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USE OF THE ABUNDANCE/BIOMASS COMPARISON METHOD FOR DETECTING ENVIRONMENTAL STRESS: SOME CONSIDERATIONS BASED ON INTERTIDAL MACROZOOBENTHOS AND BIRD COMMUNITIES

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SUMMARY

(1) The abundance/biomass comparison (ABC) method for detecting pollution effects was applied to data for macrozoobenthos taken from two intertidal areas: one virtually unpolluted (the Oosterschelde, Netherlands in 1981–84) and the other very polluted (the Westerschelde, Belgium in 1987). This method should be a sensitive indicator of natural physical and biological disturbance as well as of pollution-induced disturbance in both space and time.

(2) Studies of macrozoobenthos from several study plots in the Oosterschelde indicated some environmental stress, related to a long tidal exposure time of the plot or to human disturbance (mussel fishing). Data from all other study plots showed an unstressed pattern.

(3) Within one moderately stressed study plot in the Oosterschelde, density and biomass diversity remained fairly constant over about 4 years.

(4) In the Westerschelde, the ABC method indicated an unstressed (unpolluted) situation in one and a moderately stressed (polluted) situation in two study plots. As there were few species (two to four), the method was not very reliable.

(5) Applying the method to data for waders taken from the same study plots in the Oosterschelde revealed stress only in the plots with the shortest exposure time and the lowest available invertebrate biomass. This did not correspond with the patterns found for the macrozoobenthos. The amount of time available for feeding and the available biomass determine feeding conditions and are thus very important factors for waders.

(6) An index is proposed for expressing the ABC method in values rather than in graphs.

(7) It is argued that it is difficult to use this method in estuarine areas as an indicator of pollution because of the environmental stress typical for these areas. However, in general, it may be used to detect environmental stress.

INTRODUCTION

In freshwater ecology, the use of a biotic index for detecting pollution is generally accepted (e.g. De Pauw & Vanhooren 1983) and it is used in applied ecological research, especially since without any prior knowledge of the site one can assess its pollution. No counterpart exists in marine benthic ecology. Methods for detecting pollution without prior knowledge of the site are mainly based on deviations of the log-normal distribution (Gray 1979, 1981a; Gray & Mirza 1979) or on the comparison of the performance of one component of the community, which has been shown empirically to be more sensitive to pollution, with another less-sensitive component, e.g. the nematode:copepod ratio (Raffaelli & Mason 1981). The validity of both methods is doubtful (Gee *et al.* 1985; Hartnoll, Burrows & Ellard 1985; Hughes 1985; Lambshead 1984; Lambshead & Platt 1985).

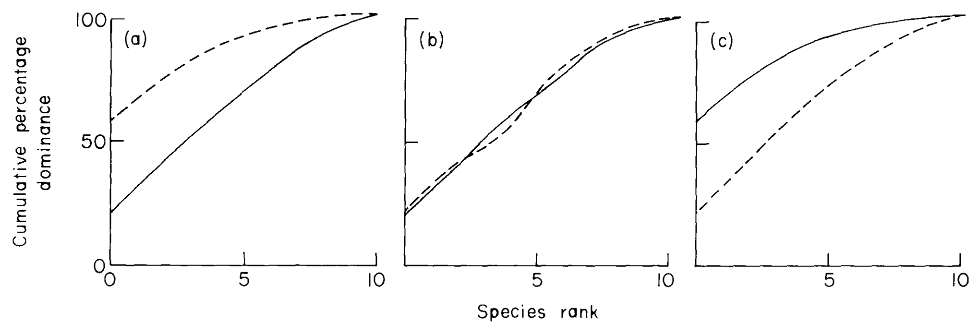

FIG. 1. Hypothetical *K*-dominance curves for species abundance (——) and biomass (- - - -), showing unstressed (a), moderately (b) and heavily stressed (c) conditions (after Warwick 1986).

The abundance/biomass comparison (ABC) method was proposed by Warwick in 1986. He suggested on theoretical considerations that the distribution of the numbers of individuals among species should differ from the distribution of biomass among species when influenced by pollution-induced disturbance. This difference can be shown easily by *K*-dominance plots (see Shaw, Lambshead & Platt (1983) and Lambshead, Platt & Shaw (1983)). The curves rank species in order of importance on the *x*-axis and show the percentage of each species on the total numbers or biomass on a cumulative scale (called percentage dominance) on the *y*-axis. When the community is approaching equilibrium, the biomass becomes increasingly dominated by one or a few large species, each represented by few individuals. The numerical dominants are smaller species. Hence, when plotted as *K*-dominance curves, 'numerical diversity' is greater than 'biomass diversity', so that the line for abundance lies well below the line for biomass, since one species forms a much larger proportion of the total biomass than it does of the total numbers (Fig. 1a). Under stress (natural physical and biological or pollution-induced disturbance), large competitive dominants should be eliminated and biomass and abundance curves should be close together and crossing one or several times (Fig. 1b). Under severe disturbance, benthic communities become increasingly dominated by one or a few very small species (usually annelids such as *Capitella* spp. or oligochaetes) and few larger species are present. Hence 'numerical diversity' is lower than 'biomass diversity' (Fig. 1c). These three cases were termed unpolluted, moderately polluted and grossly polluted by Warwick (1986). We will refer to them as unstressed, moderately stressed and heavily stressed patterns. For a more detailed description of the rationale behind the method we refer to Warwick (1986).

Application of the technique to several data sets showed that it is a sensitive indicator of natural physical and biological disturbance as well as pollution-induced disturbance over space and time (Warwick 1986; Warwick, Pearson & Ruswahyuni 1987; Warwick & Ruswahyuni 1987).

We explored the validity and possibilities of this method by applying it to data for macrozoobenthos and waders from intertidal areas. It should be applicable to intertidal communities, since natural physical disturbance, characteristic of such situations, does not appear to prevent the community from attaining a mature climax stage comparable with the sublittoral (Warwick, Pearson & Ruswahyuni 1987). We analysed abundance/ biomass curves in space and time from original data for seventeen study plots on a tidal flat in the Oosterschelde, an unpolluted estuary in the south-west Netherlands. The results are compared with data from a heavily polluted tidal flat in the Westerschelde in Belgium. We investigated whether this method could be used to detect stress in communities other than macrozoobenthos. As waders are very abundant on intertidal flats and are important predators of macrozoobenthos, combined abundance/biomass curves for waders from the seventeen study plots in the Oosterschelde are given to compare the community structure of prey and predator populations.

MATERIAL AND METHODS

Study areas

Slikken van Vianen (Oosterschelde)

The data were collected on the Slikken van Vianen, a tidal flat in the Oosterschelde, a major estuary in the south-west Netherlands. For details of the study area see Meire & Kuijken (1987). As there is no industrialization surrounding the estuary, there are no large harbours and the influx of fresh water is regulated, the area is virtually unpolluted. Salinity (*c.* 16 g Cl^- l^{-1}) and oxygen content (*c.* 9·03 mg l^{-1}) are high and constant, visibility is *c.* 1·7 m (Secchi disc), and nutrient loads and concentrations of heavy metals are low (0·16 μg Cd l^{-1}, 0·01 μg Hg, l^{-1}, 1·6 μg Cu l^{-1}, 1·7 μg Pb l^{-1}, 4·2 μg Zn l^{-1}, 1·7 μg Cr l^{-1}) (Anonymous 1986a). Data were collected on macrozoobenthos and waders from seventeen permanent plots on this tidal flat. The sediment in the plots consists of fine to very fine, well- to less-well-sorted sand with varying mud concentrations (1–20%). The tidal exposure time varies between *c.* 3 and 8 h.

Het Galgeschoor (Westerschelde)

Het Galgeschoor is a tidal flat in the Westerschelde near the Belgian–Dutch border and is in the α-mesohaline (5–10 g Cl l^{-1}) and most-polluted part of the estuary. Oxygen content (*c.* 1–2 mg l^{-1}) is low and nutrient loads and concentrations of heavy metals are high (2–5 μg Cd l^{-1}, 0·1–0·6 μg Hg l^{-1}, 15–40 μg Pb l^{-1}, 15–30 μg Cr l^{-1}; Anonymous 1986b). The sediment consists of very fine sand with high concentrations of mud. The sampling locations were in the lower part of the intertidal zone.

Macrozoobenthos sampling

On the Slikken van Vianen, five samples per plot were taken on 1 October 1984, with a core of 156 cm^2 to a depth of *c.* 40 cm. Plot 32 was sampled twelve times between May 1981 and October 1984; ten samples were taken on each occasion. Het Galgeschoor was sampled on 15 June 1987 with a core of 58 cm^2 also to a depth of *c.* 40 cm (twenty samples per plot). All samples were brought to the laboratory, where they were fixed with 40% formalin and later sieved on a 1-mm mesh sieve. Samples were stained with Rose Bengal (0·2 g l^{-1} formalin) and, after sorting, species were identified and the number of individuals was counted. Biomass (ash-free dry weight, AFDW) was determined after drying for 12 h at 105 °C and incinerating for 2 h at 550 °C. Oligochaeta and Nemertini were not identified.

Wader counts

The numbers and activity of birds in each plot at the Slikken van Vianen were noted every 30 min during most of a whole tidal cycle. In the first and last hour in which each plot was exposed, counts were made at least every 15 min, as bird numbers could change

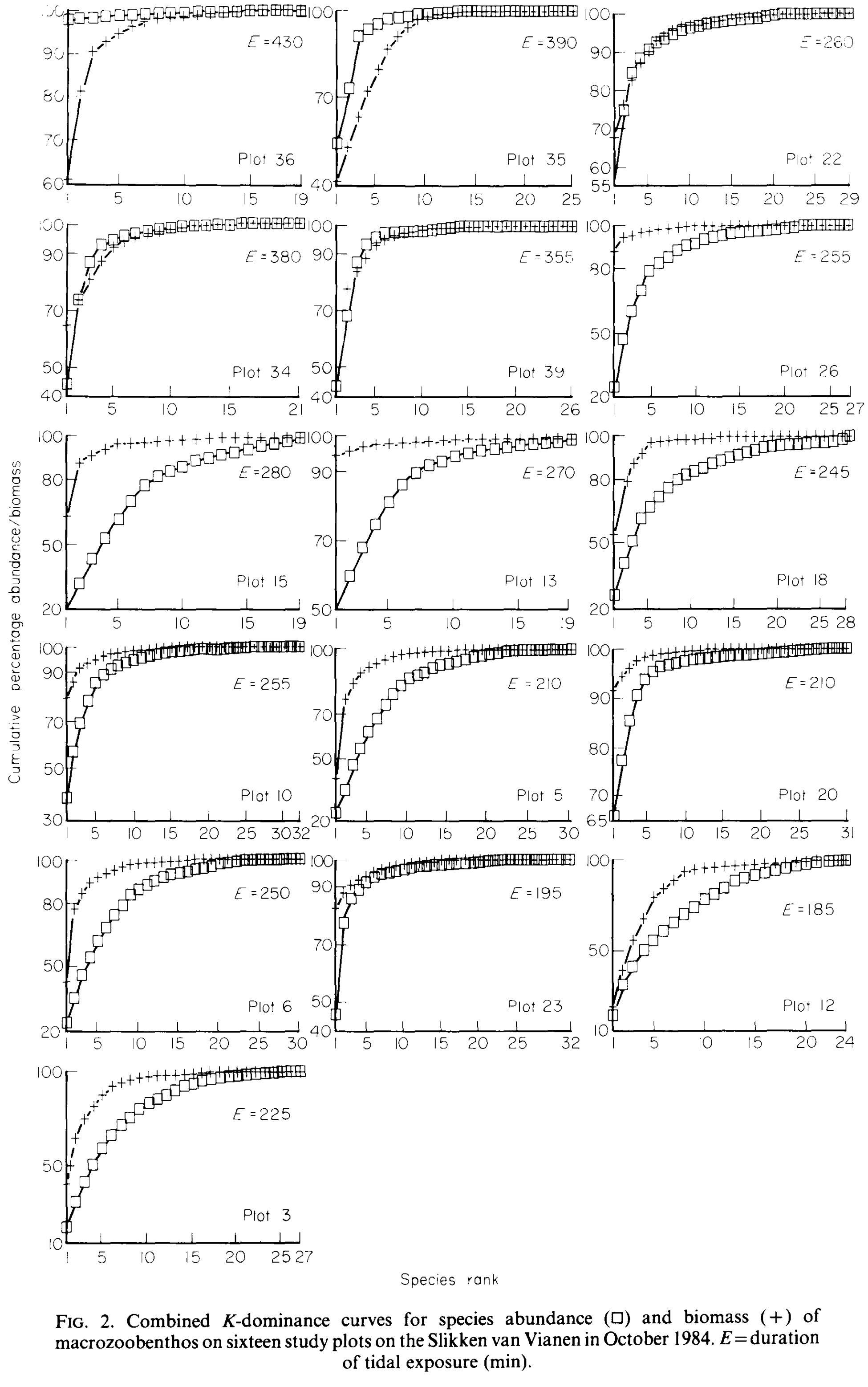

FIG. 2. Combined *K*-dominance curves for species abundance (□) and biomass (+) of macrozoobenthos on sixteen study plots on the Slikken van Vianen in October 1984. E = duration of tidal exposure (min).

quickly at that time. On average, twelve to fifteen counts were made per plot per tidal cycle; data for 12 days in August and September 1984 are used in this study. At this time, numbers of most species are highest (Meire & Kuijken 1987) and this time just preceded the macrozoobenthos sampling date. Based on these counts, the average population density per plot was calculated for each species, and converted to biomass by multiplying by the average weight of the species in the Oosterschelde at that time of the year (E. Marteyn, personal communication).

RESULTS

Unpolluted site: Slikken van Vianen

Macrozoobenthos

In total, fifty-four species (fourteen Mollusca, twenty-seven Polychaeta, eleven Crustacea and two Echinodermata) were found. The species composition corresponded with the *Macoma balthica* L. community of Petersen (1918) or the 'boreal shallow mud association' of Jones (1950), although complemented by such species as *Nephtys hombergii* Savigny, *Scoloplos armiger* O. F. Muller and *Anaitides mucosa* Oersted etc., which are restricted to more-saline areas. The various study plots represent the different benthic communities found on tidal flats (Meire & Kuijken 1984; Meire & Coosen 1986). These are mussel beds (plots 6, 10, 18, 20, 22, 23), low silt areas (plots 3, 5, 12, 26) or high silt areas (plots 34, 35, 39) and more-sandy sites low (plots 13, 15) or high in the intertidal zone (plots 36, 32).

Total population density of macrozoobenthos ranged between 500 and 75000 individuals m^{-2} and the biomass between 1 and 400 g AFDW m^{-2}. Mussel beds had the highest densities and biomass.

The combined abundance/biomass curves (ABC) of the macrofauna in the seventeen study plots are given in Fig. 2. Contrary to the previously published ABCs, the x-axis is not logarithmic. This is, however, equally appropriate (Warwick 1986). The plots are ranked according to decreasing tidal exposure time. Of all plots with an exposure time of 6 h or more, combined K-dominance curves for numbers and biomass indicated moderate or heavy stress. In all other plots (except plot 22), the biomass curve was well above the abundance curve, indicating an unstressed community. Plot 22 is on a commercial mussel bed and hence is regularly fished.

To assess any seasonal pattern or variation, the combined ABCs for twelve sampling dates of plot 32 are given in Fig. 3. This plot, high in the intertidal zone, is dominated by the following species: *Hydrobia ulvae* Pennant, *Cerastoderma edule* L., *Macoma balthica, Nereis diversicolor* O. F. Muller, *Nephtys hombergii, Scoloplos armiger* and *Arenicola marina* L. The density ranged between 5000 and 31000 individuals m^{-2} and the biomass between 6 and 27 g AFDW m^{-2}. All curves but one showed the same moderately to heavily stressed pattern.

Waders

Waders are important predators of macrozoobenthos. Sixteen species occur regularly on the Slikken van Vianen (see Meininger, Baptist & Slob 1984; Meire & Kuijken 1987). The commonest species are oystercatcher (*Haematopus ostralegus* L.), bar-tailed godwit (*Limosa lapponica* L.), dunlin (*Calidris alpina* L.) and curlew (*Numenius arquata* L.). Population densities show strong seasonal and tidal variations both within and between plots. They vary between < 1 to > 100 birds ha^{-1}. The combined ABCs of waders for the

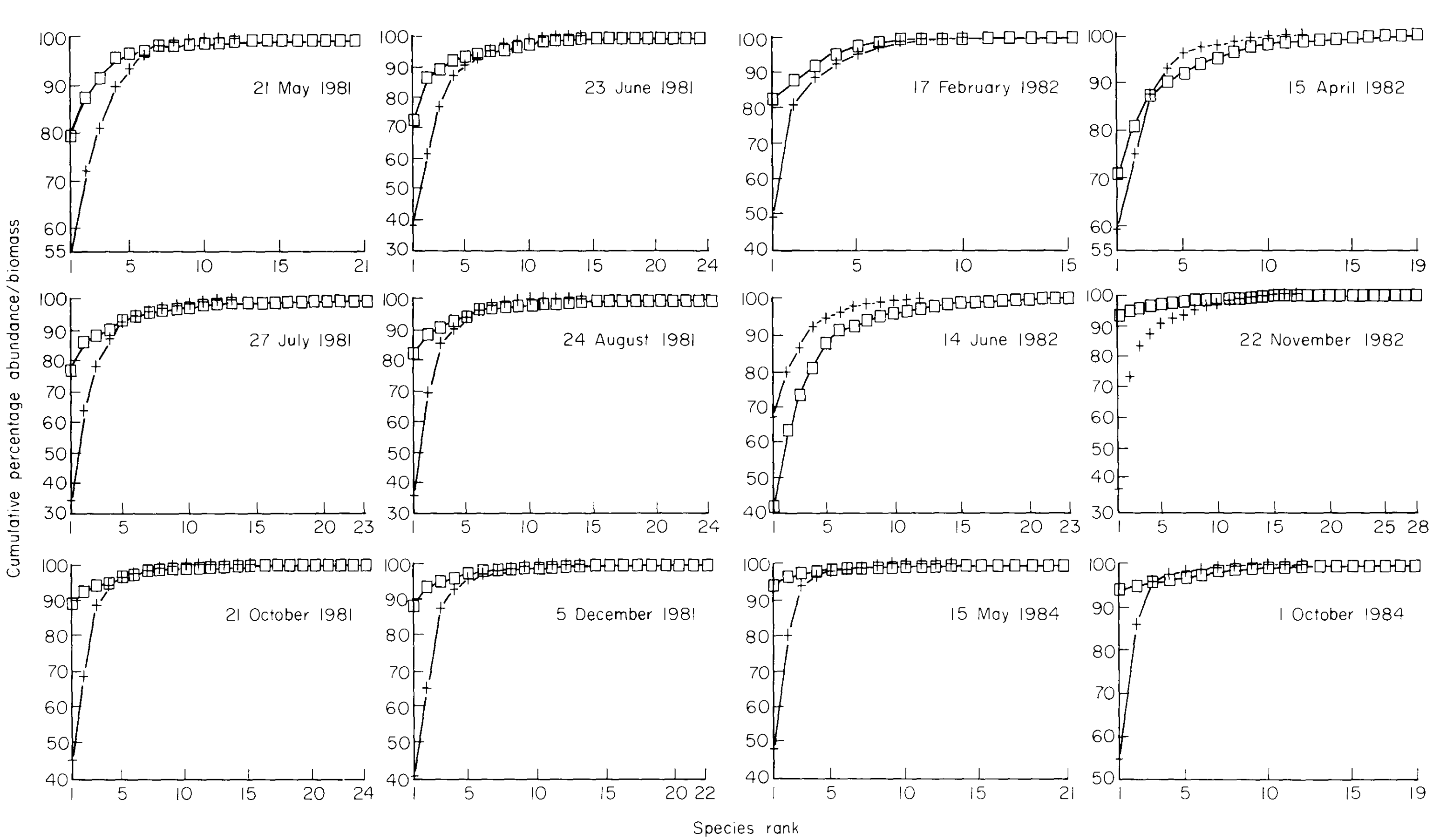

Fig. 3. Combined *K*-dominance curves for species abundance (□) and biomass (+) of macrozoobenthos in plot 32 on the Slikken van Vianen on twelve sampling dates in 1981–84.

TABLE 1. Number of macrozoobenthos species, tidal exposure time (min), biomass ($g\ m^{-2}$), abundance/biomass comparison (ABC) index and percentage of crosses (for explanation see text) for the seventeen study plots on the Slikken van Vianen (Oosterschelde, Netherlands) in 1981–84

Plot	Number of species	ABC index	Percentage of crosses	Exposure time	Biomass
3	28	11·06	0	225	42
5	31	10·25	0	210	70
6	32	4·71	0	250	157
10	33	4·95	0	255	255
12	25	9·39	0	185	5
13	21	10·03	0	270	23
15	21	17·73	0	280	8
18	29	12·28	0	245	74
20	32	2·78	0	210	435
22	30	0·71	16	260	139
23	33	2·37	0	195	179
26	28	9·95	0	255	215
32	12	−3·07	17	440	25
34	21	0·32	33	380	97
35	26	−4·69	46	390	64
36	20	−3·98	90	430	20
39	27	0·85	33	355	79

study plots discussed above, in the same sequence, are given in Fig. 4. For the two lowest plots (plots 12 and 23), with a tidal exposure of *c*. 3 h, the ABCs cross, as they do for plot 15, which has an average exposure of *c*. 5 h, indicating moderate stress. Plots 15 and 12 had the lowest benthos biomass (5 and 8 g AFDW m^{-2}, respectively, compared with 20–435 g AFDW m^{-2} for the other plots; see Table 1). All other plots showed an unstressed pattern.

Polluted site: Het Galgeschoor

Only nine macrozoobenthos species were found. Oligochaeta (*Tubifex costatus* Claparede) were most abundant, followed by *Polydora ligni* Webster, and *Capitella capitata* Fabricius. *Nereis diversicolor, Pygospio elegans* Claparede and *Macoma balthica* were rare. Population densities ranged between 400 and 10000 individuals m^{-2} and biomass between 0·009 and 0·97 g AFDW m^{-2}. In the mesohaline part of the estuary, species richness was always low. Compared with data from 1953 when the estuary was virtually unpolluted (Leloup & Konietzko 1956), no species had disappeared but population densities and biomass had decreased substantially. The ABCs are given in Fig. 5. Two of the three plots showed a moderately stressed and one plot showed an unstressed pattern and contained only two species.

A new index

When comparing data sets from many study sites, ABCs could be converted into an index. The surface between both curves could be taken as an index, but this is difficult as

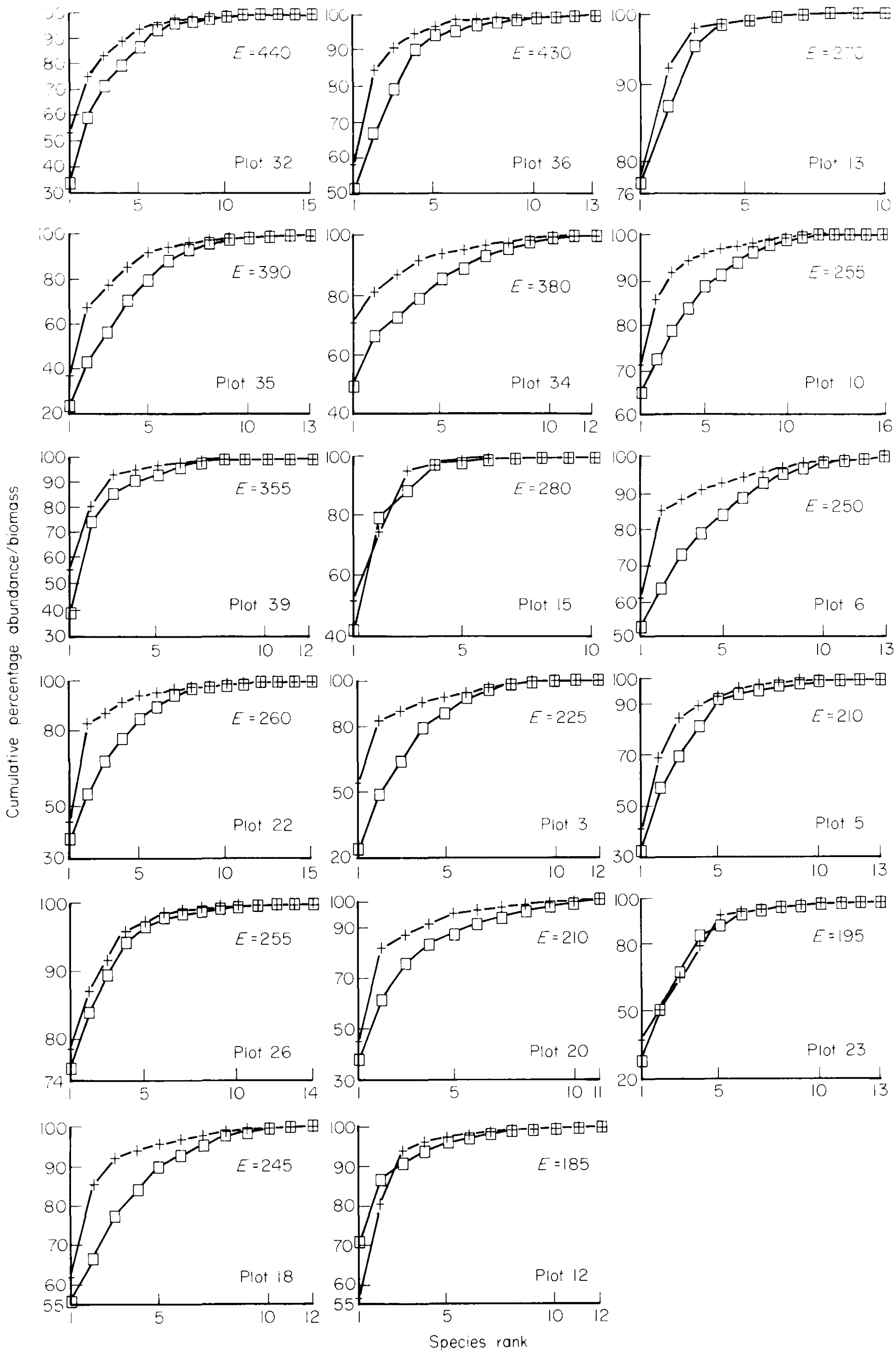

FIG. 4. Combined *K*-dominance curves for species abundance (□) and biomass (+) of waders on seventeen study plots on the Slikkken van Vianen in August and September 1984. *E* = duration of tidal exposure (min).

the number of species is different for each case. Therefore, we propose as an index the average of the difference between cumulative biomass and abundance:

$$\text{ABC index} = \frac{B_i - A_i}{N}$$

where B_i is the percentage dominance of species i (ranked from the highest to the lowest biomass) and A_i the percentage dominance of species i (ranked from the most to the least abundant species) and N is the total number of species.

This index is negative in heavily stressed, near zero in moderately stressed and positive in unstressed situations. The number of times the percentage dominance curve for abundance is higher than the percentage dominance curve for biomass can be totalled and expressed as a percentage of the total number of species (percentage crossings). The values of this index for macrozoobenthos of the seventeen study plots on the Slikken van Vianen are given in Table 1.

DISCUSSION

Accuracy of the data

Before an index or method for detecting pollution effects can be used properly, its behaviour under normal environmental conditions must be thoroughly known and the limitations of the data set on which the index is applied must be underlined. As the rationale of the method relies heavily on the abundance of small individuals, thought to be least pollution-sensitive, one can ask whether using a 1-mm mesh sieve, the standard in all macrozoobenthos studies (Gray 1981b), does not strongly influence the results, as many small individuals can be missed. We believe not, because (i) using a smaller sieve does not usually result in finding more, very small, macrobenthos species; and (ii) small stages of most of the occurring species are missed, hence including them will probably not alter the dominance pattern. Using a larger sieve or sieving and/or sorting the samples in the field could have a much more pronounced effect on the results, i.e. smaller polychaetes and oligochaetes would then be easily missed but not the smaller molluscs (*H. ulvae* and larvae of *C. edule and M. balthica*), causing a disproportionally high share of these species in the total density. The sampling effort (number and size of the samples) can affect the results the other way round. Small, very abundant species can be sampled accurately with few samples; the large individuals, dominating biomass, can easily be missed if too few samples are taken (Meire *et al.* 1989). The presence or absence of these few large individuals can, however, significantly change the results.

Stress

A precise definition of stress is required. Interesting discussions are found in several papers in Barrett & Rosenberg (1981). We define stress as perturbation applied to a system by a stressor which is foreign to that system or which may be natural to it but, in the instance concerned, is applied to excess (Barrett 1981). Pollution is an obvious stressor. Odum, Finn & Franz (1979) suggest the use of stress for unfavourable deflections from what is usual or expected and as a subsidy for favourable deflections in which the performance of the ecosystem is in some way improved. Lugo (1978) emphasized an important characteristic of stressed ecosystems, i.e. that energy expenditure is increased or potential energy is decreased. In any case, stress exerts an energy cost and interferes with the normal function of the system (Boesch & Rosenberg 1981). The concept of stress

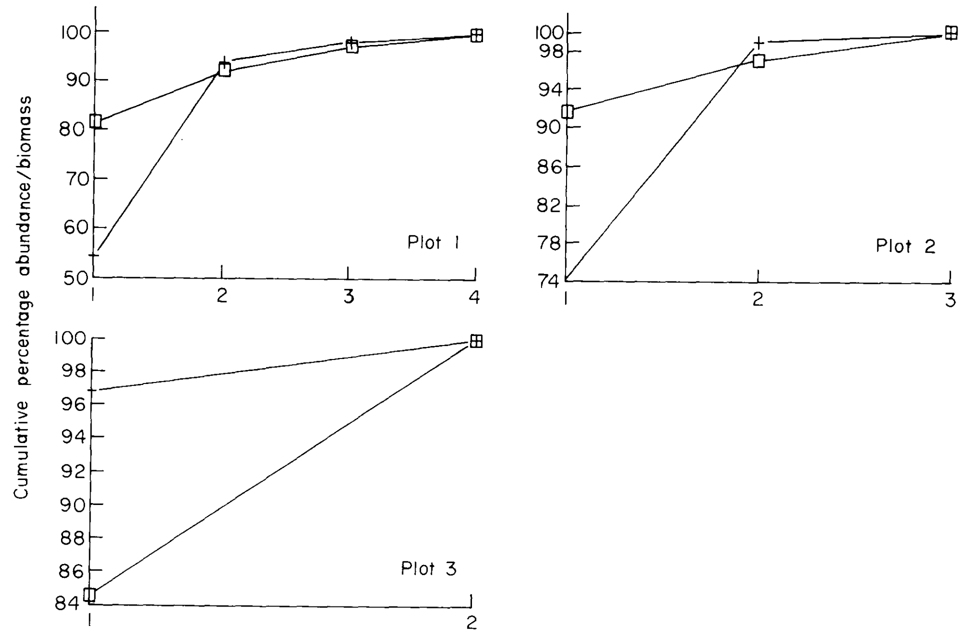

FIG. 5. Combined *K*-dominance curves for species abundance (□) and biomass (+) of macrozoobenthos on three study plots on Het Galgeschoor in June 1987.

generally refers to a specific agent of unusual quantity or quality, although it is recognized that stress also results from normal ecosystems, e.g. predation or competition (Auerbach 1981). The response of cells, organisms, populations and ecosystems to a variety of stressors may follow a common pattern (since it must be dealt with by existing pathways). While these definitions contribute towards an understanding of the concepts of stress, they provide no help in terms of measurement of some altered function (Ivanovici & Wiebe 1981). This is difficult without consideration of the different levels of organization, which include ecosystem, physiological and biochemical responses. Much research has concentrated on ecosystem responses, e.g. changes in community structure, as does the ABC index. In the following, we discuss the value of this ABC method for detecting stress in general, or pollution effects in particular.

The ABC method was proposed by Warwick (1986) for detecting pollution effects. It is based on sound ecological principles instead of on statistical properties such as the log-normal distribution, and the first data sets analysed supported the method (Warwick 1986). Warwick, Pearson & Ruswahyuni (1987) and Warwick & Ruswahyuni (1987) found, however, that when applied to other data sets the method is sensitive to all kinds of stress. This is to be expected, as the response of ecosystems is similar to both natural environmental stress and pollution-induced stress.

The data of intertidal sites, subjected to considerable physical disturbance (wave action, temperature, salinity, etc.) analysed by Warwick, Pearson & Ruswahyuni (1987) suggested an undisturbed or unstressed community pattern. This is partly supported by our data. Indeed, most plots of the unpolluted site, the Slikken van Vianen, conform to the unstressed pattern. Obviously, natural environmental stress factors also produce stressed patterns, as was found in some plots in the unpolluted study area. Indeed, plots higher in the intertidal zone, subject to more (climatic) stress, conform to the moderately or heavily stressed pattern. We also found a significant positive correlation between the ABC index and the exposure time of the plots ($r = -0{\cdot}7$; $P < 0{\cdot}01$). Plot 22, although rather low in the intertidal zone, showed moderate stress. This can be attributed to the fact that the mussel bed, on which this plot is situated, is regularly fished and the benthic community is not able to reach a stable situation. Hence the method seems indeed to detect all kinds of disturbance in the community.

If the higher parts of the intertidal zone are nursery grounds for some species, it might seem strange that these are stressed areas. First, many larvae may be transported passively to these areas as the sedimentation here is normally high (low-current velocities). It is known that *A. marina* larvae settle on the higher parts but further research indicated also sublittoral settling locations (Farke & Berghuis 1979). It is also known that many species actively leave these areas (e.g. Beukema & De Vlas 1989), indicating unfavourable conditions.

Effect of seasonal patterns on the index

It is well known that benthos populations can vary enormously between seasons. In winter, overall density and biomass are at a minimum. In spring, many species reproduce, resulting in high population densities (of mainly small individuals) and in autumn normally the highest biomass is reached (Beukema 1983; Wolff & de Wolf 1976). These changes seem not to influence the ABC plots as indicated by the analysis of twelve data sets of plot 32. All but one indicated more or less stress. In June 1982, when the curves showed an unstressed pattern, the density of *H. ulvae* was exceptionally low and the biomass of *A. marina* rather high. Indeed the density of *H. ulvae* represents 71–94% of the overall density, and its biomass only 15–50% of the overall biomass, causing stressed curves each time. In June 1982, it represented only 41% of the density and 5% of the biomass. The reason for this is unclear but it could emphasize the importance of sampling accuracy, since this species is aggregated (Meire *et al.* 1989) and hence difficult to sample accurately.

The ABC method as an indicator of pollution

These results show, on the one hand, that the sensitivity of the method towards stress is very good but, on the other hand, that it is very important to know the community structure under normal conditions. Indeed, only changes with regard to this can be interpreted because, according to the data presented, stressed patterns can occur under normal conditions. Further, if the normal pattern already indicates stress we can question whether any further changes to the community structure, due to pollution, could be detected. This reduces the applicability of the method for detecting pollution, especially in estuarine areas. In the more brackish part of the estuary, natural environmental stress increases (salinity fluctuations, turbidity, etc.) and one would expect, from the present data at least, crossing curves in the normal situation. A further complication arises if only a few species are present, as illustrated by the data on Het Galgeschoor. No plot showed the severely stressed pattern, one plot even gave an undisturbed pattern, although the area is very heavily polluted and in several parts of the intertidal zone macrofauna populations have disappeared completely. When there are very few species the numerically dominant species will also dominate the biomass, as the few individuals of the one or two other species represent only a small part of both density and biomass. The success of the method for detecting pollution effects is therefore dependent on the availability of a reference set and on an adequate sampling programme. The method may be more successful as an index of pollution in the more diverse marine sublittoral areas; it may be more appropriate as an index of environmental stress, although natural stress factors can occur here as well.

The ABC method as an index of stress

The structure of the benthic community is not immediately reflected in the structure of the wader community. This can be expected, as stress for birds does not necessarily come from numerically dominant but small species (e.g. *H. ulvae*) but from the total prey biomass available to the birds and its exposure time, both variables relating immediately to the feeding conditions of the predators. This is well reflected in the results and fits the definition that in a stressed situation the energy expenditure is higher or the potential energy is lower. Indeed, at low prey densities, the return of foraging is low and when the available foraging time is short the total amount of food collected is also small. A long exposure time is advantageous to birds, given that the available biomass is not too small (no correlation between exposure time and biomass was found).

We strongly advise the application of this method to as diverse as possible a range of data sets to further evaluate its applicability as an indicator of environmental stress. Its use as a method for detecting pollution effects without prior knowledge of the site is certainly restricted and needs further investigation.

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