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A new method for detecting pollution effects on marine macrobenthic communities

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Abstract

A method is described by which the pollution status of a marine macrobenthic community may be assessed without reference to a temporal or spatial series of control samples. Theoretical considerations suggest that the distribution of numbers of individuals among species should behave differently from the distribution of biomass among species when influenced by pollution-induced disturbance. Combined *k*-dominance plots for species biomass and numbers take three possible forms representing unpolluted, moderately polluted and grossly polluted conditions, one curve acting as an "internal control" against which the other can be compared. Field data from unpolluted communities and from a well documented temporal pollution gradient support the model, but further empirical testing is required.

Introduction

Benthic community structure is being widely used in programmes monitoring pollution effects, but often with equivocal results. McIntyre (1984) goes as far as to suggest that "the failure of the popular benthic community monitoring approach to deliver the goods in some cases" is partly responsible for the general disillusionment with the monitoring of pollution effects as a whole. It is not that ecologists do not have an intuitive understanding of the effects of pollution on benthic communities, but it has been difficult to find adequate ways to measure these effects in view of the natural variability of community structure in both time and space.

It is generally accepted that the theoretical basis of pollution-induced disturbance on benthic and other communities can be explained in terms of the intermediate disturbance hypothesis of Connell (1978) and the general hypothesis of species diversity of Huston (1979). Under "stable" conditions of infrequent disturbance, interspecific competition will result in competitive displacement that tends towards a relatively low diversity equilibrium. The competitive dominants are traditionally regarded as *K*-selected or conservative species with the attributes of large body size, long lifespan, and a population size which is fairly constant in time and close to the carrying capacity of the environment (Pianka, 1970). It might be noted here, that in marine benthic communities these species are rarely dominant numerically, but are dominant in terms of biomass which is more closely related to their share of available resources (food and space). Also present in these communities are smaller *r*-selected or opportunistic species with a short lifespan and highly variable population size which is not in equilibrium with available resources. In benthic communities these are often small annelid worms which are usually numerically dominant, and do not represent a large proportion of the community biomass. With pollution perturbation of a community, the frequency of disturbance is usually faster than its rate of recovery. Hence, a competitive equilibrium is prevented and diversity increases. Conservative species are less favoured and are the first casualties, while opportunistic species are more favoured and often become the biomass dominants as well as the numerical dominants. A further increase in disturbance starts to reduce the numbers of the less resilient opportunists, so that diversity again begins to decrease.

The problem of determining the position occupied by a particular benthic community on this sliding scale of pollution effects is largely due to the lack of adequate controls. Almost any measure of the relative abundances of species will be of some use in detecting the effects of pollution if a sufficient historical data set is available for that site, or if extensive comparisons can be made with physically comparable sites elsewhere (although in the latter case strict comparability of sites is a problem). Benthic ecologists rarely enjoy the luxury of such data, and are more often than not asked to base their assessment on a single series of samples at a given location. In such cases reliance must be placed on "internal controls", either comparing an aspect of community structure with some theoretical expectation or comparing the performance of one component of the community, which has been shown empirically to be more sensitive to pollution, with another less sensitive component. Neither of these approaches has gained widespread practical acceptance. An example of the former is the departure of the distribution of numbers of individuals among species from the log-normal model (Gray, 1979, 1981; Gray and Mirza, 1979), where doubts have been expressed as to whether undisturbed benthic communities conform to this model empirically (Sanders, 1968; Lambshead and Platt, 1985) or on theoretical grounds (Hughes, 1985). An example of the latter is the nematode:copepod (N:C) ratio (Raffaelli and Mason, 1981), which assumes that since copepods are in general more sensitive to the effects of pollution than nematodes, this will be reflected in the simple ratio of their abundances. However, the response of the N:C ratio to pollution has proved to be unpredictable (e.g. Lambshead, 1984; Gee *et al.,* 1985). The latter authors suggest that the differential responses in the distributions of species abundance between these two taxa might be a better indication of pollution, but since taxonomic expertise in these two meiofaunal groups is lacking in most laboratories, this is unlikely to be of widespread practical use.

A better approach would be to define structural properties of the same faunal assemblage that respond differently to the effects of pollution. Below, I suggest a possible method based on the expectation that, according to the scenario of pollution effects outlined above, the distribution of numbers of individuals among species in macrobenthic communities should behave differently from the distribution of biomass.

A conceptual model

Under stable unpolluted conditions, where the benthic community is approaching equilibrium, the biomass will become increasingly dominated by one or a few large species, each represented by rather few individuals, which are in equilibrium with the available resources. The numerical dominants are, however, smaller species which are out of equilibrium with resources and with a strong stochastic element in the determination of their abundance. Under such circumstances the distribution of numbers of individuals among species will be more even than the distribution of biomass, the latter showing strong dominance. It is not possible to calculate diversity indices based on biomass units for comparison with those based on species abundances, but we can make comparative plots of the relative proportions of biomass and numbers attributable to each species. Here I will use *k*-dominance curves (Lambshead *et al.,* 1983) in which the species are ranked in order of importance on the *x*-axis (logarithmic scale) with percentage dominance on the *y*-axis (cumulative scale), but other plotting methods might be equally appropriate.

The expected curves for unpolluted communities are shown in Fig. 1A, with the biomass curve above the numbers curve throughout its entire length, indicating higher "numbers diversity" than "biomass diversity". Under moderate pollution, the large competitive dominants are eliminated and the inequality in size between the numerical and biomass dominants is reduced so that we have no reason to expect a difference between the biomass and numbers curves, which should be close together and may cross each other one or more times (Fig. 1B). As pollution becomes more severe, benthic communities become increasingly dominated numerically by one or a few very small species (usually annelids such as *Capitella* spp. or oligochaetes), and few larger species are present although these will contribute proportionally more to the total community biomass in relation to their abundance than will the small numerical dominants. In such a case we would expect plots as in Fig. 1C, where the numbers curve is above the biomass curve throughout its length, showing higher "biomass diversity" than "numbers diversity". These three conditions, unpolluted, moderately

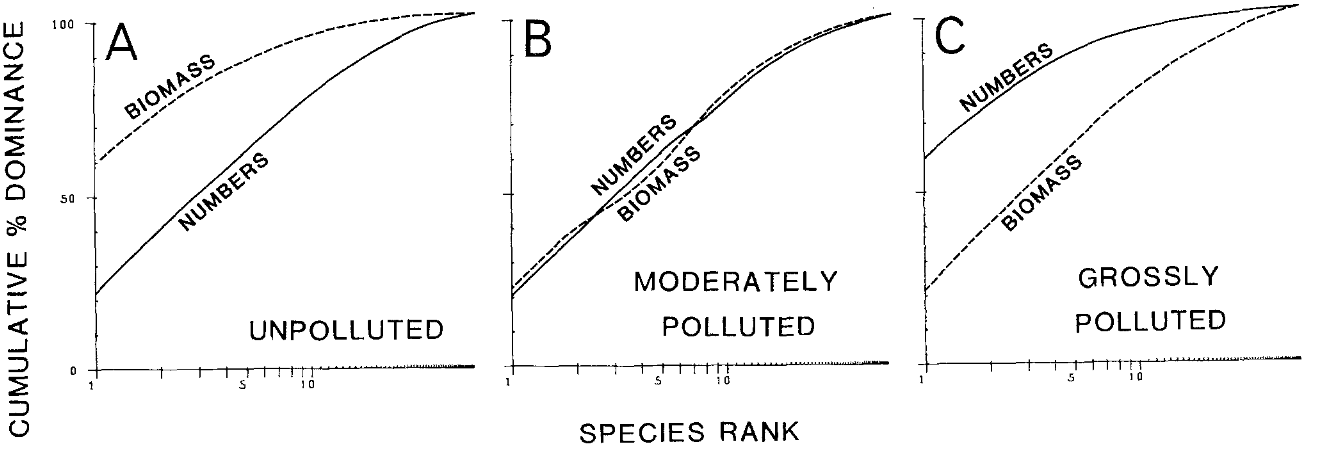

Fig. 1. Hypothetical *k*-dominance curves for species biomass and numbers, showing unpolluted, moderately polluted and grossly polluted conditions

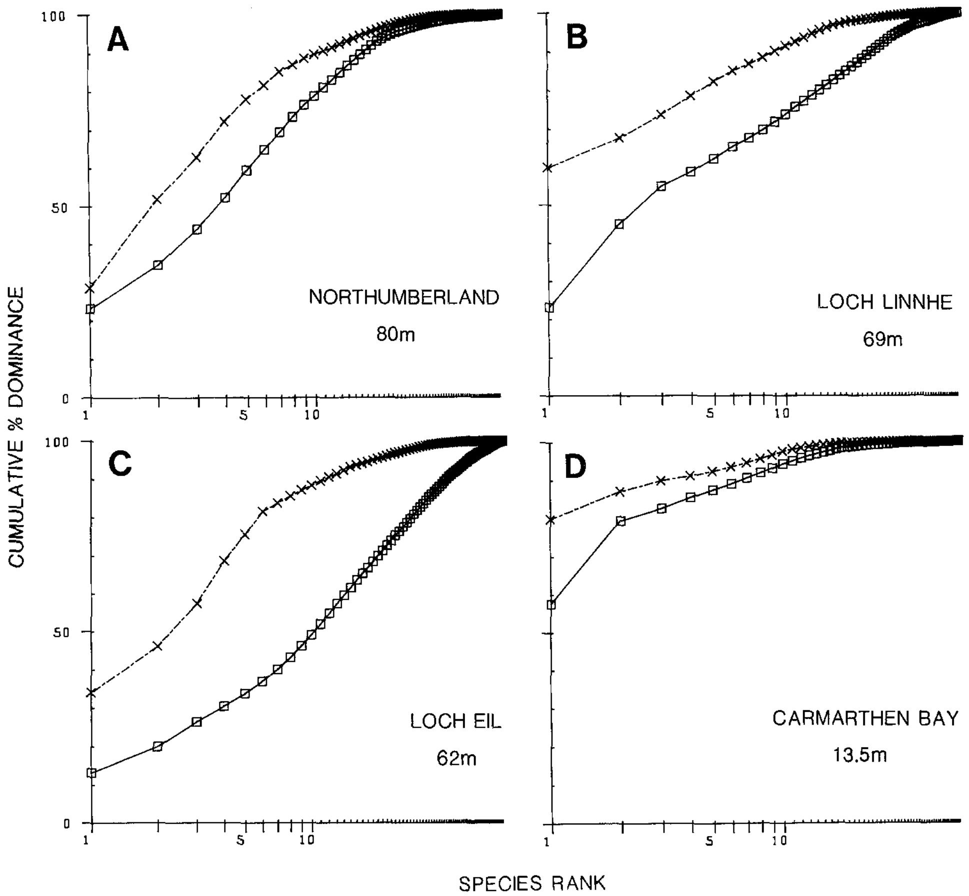

Fig. 2. Combined *k*-dominance curves for species biomass (crosses and dashed lines) and numbers (squares and continuous lines) from field data on four unpolluted macrobenthic communities

polluted and grossly polluted, should be recognisable in a community without reference to control samples in time or space. However, in the unpolluted condition there is a probable drawback to plotting accurate biomass curves, as the biomass dominants are represented by few individuals which will be liable to a higher sampling error than the numerical dominants. Adequate replication of sampling is therefore a prerequisite for this method.

Field data

In Fig. 2, species biomass and numbers curves are plotted from published data on four unpolluted macrobenthic communities from a variety of depths and sediment types: a silty station at 80 m off the coast of Northumberland (Buchanan and Warwick, 1974), a silty-sand station at 69 m in Loch Linnhe (Station 34) sampled in spring 1963 (Pearson, 1975), a mixed sand and silt station at 62 m in Loch Eil (Station 2), sampled at the same time (same literature source), and a sand station at 13.5 m in Carmarthen Bay (Warwick *et al.*, 1978). Although the absolute values of dominance differ markedly between these communities, each conforms to the model in that the biomass curve is above the numbers curve throughout its entire length.

Published data on species biomass and numbers for known temporal or spatial pollution gradients are difficult to find. Like others before me, I have therefore relied on Pearson's (1975) data for Loch Linnhe and Loch Eil. In that publication, thanks to far-sighted editorial policy, the raw data for two stations, based on five grab samples taken in spring over the period 1963–1973, are given in full. Effluent discharge from a pulp-mill began in March 1966 and was maintained at 10 to 14 tonnes per day from 1967–1969. An increase in effluent output began in 1969 and reached a maximum in late 1970 (more than 30 tonnes per day), but from the autumn of 1971 was again reduced to 10–14 tonnes per day. At Station 34 in Loch Linnhe, species diversity, *H*(*s*), had begun to decrease by 1968 and showed a further marked decrease after 1970, reaching its lowest in 1972, but returned again to pre-1968 levels in 1973, indicating an almost complete recovery (Fig. 3 A). This pattern was also evident from rarefaction curves plotted for each year. In Fig. 3 B–L, I have plotted species biomass and numbers curves for all eleven years to see whether the pollution status for any one year could have been assessed in isolation without reference to the historical data. The match with expected theory is almost perfect in this case. The non-polluted state is indicated between 1963 and 1967. Between 1968 and 1970 the plots fulfill the moderately polluted criteria. In 1971 and 1972 the plots indicate gross pollution (most extreme in 1972), and in 1973 there is a return to the non-polluted condition.

At Station 2 in Loch Eil (Fig. 4) the pattern is similar although the match with historical data is less than

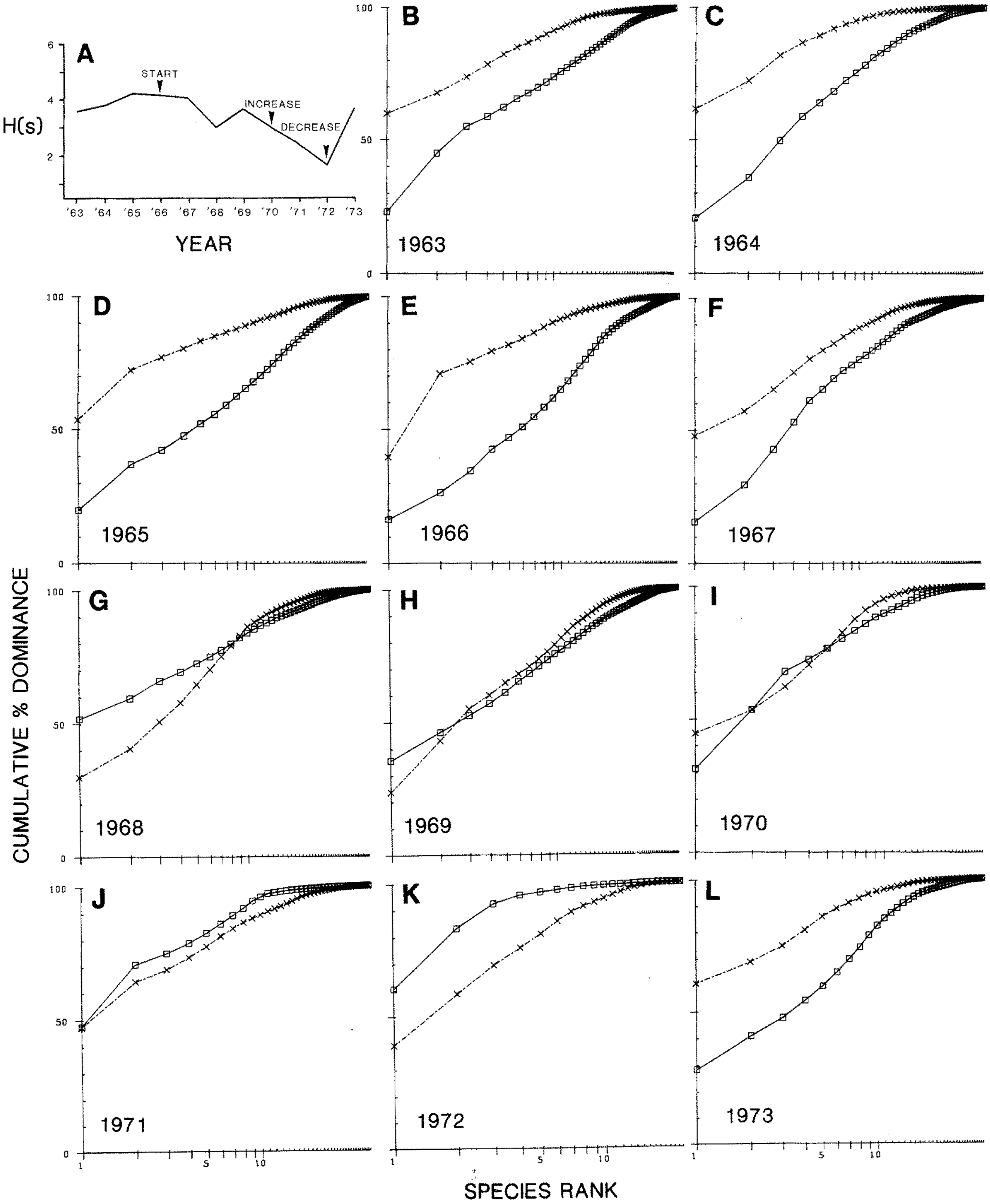

Fig. 3. (A) Species diversity in Loch Linnhe, 1963–1973, showing timing of pollution events (from Pearson, 1975); (B)–(L) combined *k*-dominance curves for biomass (crosses and dashed lines) and numbers (squares and continuous lines) for the individual years

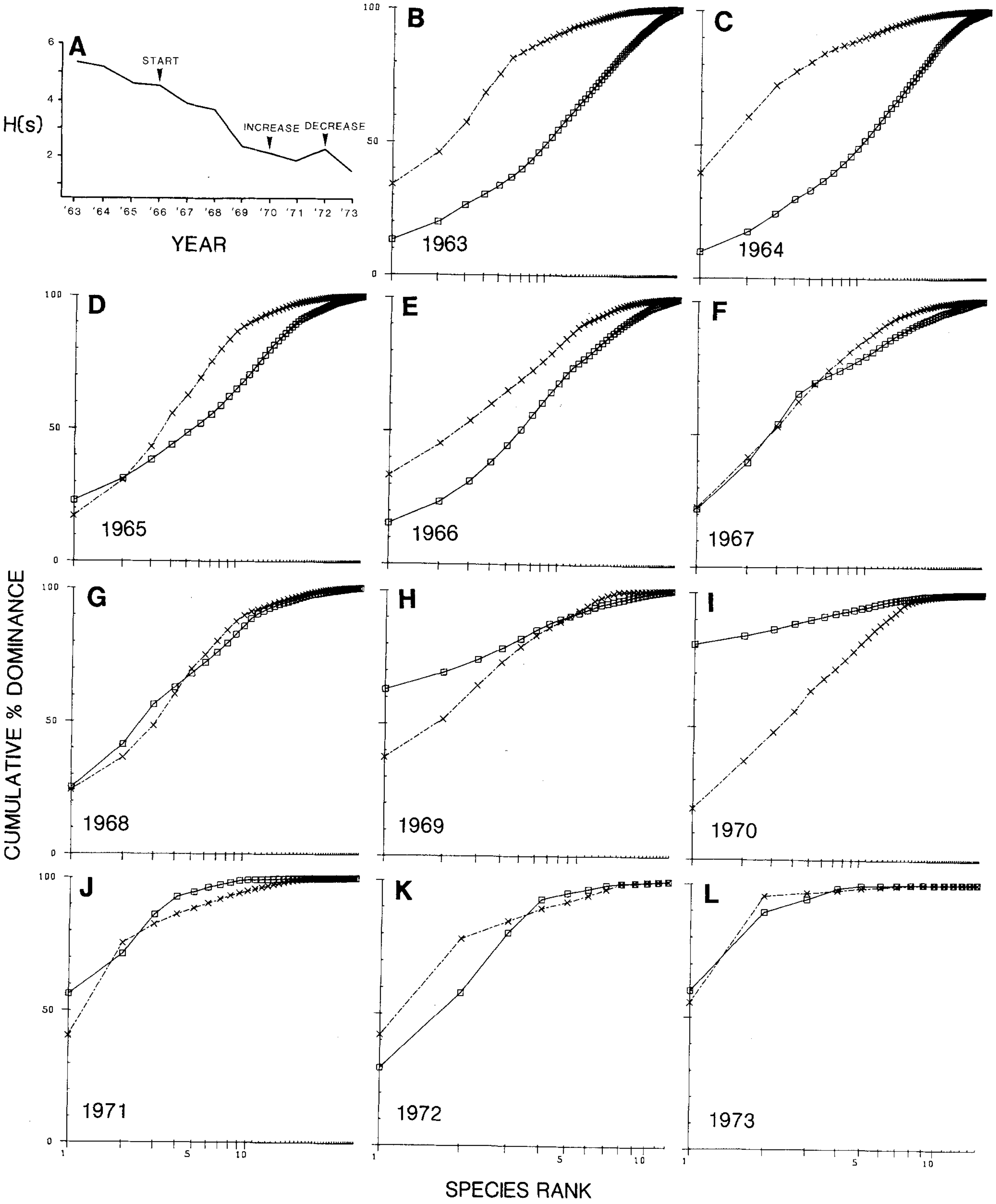

Fig. 4. Species diversity in Loch Eil, 1963–1973. Further details as in legend to Fig. 3

perfect: specifically, in 1965 the biomass and numbers curves cross. This may have been due to sampling error. Both the biomass dominants in 1964, the bivalves *Astarte elliptica* (36 per 0.5 m^2) and *Venerupis decussata* (93 per 0.5 m^2), were collected in much smaller numbers (7 and 8 per 0.5 m^2, respectively) in the 1965 grab samples. However, the sediment at this station is heterogeneous, with a patchy distribution of naturally occurring terrigenous leaf litter and twigs (Pearson, 1972), and since there was also a drop in species diversity from 1964 to 1965 (Fig. 4A), it may be that a particularly dense patch of debris was sampled on this occasion. Response to the onset of pollution was detected a year earlier than in Loch Linnhe, as indicated both by the drop in species diversity between 1966 and 1967 and the moderately polluted biomass/numbers plot in 1967 (Fig. 4F). The grossly polluted biomass/numbers plot also appeared earlier, immediately after the increased effluent discharge, and from 1971–1973 the moderately polluted condition prevailed, with no improvement in 1973, as confirmed by the historical diversity data (Fig. 4A).

Conclusion

In only one case out of 22 would a comparison of species biomass and numbers curves for the Loch Linnhe and Loch Eil data have given a false impression of the pollution status of the benthic community at that time. Since these data are all based on only five 0.1 m^2 Van Veen grab samples, it is quite likely that this one exception resulted from a failure to collect a sufficiently representative sample of the rare biomass dominants. Ten such samples should perhaps be the working minimum.

I offer this method as one which I believe is soundly based on ecological principles but is severely deficient in empirical testing. Since most benthic monitoring programmes involve the sorting of macrofauna into species and counting them, determination of the biomass of each species (whether wet or dry) is only a small extra step. I hope, therefore, that more data sets to test the practicality of this method will soon emerge. It seems unlikely that such a method will be applicable to the meiobenthos, as there is no obvious size difference between conservative and opportunistic species: indeed the dominant species under polluted conditions are often some of the largest (e.g. oncholaimid nematodes and tisbid copepods).

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