile epifauna" is a fairly good example for studying spatial variations along a current gradient. The "clean medium-size sand community with *Ophelia borealis*" was chosen for illustrating temporal fluctuations of a constantly low stressed community. The intertidal upper level community well illustrates the temporal variations of the structure of a community in a highly fluctuating environment.

METHODS

Samples were obtained by standard methods for benthic macrofauna studies: a Rallier du Baty dredge for the pebble community, a Smith McIntyre grab for the *Ophelia borealis* community and a hand corer for intertidal samples.

The sampling period was chosen with the aim of making a valid comparison between samples: a) samples along a spatial gradient in the pebble community were made at the same time (February 1985); b) samples for the study of temporal variations were obtained during the same period over several years (May for the *Ophelia borealis* community, end of May-early June for the intertidal community).

RFD were drawn by using Frontier's method (1976): a log scale for frequencies and ranks. According to the shape of the RFD, several stages were described:

Stage 1

It corresponds to pioneer communities at the beginning of the ecological succession, or communities remaining at this stage because of environemental pressure. Curves are steep and show an inflexion ; the diversity is low.

Stage 2

It corresponds to mature communities. Curves are convex and the diversity value is maximum.

Stage 3

It corresponds to the final stage of succession. The curve is essentially linear and the diversity is lower than in stage 2. In benthic studies, we have never found stage 3.

The shapes of RFD give the "structure" of the multispecific populations, and are independent of the precise species occupying the ranks. The ranked list of species gives further information, indicating possible permutations of species within the same "structure", *i.e.* a rearrangement of the community.

Changes in the structure of a community are directly visualized by the variations in the shape of RFD. They are interpreted here as modifications of the strength of a stress or the appearance of another one.

RESULTS. DISCUSSION

Spatial fluctuations

The pebble community with sessile epifauna occurs in areas of high hydrodynamism of the Dover Strait (Fig. 1). The decrease of hydrodynamism from South-West to

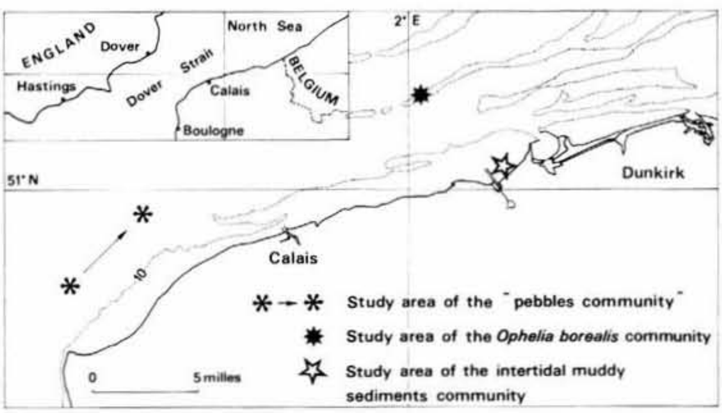

Figure 1

Studied area.

Zone d'étude

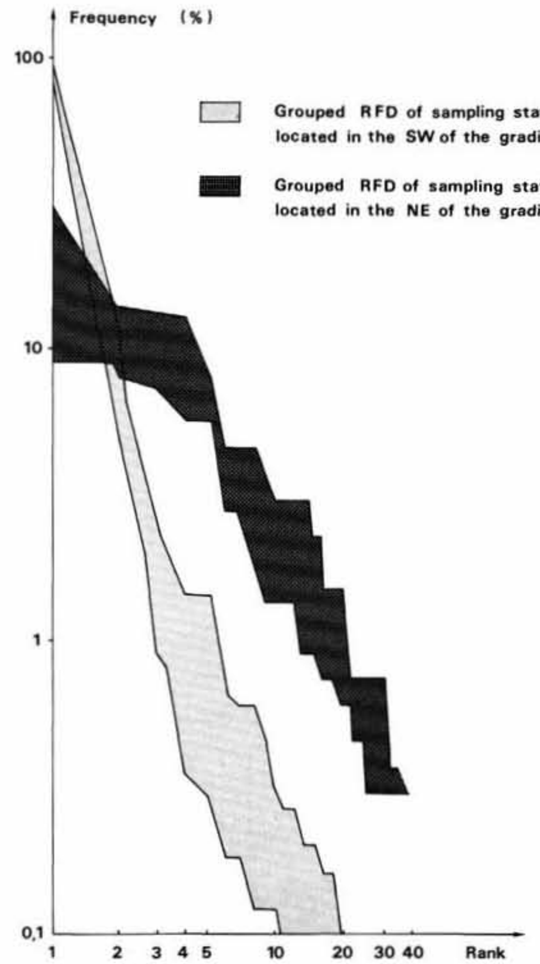

Figure 2

Spatial evolution of RFD along a silting-up gradient.

Évolution spatiale des DRF le long d'un gradient d'envasement.

North-East, particularly between Cap Gris-Nez and Cap Blanc-Nez, results in a gradient of silt richness of the sediment, from 0 % in the South-West to 4.5 % in the North-East (Davoult, 1990), RFD are vertical in the South-West (< 1 % of silt), and concave in the North-East (1 to 4.5 % of silt; Fig. 2).

Looking more precisely at the specific composition and the species hierarchy, it can be observed that the southwestern part of the community is principally dominated by *Ophiothrix fragilis* (80 to 90 % of individuals) and *Pisidia longicornis* (5 to 12 %). The first dominance ranks are always occupied by the same group of species, often in the same order. The Shannon diversity index is low (less than 2.5). Silt content increases towards the North-East, resulting in the complete disappearance of *Ophiothrix fragilis* as soon as the content reaches 1 %. Mud-dwelling species such as *Sabella penicillus*, *Abra alba* and *Ophiura texturata* are in the first ranks. Ranks of the species are variable, and the diversity is higher (more than 3.5), but the accompanying species are the same as in the pebble community. This effect is due to pebbles emerging from the silted sediment, with their epifauna still present. This particularity results in an amazingly high diversity for a silted sediment, since typically an increasing silt content is considered as a stress which generally reduces the diversity. In fact, the increasing silt content is due to decrease of the hydrodynamical flux - the hydrodynamical regime being a more important stress than the silt enrichment - and the decrease of this stress induces the increase of the diversity.

As a result, a small number of strongly dominant species disappear when the silt content increases, whereas some mud-dwelling species appear, showing a moderate dominance. The diversity index increases through a rearrangement of the species distribution. So, for the same number of species and individuals, diversity is increasing from South-West to North-East.

Temporal fluctuations

Two examples have been chosen for applying RFD to temporal fluctuations.

Clean medium-size sand community with Ophelia borealis *(Fig. 1)*

This community occupies the main surface of the permanent sand-banks of the area (Prygiel *et al.*, 1988), RFD are convex and stable in space and time (Fig. 3; Prygiel, 1987). Quantitative temporal fluctuations of species are moderate, but the ranking of these species is very variable (Tab. 1). The number of individuals (Tab. 1) and the biomass (< 2 $gDW.m^{-2}$) are low. At this scale of observation, the most dominant species may be a carnivorous one (*Nephtys cirrosa*), a surface deposivore (*Bathyporeia elegans*), or a sub-surface deposivore

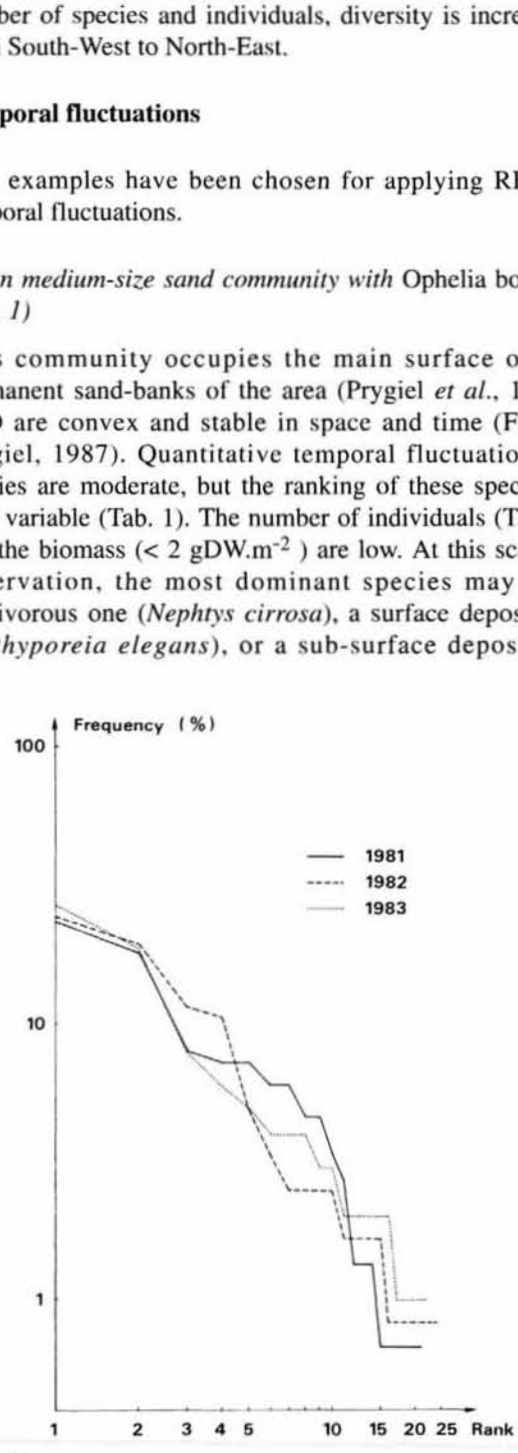

Figure 3

RFD of Ophelia borealis *community (May).*

DRF de la communauté à *Ophelia borealis* (mai).

Table 1

Ranks of main species of the Ophelia borealis *community.*

Rangs des espèces principales du peuplement à *Ophelia borealis*.

	Rank of species		
	1981	1982	1983
Bathyporeia elegans	2	1	6
B. guillamsoniana	6	4	> 10
Chaetozone setosa	8	5	> 10
Diastylis bradyi	9	> 10	> 10
Echinocardium cordatum	> 10	> 10	5
Gastrosaccus spinifer	5	9	10
Magelona mirabilis	4	6	3
Nephtys cirosa	3	3	1
Nephtys longosetosa	> 10	10	> 10
Nerine bonnieri	> 10	7	8
Ophelia borealis	1	> 10	> 10
Scoloplos armiger	> 10	2	2
Spio martinensis	> 10	8	> 10
Spiophanes bombyx	7	> 10	4
Spisula solida	> 10	> 10	9
Tellina fabula	10	> 10	7
Mean density (Ind. m^{-2})	150	122	101
Shannon index H	3.6	3.6	3.6

(*Ophelia borealis*). Species abundances differ little from one another, and fluctuate somewhat, so that continuous rank rearrangements occur. As a result, there is no excessive pressure of any trophic group (for instance the carnivores) on the community, which could perturb the dynamic stability.

The community remains stable despite the transport of surface sediment, well known on sand banks in the eastern Channel and the southern bight of the North Sea (Clabaut, 1988).

Conversely, the dynamic equilibrium can be modified as soon as environmental perturbations occur. For example, the deposition of dredged harbour silt induces a local stress, which is immediately reflected in a modification of RFD shapes (Bourgain *et al.*, 1988).

Intertidal upper level community (Fig. 1)

This level is silt-enriched and subjected to a salinity decrease. RFD are steep, as indicated by the grey zone of Figure 4. The hierarchy of species has been observed to be constant, (Grégoire, 1976; Davoult, 1983; Dewarumez, 1983). The four most important species (*Hydrobia ulvae*, *Corophium arenarium*, *Eurydice affinis* and *Bathyporeia pilosa*) practically always occur in the same rank order. These species are typically found in lower salinity areas with high silt content. Density fluctuations are very high, generally from 1 to 100 for *Hydrobia ulvae* (maximum observed density 6 000 ind.m^{-2}). Total biomass also shows high variations (Tab. 2), The pressure of some environmental factors is drastic, particularly silt content (up to 9 %, Tab. 2), duration of tidal emersion, and salinity decrease due to continuous run-down of fresh water during low tide. RFD are rectilinear and steep, the diversity is very low ($H = 0.72 \pm 0.34$).

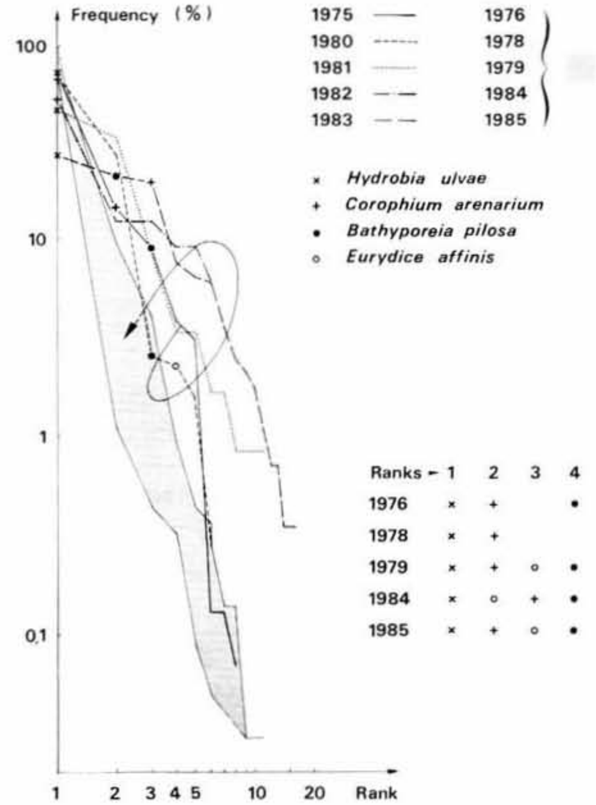

Figure 4

Historical succession of RFD from the upper level intertidal community (May-June).

Succession des DRF du peuplement intertidal de haut niveau (mai-juin).

If the pressure of one factor is reduced, a rearrangement of the community is observed. In the example above (the

Table 2

Historical series of silt content, biomass (decalcified dry weight, g.m^{-2}) and diversity (Shannon index) in the upper level intertidal community.

Variations interannuelles du taux de pélites, de la biomasse (poids sec décalcifié, g.m^{-2}) et de la diversité (indice de Shannon) du peuplement intertidal de haut niveau.

Year	1975	1976	1978	1979	1980	1981	1982	1983	1984	1985
% silt				8.04	1.67	1.19	0.10	2.03	9.91	9.20
Biomass	2.99	6.36	4.39	4.83	2.28	0.81	2.22	1.81	7.16	9.01
Diversity	1.14	0.85	0.51	0.73	1.27	2.10	2.11	2.99	0.28	0.96

Gravelines beach; *see* Fig. 1), modifications of local currents due to harbour alteration and industrial construction resulted in a silt decrease: 8 % in 1979, to 0.3 % in 1982. RFD turn out to be progressively convex (Fig. 4). Equilibrium occurs in 1983, despite a slight increase of the silt content (2 %, Tab. 2). During the 1980-1983 period, a permanent rearrangement of the community occured, while the hierarchy of species fluctuated. *Hydrobia ulvae* was still dominant, but its density varied little (maximum density: 80 ind.m^{-2}). New species (*Ophelia rathkei, Crangon crangon, Bathyporeia sarsi, Spio martinensis*) appear; they are less tolerant of salinity and silt content. It was still the same community as before, despite the fact that the structure was modified and the diversity increased because the number of sampled species increased at the same time. Finally, the RFD was of "type 2".

In 1984 and 1985, sedimentation conditions made the silt content increase (9 %); the RFD was then again rectilinear (Fig. 4) .

Fitting a linear regression shows a strong correlation between: a) biomass and silt content ($r = 0.92$, $n = 7$, $p < 0.01$); and b) diversity and silt content ($r = 0.81$, $n = 7$, $p < 0.05$).

CONCLUSION

Benthic communities are more long-lived than planktonic ones. Some communities may show a "stage 1" RFD for years, hence it is difficult to call them "juveniles". The assumption is that the selection pressure of one or more environmental factors on the community prevents it from evolving towards greater diversity. Hence, "stage 1" (vertical or concave) RFD can be interpreted in benthic studies as indicating the presence of a significant stress and resulting in some important fluctuations of total biomass and density, and consequently in a selection of few robust species.

Examples of such an effect are shown by communities of silted and low-salinity upper level beaches and by those located in areas of high hydrodynamical flux.

"Stage 2" (convex) RFD indicate non stressed communities. The rank of species varies, indicating an permanent rearrangement within the community, leading to a dynamical stability of the number of individuals and the biomass. "Stage 3" RFD seem to be very rare in benthic communities.

Passage from one stage to the other can be rapid when the stress passes either side of a threshold.

It can be inferred that the two extreme shapes of RFD are realized: a) when the environmental conditions exert a permanent stress on the population; and b) when they exert no stress at all. Between both extreme situations, intermediate shapes are observed. Such fluctuations are particularly observed in the *Abra alba* community from fine silted sand (which displays a high number of species and a very high total biomass), when undergoing a fluctuating environmental pressure. The quantitative fluctuations of the few dominant species are important (Dewarumez *et al.*, 1986). Shapes of RFD are intermediate and fluctuate in space and time, following: a) the random and local fluctuations of the silt content; and b) the recruitment events.

RFD can be useful in studying spatial variations along a gradient or in a transitional area between two benthic communities, as well as in annual or pluriannual variations inside a community. Hence RFD appear to be a good tool for monitoring the stress levels of a benthic community in a fluctuating ecosystem.

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