Marine Pollution Bulletin, Volume 24, No. 1, pp. 21–26, 1992.
Printed in Great Britain.
Marine Pollution Bulletin Volume 24 No 1, pp 21-26 1992

The Effect of Sewage and Natural Seasonal Disturbances on Benthic Macrofaunal Communities in Fitzroy Bay, Wellington, New Zealand

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Benthic macrofauna were sampled on 6 occasions over a 14 month period from Fitzroy Bay, Wellington, New Zealand to assess the effects of an existing sewage effluent discharge on these organisms and to determine natural seasonal fluctuations in community structure within the vicinity of a proposed new ocean outfall. Results of Abundance/Biomass Comparison (ABC), Cluster, and Multi-Dimensional Scaling analyses indicated that only benthic communities within a 500 m radius of the present sewage outfall were affected by the discharge. However, seasonal data indicated that most sites within Fitzroy Bay were disturbed on at least one occasion during the sampling period. The data suggest that ABC analyses should be conducted over several seasons to provide a more accurate assessment of pollution-induced and/or natural physical and biological disturbance.

Fitzroy Bay is located on the eastern side of the entrance to Wellington Harbour, at the southern end of the North Island of New Zealand (Fig. 1). The area receives an average of 50 MLD (million l day^{-1}) of wastewater discharge from 120 000 residents and from light industrial sources in the Hutt Valley region of greater Wellington City. This wastewater is initially passed through a milliscreen treatment plant before being discharged at the shoreline through the Bluff Point Sewer Outfall near Pencarrow Head (Fig. 1). The effluent field flows predominantly to the southeast across Fitzroy Bay towards Baring Head for approximately 80% of the year (Steven *et al.*, 1981).

Concern over the environmental effects of continued shoreline discharge of milliscreened and untreated sewage into the waters along Wellington's south coast has become a major environmental and political issue. Local authorities have explored several possible disposal options which would meet proposed new water classification criteria. The preferred option involves the discharge of milliscreened and advanced primary or secondary treated effluent through a long ocean outfall about 2 km offshore in Fitzroy Bay (Fig. 1).

Sedimentological and biological data are available for nearshore waters along the coastline of Fitzroy Bay and the entrance to Wellington Harbour (Carter, 1977; Matthews, 1980; Anderlini, 1988, 1989). However, no data existed before 1989 on benthic sediments and macrofauna occurring within the vicinity of the proposed outfall discharge point. Therefore, a preliminary investigation of offshore benthic macrofauna and sediments was conducted (Anderlini & Wear, 1989). The results of this preliminary study described the types of sediment and benthic communities which exist in Fitzroy Bay, but did not examine seasonal variability within the likely radius of outfall influence.

Seasonal data are needed to understand the dynamics of benthic community structure and are essential when assessing the potential biological effects of an ocean outfall discharge. Knowledge of natural background variability in benthic populations is also essential for designing an appropriate and cost effective long term monitoring programme sensitive enough to detect any future perturbations or changes directly attributable to the construction and operation of a new outfall rather than to natural variability.

Recently, Warwick (1986) and Warwick *et al.* (1987) proposed a new method for detecting disturbances in benthic community structure which appears to be both robust and sensitive, and provides a direct assessment of the status of a particular community. The method is known as the Abundance/Biomass Comparison (ABC) and employs *k*-dominance curves (Lambshead *et al.*, 1983) in which species are ranked in descending order of both abundance and biomass on the x-axis (logarithmic scale) with percentage dominance on the y-axis (cumulative scale). Two curves for numbers and biomass are plotted separately on the same graph, and Warwick has shown that the relationship between the

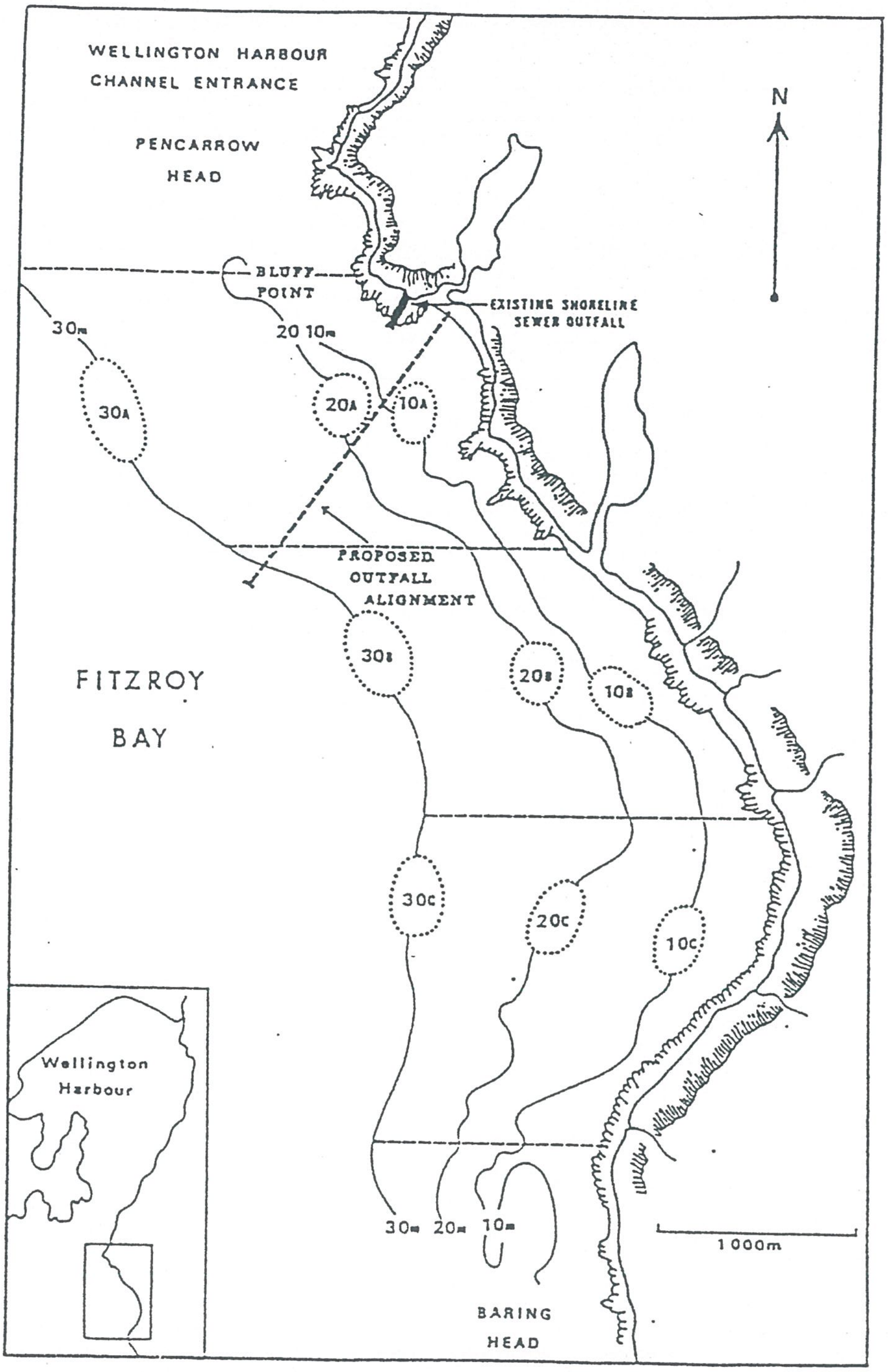

Fig. 1 Map of Fitzroy Bay showing location of collection sites (10A–30C) and existing and proposed sewage outfalls.

two curves can indicate whether the community structure is stable or subject to pollution induced or natural disturbance.

The expected curves for stable unpolluted conditions and their relationship to each other are shown in Fig. 2A. Here, the biomass curve lies above the numbers curve over its entire length, and the community is dominated by one or a few species, each represented by rather few and often large individuals. Under conditions of moderate pollution or disturbance, the large competitive dominants are greatly reduced, and the inequality in size between the numerical and biomass dominants is reduced so that the curves lie close together and may cross each other one or more times (Fig. 2B). As pollution becomes more severe, benthic communities become increasingly dominated numerically by one or more very small *r*-selected or opportunistic species (usually annelids), and the very few larger species present will contribute proportionally more to the total community biomass in relation to their numerical abundance than will the smaller numerical dominants. In such a case the expected plots would be similar to Fig. 2C in which the numbers curve lies above the biomass curve over its entire length and 'biomass diversity' exceeds 'numbers diversity' (Warwick, 1986). The community is thus greatly stressed or disturbed.

The method was tested, along with other currently accepted measures of community structure, at a recent experts meeting in Norway and proved very successful in identifying pollution-induced disturbances in benthic

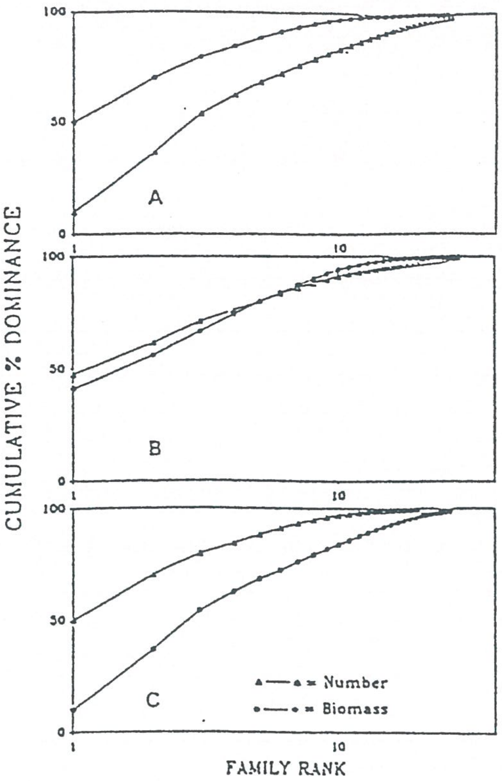

Fig. 2 Hypothetical k-dominance curves for species biomass and numbers showing unpolluted (A), moderately polluted (B), and grossly polluted (C) conditions (after Warwick, 1986).

macrofaunal structure along a known pollution gradient (Gray *et al.*, 1988). Warwick (1988), has also shown that benthic community data can be aggregated to the family level of taxonomic identification without loss of information.

Beukema (1988) questioned whether the ABC method was appropriate for assessing the pollution status of tidal flat communities, but Ritz *et al.* (1989) have shown that the method is a sensitive indicator of the effects of organic enrichment on macrobenthic communities. The ABC method was also used by Austen *et al.* (1989) to examine macrobenthic community structure along a pollution gradient in southern Portugal. The results of their investigation indicated that macrobenthos appeared to be affected by sewage enrichment in the vicinity of a sewage outfall during winter but were disturbed throughout the area in summer.

In the present investigation, the ABC method was used to assess the impact of an existing sewage discharge on benthic macrofaunal communities in Fitzroy Bay and to examine natural seasonal variation in these populations so that possible changes related to the construction and operation of a long ocean outfall discharge could be separately identified.

Materials and Methods

Benthic Sediment Collections

The sampling regime employed during this study was selected on the basis of the results of a preliminary investigation (Anderlini & Wear, 1989). The sampling area was divided into three zones of approximately equal area and one station was established along each of the 10, 20, and 30 m depth contours in each zone (Fig. 1). Benthic sediment samples were collected from these nine stations on six occasions every two months between January 1989 and February 1990.

During each collection five replicate samples of at least 5 l volume were collected from each station to ensure the collection of a sufficient number of organisms for biological analyses and to ensure collection of species which occur rarely. All samples were obtained using a 0.1 m^2 stainless steel, Van Veen grab sampler. Each grab sample was emptied into a clean plastic container and excess water sieved through a 0.5 mm mesh screen to avoid loss of organisms. Samples were then transferred to plastic bags for transport to the laboratory.

Individual sediment samples were sieved through a 1.0 mm mesh screen to separate benthic macrofauna from the sediment. The collected fauna was then transferred to jars, fixed in 10% buffered formalin and identified to family level.

Sample Analyses

The relatively low number of macrofaunal animals present within the study area made it more appropriate to combine the data from replicate samples. Therefore, total abundance and biomass data from replicate samples from each site and collection were used in the ABC analyses. The means and standard deviations of the cumulative percentages of abundance/biomass values for all six collections were determined and plotted for each site. ABC plots were also constructed for each collection and site. However, these data were reduced to two summary statistics which describe the configuration and relative distance between the abundance and biomass curves in ABC plots.

The first statistic involves summing the differences between the ranked cumulative percentages of numbers and biomass values, S(N−B), which describes the mutual position of the N and B plots (Beukema, 1988). In this statistic, negative values indicate an unstressed community structure, whereas positive values reflect a disturbed community.

The other summary statistic used, the Shannon–Wiener Evenness Proportion (SEP), recommended by MacManus & Pauly (1990), is based on the Shannon–Wiener diversity index. SEP values greater than 1.0 indicate a disturbed community while values less than 1.0 are indicative of stable communities.

The combined abundance data from all collections were also tested by two multivariate measures of community structure in order to compare the results of these methods with the results of ABC analyses. Untransformed abundance data were subjected to agglomerative, group-average linked, Cluster analyses and non-metric, Multi-Dimensional Scaling (MDS) analyses using Pearson correlation coefficients.

Results and Discussion

Biological analyses identified 63 benthic macrofaunal families, of which 15 were numerically dominant. Most families were represented by only a single species and the number of individuals within each species was

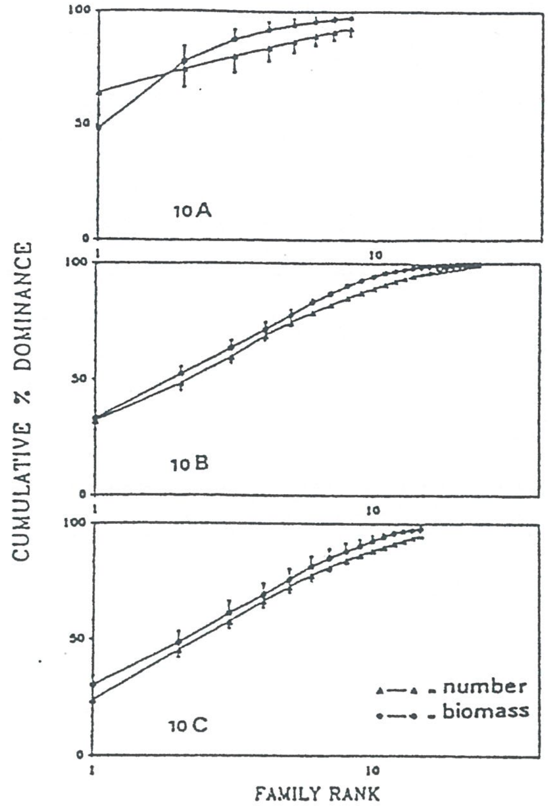

Fig. 3 ABC plots of total abundance and biomass data for Sites 10A–10C. Curves based on means and standard deviations of data from six collection periods.

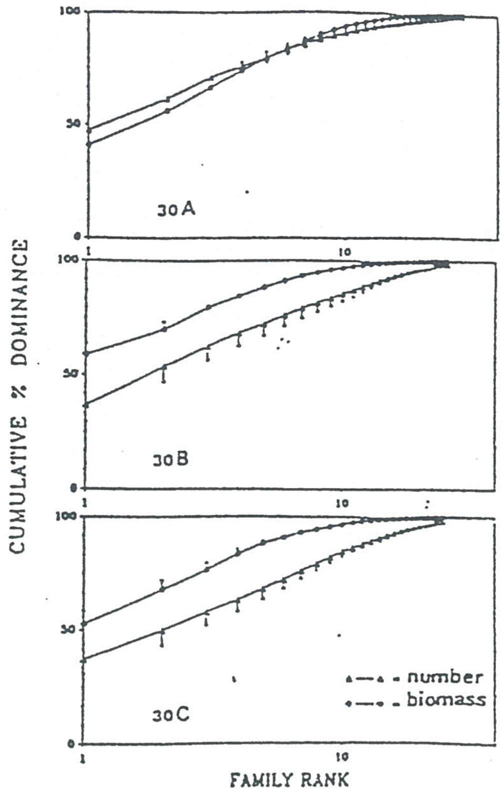

Fig. 5 ABC plots of total abundance and biomass data for Sites 30A–30C. Curves based on means and standard deviations of data from six collection periods.

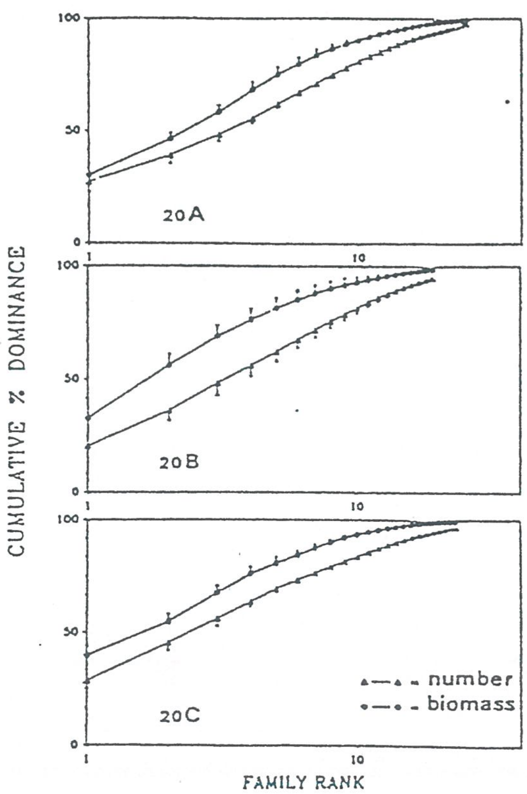

Fig. 4 ABC plots of total abundance and biomass data for Sites 20A–20C. Curves based on means and standard deviations of data from six collection periods.

low throughout the study period. The most common families were polychaetes—primarily nephtyids, glycerids, cirratulids, sabellids, and spionids, which were the numerical dominants at most sites. Molluscs were poorly represented and amphipods were the most

TABLE 1

Results of two summary statistics of ABC data, S(N−B) after Beukema (1988) and SEP after MacManus & Pauly (1990). Values are means and one standard deviation of cumulative percentage abundance/biomass data from 6 collections.

Site	S(N−B)	SD	SEP	SD
10A	−47.3	11.9	1.24	0.5
10B	−71.0	32.4	0.93	0.1
10C	−69.9	15.0	0.93	0.2
20A	−179.5	12.9	0.87	0.1
20B	−240.1	92.2	0.77	0.1
20C	−189.0	70.7	0.83	0.1
30A	−30.3	8.0	1.07	0.2
30B	−234.1	19.4	0.75	0.3
30C	−273.4	97.7	0.71	0.1

common crustaceans, especially the families Oedicerotidae and Phoxocephalidae. The most common echinoderms were the deposit feeding brittle stars (Amphiuridae).

ABC graphs of abundance/biomass data for individual collections at each site revealed that benthic community structure varied with time and that communities at all sites, except Sites 20B and 30C, were disturbed at least once during the investigation. Data for Sites 10A, 10B, and 30A indicated that benthic communities at these sites were disturbed during the majority of the collections. However, the results of ABC analysis of mean abundance/biomass data for all six collections indicated that only Sites 10A and 30A were significantly disturbed according to Warwick's interpretation of ABC plots (Figs 3–5).

The results of condensing the abundance/biomass data to two summary statistics are presented in Table 1. The means and standard deviations of S(N−B) values

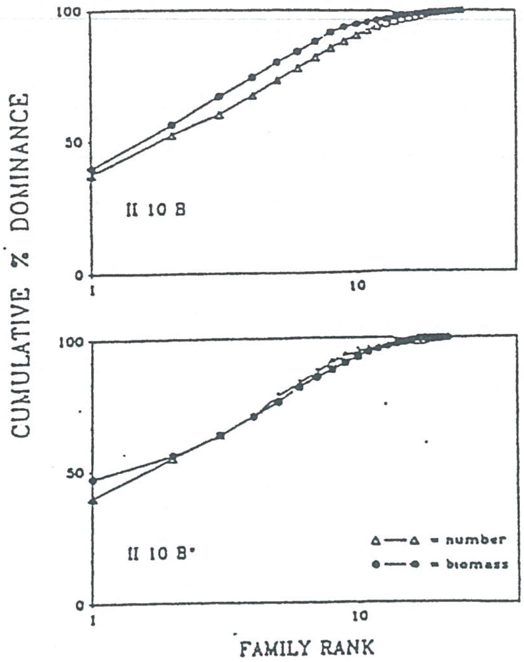

Fig. 6 ABC plots of total abundance and biomass data for Site 10B before and after (*) a severe storm period.

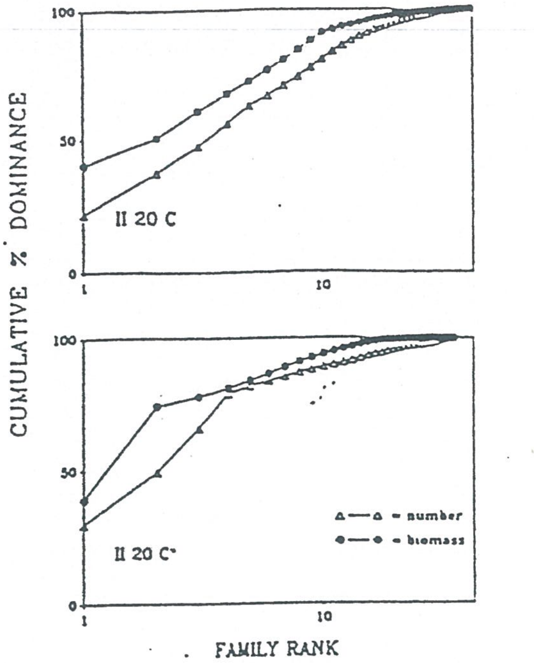

Fig. 8 ABC plots of total abundance and biomass data for Site 20C before and after (*) a severe storm period.

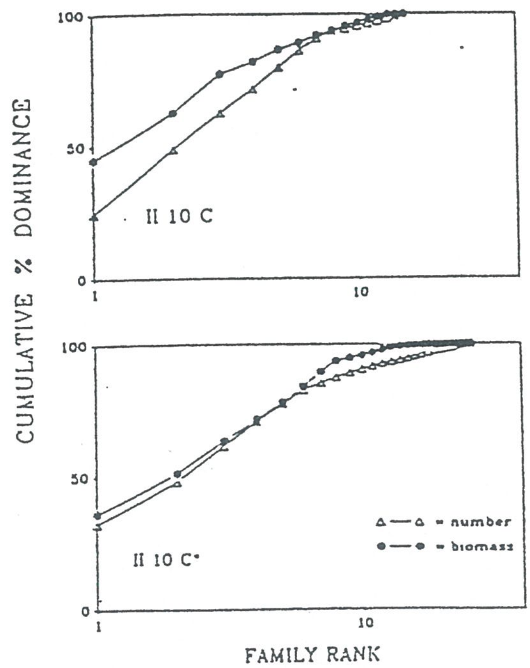

Fig. 7 ABC plots of total abundance and biomass data for Site 10C before and after (*) a severe storm period.

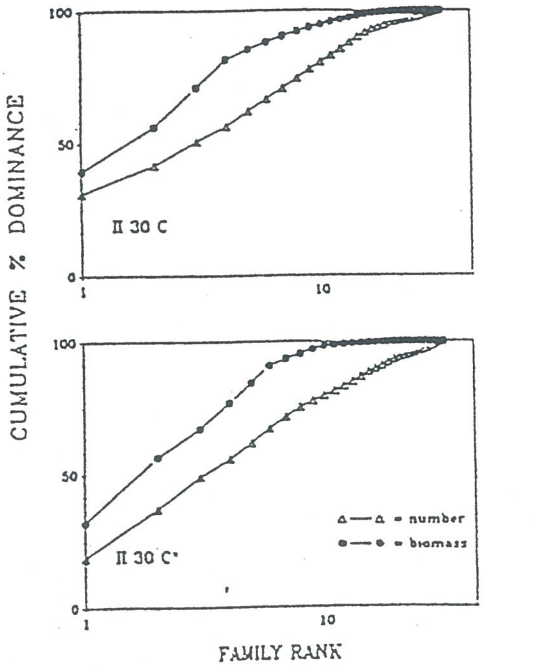

Fig. 9 ABC plots of total abundance and biomass data for Site 30C before and after (*) a severe storm period.

revealed that none of the nine sites were significantly disturbed according to Beukema's (1988) interpretation of ABC plot data. However, mean values for Sites 10A, B, C, and 30A were all an order of magnitude lower than the other sites, which may indicate that communities at these sites were relatively less stable than at other sites. Mean SEP values were consistent with mean ABC plots; i.e. Sites 10A and 30A were the only two sites which appeared to be disturbed according to MacManus and Pauly (1990).

Data for samples collected from Sites 10B, 10C, 20C, and 30C just prior to and immediately following a particularly severe week-long southerly storm in May 1989 (average maximum wind speed 90 km/hr, 4–5 m seas) are plotted in Figs 6–9. Data for the two shallow sites 10B and 10C showed a significant shift in the ABC curves from an undisturbed condition to a condition of early disturbance immediately following the storm event (Figs 6 and 7). Site 20C data showed some alteration in the shape of the ABC curves but did not indicate substantial disturbance (Fig. 8). Little change in the ABC curves was noted for Site 30C (Fig. 9).

The results of Cluster analysis of the total untransformed abundance data from all collections separated the nine sites into four groups (Fig. 10). The first group contained only Site 10A; group 2 consisted of Sites 10B, 10C, 20A, and 20B; group 3 included Sites 30A and 30C; and Sites 20C and 30B comprised group 4.

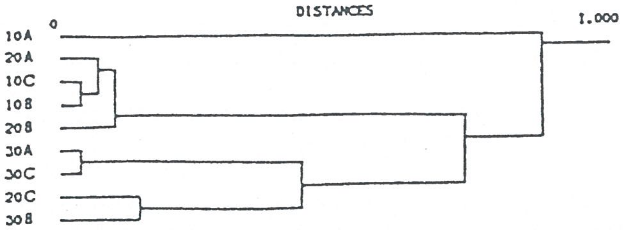

Fig. 10 Dendrogram for group-average clustering of Pearson correlation coefficients for total, untransformed abundance data from all sites and collections.

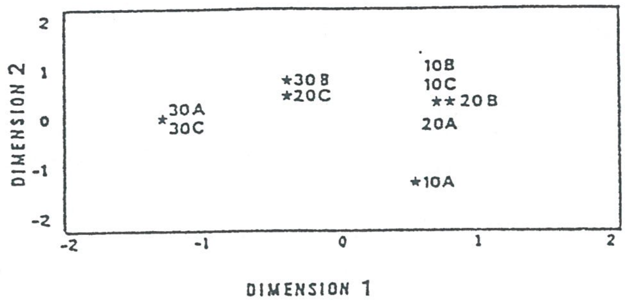

Fig. 11 Multi-dimensional scaling (MDS) ordination of Pearson correlation coefficients for total, untransformed abundance data from all sites and collections.

This separation was more marked when the data were subjected to MDS analysis which separated the sites into the same four groups (Fig. 11).

Conclusions

The results of ABC, Cluster, and MDS analyses presented in this paper indicate that the present discharge of sewage from the Pencarrow Sewer Outfall affects benthic macrofaunal community structure within a radius of approximately 500 m of the discharge (Site 10A) and may also influence benthic macrofaunal community structure along the nearshore waters in the central portion of Fitzroy Bay (Site 10B). Benthic communities in other parts of the Bay, including Site 30A, appear to be affected primarily by seasonal, physical and possibly biological disturbances. ABC analyses of pre- and post-storm collection data indicate short-term natural disturbances may affect the stability of benthic populations at some sites in Fitzroy Bay. However, such disturbances appear to be localized and of short duration.

The results of this investigation also suggest that ABC analyses should be conducted over several seasons to provide a more accurate assessment of pollution-induced and/or natural physical and biological disturbance. Our data indicate that reliance on single period collections may produce erroneous interpretations of the ABC graphs, especially in areas subject to dynamic seasonal weather and sea conditions. However, ABC analysis of seasonal data appears to be a sensitive method of detecting short-term changes in benthic community structure and an excellent means of separating pollution-induced disturbance from natural seasonal fluctuations in community structure.

We would like to express our appreciation to the staff of the Environmental Services Section of the Lower Hutt City Council, especially Mr John Speir and Mr Allan Bannatyne, for their support and cooperation during the course of this investigation. We also thank the crew of the RV *Lucy C* for their assistance and patience during collections, and Mr John Goldsmith of the Lower Hutt City Council's Trade Waste Laboratory and his staff for providing assistance and equipment.

The authors would also like to thank Dr. Anthony Underwood of Sydney University for his valuable comments and suggestions on the use of the ABC analytical method for this study. We are especially appreciative of the efforts of Ms Susan Anderson and Mr Steven White who identified some of the macrofaunal species collected during this investigation. Finally we would like to thank Mr George Grainger of the Victoria University of Wellington's Marine Laboratory at Island Bay for technical assistance.

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