A Report on the Infaunal Communities within Weston Bay in relation to the Sewage Outfall at Black Rock.

Mitch Perkins
Biology Unit, Catchment Control.
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## 2. ABSTRACT

The aim of this study was to establish whether sewage effluent discharged from the outfall at Black Rock, was having an impact on invertebrate communities within Weston Bay. The outfall receives effluent from the Black Rock Pumping Station, which serves up to 100,000 residents and visitors to Weston-Super-Mare. Screened effluent, which is discharged from the outfall into a channel formed by the River Axe, is disinfected during the summer bathing season to ensure that local beaches do not fail the European Communities Bathing Water Directive.

During November 1991 and January 1992, a total of 48 sites from intertidal and subtidal areas of Weston Bay were sampled. These samples were examined for benthic infauna and analysed for organic carbon and nitrogen content, and sediment particle size. Multivariate techniques were used to reveal patterns in faunal distribution, and help explain if any of the environmental parameters examined could be influencing the faunal assemblages present within the bay.

There were no obvious patterns in the organic carbon and nitrogen data. The majority of nitrogen results were below the detection limit, and generally levels of organic carbon were higher offshore . The lack of information provided by this data was attributed to the interfering presence of coal dust which is common in the Severn Estuary.

Particle size analysis revealed that the intertidal sediments could predominantly be described as silt (<62.5µm) with sand (500-62.5µm) occurring along the upper-shore and to the north of the bay. Subtidal sediments were generally more mixed, with the deeper sites containing larger particles of >2mm. Inshore sites located close to Brean Down and the mouth of the River Axe were largely silt.

Multivariate analyses revealed that intertidal communities were significantly correlated with distance from the Black Rock outfall. Pollution tolerant species such as the polychaete *Nereis diversicolor* , were only recorded from sites within 860m of the outfall; while sites outside of this area contained different species assemblages, generally typified by *Nephtys hombergii* and *Nephtys* juveniles. The highest numbers of *Nereis* were recorded from 3 sites adjacent to the outfall and located within 300m (sites 2, 6 and 7) of Black Rock, these sites also contained the highest numbers of the oligochaete family Enchytraeidae, which are another pollution tolerant group. These results suggested that some component of the Black Rock effluent was influencing faunal distribution. The influence of the most obvious component, sewage derived organic material, could not be proven due to the lack of information provided by the organic carbon data. Other possible influences included the industrial waste component of the effluent and the summer disinfection process. This study could not clarify which components of the effluent were impacting the bay.

Multivariate analysis of the subtidal data revealed that infaunal assemblages could be mainly attributed to sediment type. Three distinct communities were observed:-

1) *Sabellaria* reefs and their associated fauna
2) Species poor sites containing predominantly small interstitial organisms
3) Mixed communities dominated by burrowing molluscs and polychaetes

The *Sabellaria* beds were mainly located offshore and in deeper waters, and are typically associated with larger sediment types. Impoverished sites contained interstitial species and
were associated with the coarser, sandy sediments; while the burrowing polychaetes and molluscs were recorded from siltier stations mainly located within the lee of Brean Down.

To conclude, differences in faunal assemblages within the intertidal zone were found by multivariate techniques, to be significantly correlated to distance from the Black Rock outfall. It would thus appear that the effluent is impacting the fauna of Weston Bay within a 860m radius of Black Rock.

## 3. INTRODUCTION

The aim of this study was to determine the impact of disinfected sewage discharged from the Black Rock outfall, on the bentic macrofauna of Weston Bay.

Black Rock Pumping Station currently receives sewage from up to 100,000 residents and vistors to Weston-Super-Mare, plus stormwater from an area of over 10 square kilometres. The dry weather flow of the effluent must not exceed 28500m$^3$/D and levels of total cadmium must not be greater than 40µg/l (D.O.E. COPA/1288). Several industrial effluents are also received by the pumping station from engineering, plating, abattoir, printing and kerbstone manufacturing processes. These effluents comprise approximately 790m$^3$/D of the total volume and are each subject to standard trade effluent consents (personnal communication).

The sewage is passed through fine (1.5mm) screens before being discharged from a short outfall at Black Rock into the channel of the River Axe. This discharge occurs on all states of the tide and during the summer bathing season is disinfected using sodium hypochlorite (Wessex Water WR91/23718). The summer bathing season is defined as beginning on the first monday in May which falls a fortnight before the Spring Bank Holiday, and ending on the sunday which falls in the second full weekend of September (D.O.E COPA/1288).

Disinfection was first introduced in 1976 to ensure that local beaches (Uphill, Weston and Sand Bay) satisfied the requirements of the European Communities Bathing Water Directive (76/160/EEC). During the 1985 bathing season, levels of residual chlorine at the outfall were recorded as high as 31-34mg/l (Wessex Water 1985). Improvements at the Black Rock Pumping Station in 1989 were introduced to provide better control of the hypochlorite dosing, and greater mixing and contact of the disinfectant with the effluent prior to discharge (Paynting T. 1989). The level of residual chlorine at the Black Rock Pumping Station required to acheive microbiological compliance during the 1991 bathing season was 35mg/l, actual dosing levels ranged between 33-43mg/l. Levels at the Black Rock outfall probably ranged between 10-15mg/l, depending on residence time at the pumping station (Personal Communication).

During November 1991 and January 1992 a total of 48 sites were sampled from both intertidal and subtidal stations in the Bay (Figure 1). Infaunal samples were sieved through a 0.5mm mesh, and identified to species level where ever possible. Separate sediment samples were taken for organic carbon and nitrogen content, and full particle size analysis. Collections of fucoid seaweeds and limpets and were also taken from Brean Down, Anchor Head and Sand Point, to examine whether by-products of disinfection were being accumulated. Visits to these sites were completed on two occasions, the first outside the disinfection period (25-26/11/91) and the second, one month after the start of treatment (1-2/06/92). However at the time of reporting, these results were not available and will consequently be included in a separate account. This later report will also contain results for samples to be taken in September 1992, which will coincide with the end of this year's disinfection period.

Future improvements in the treatment of effluent from Weston Super Mare have been proposed (Wessex Water WR91/23718) which would include the building of a new Sewage Treatment Works on the Bleadon Level (2km south of Weston-Super-Mare). This works would be served by the Black Rock P.S. and biologically treated effluent would be discharged into the R. Axe on the ebb tide. The Black Rock outfall would then only be used to discharge stormwater. Disinfection would continue at both outfalls during the bathing season.

# 4. METHODS

## 4.1 Survey Design

A total of 48 subtidal and intertidal sites were selected to determine the impact of effluent from the outfall at Black Rock on the benthic macrofauna of Weston Bay (Figure 1). Sampling stations were concentrated in the immediate vicinity of the outfall to facilitate the detection of pollution gradients (Baker et al 1987) and arranged along 'depth' transects to minimise the influence of this parameter on species variability between adjacent sites.

Due to the different sampling methods employed, subtidal and intertidal surveys were undertaken separately.

## 4.2 Intertidal Survey (21st November 1991)

Due to the nature of the shore and the size of area to be surveyed, the 24 intertidal sites were sampled from a hovercraft (supplied by I.C.I Brixham). Position fixes for each site had been established prior to the survey (Appendix I), but due to inaccuracies in the Decca navigation system, were located by eye using fixed landmarks.

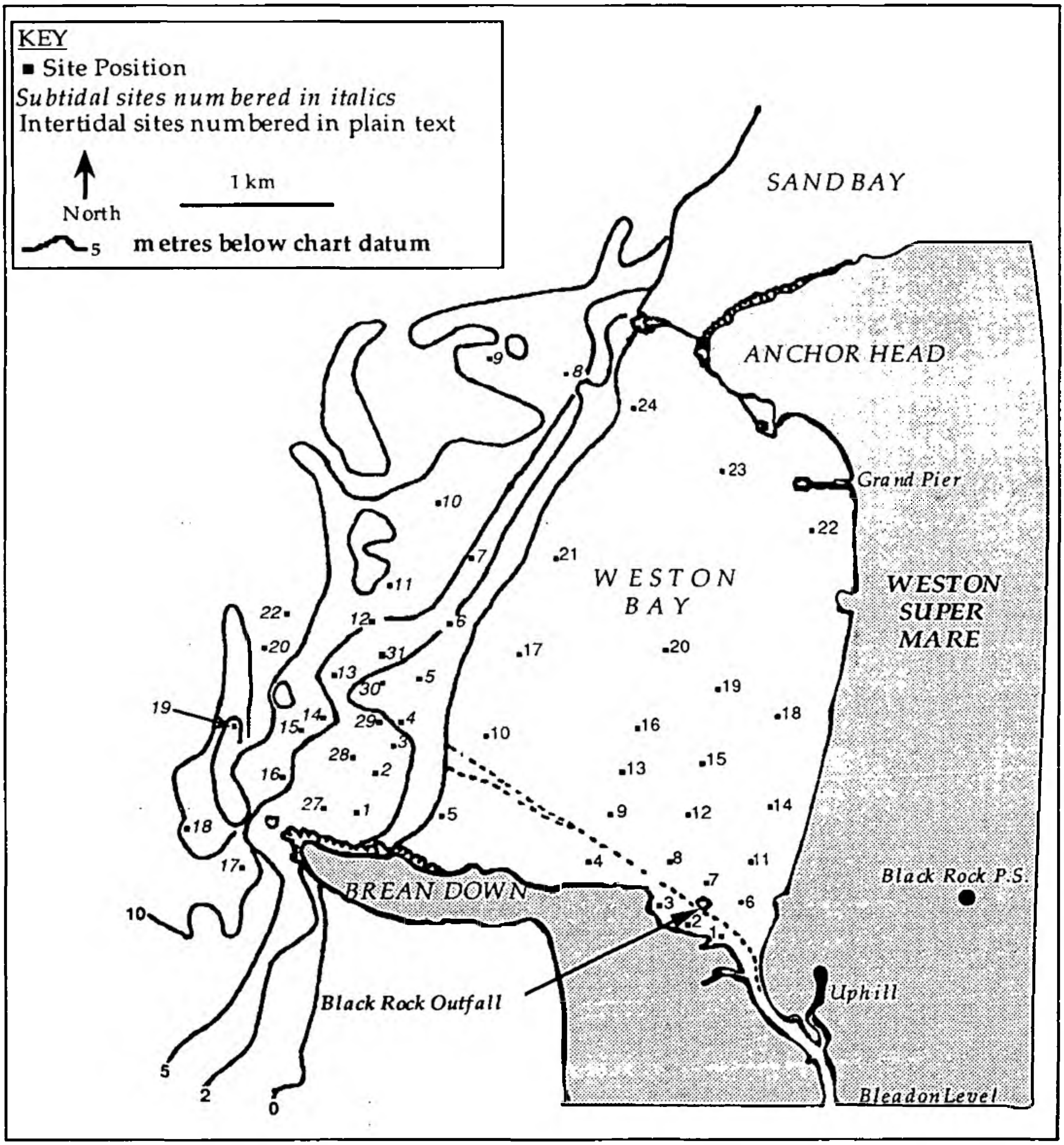
Each station was sampled for benthic macroinvertebrates, full particle size analysis and organic carbon. Infaunal samples were taken using a $0.1m^2$ stainless steel box corer to a depth of 20cm and temporarily retained in large plastic bags. Samples were later sieved on site using a 0.5mm mesh and preserved in labelled pots containing 10% formalin (ie: 4% formaldehyde).

Inorder to reflect the environmental conditions prevailing at each site, without effecting the species composition of infaunal samples; sediments for organic carbon and particle size analyses were taken immediately outside the box corer. A surface scrape (top 1cm) of sediment was taken for organic carbon and nitrogen analysis and retained in a clean plastic container. Sediment for particle size analysis was sampled to a depth of 10cm and placed in a self-seal plastic bag. All non-biological samples were kept frozen (at -20°C) prior to analysis.

## 4.3 Subtidal Survey (15-16th January 1992)

The Wessex N.R.A. survey vessel 'Vigilance' was used to sample the subtidal area of Weston Bay. A total of 26 previously selected sites were located using standard G.P.S. (Global Positioning System). Due to the hardness of the seabed around the edge of the survey area, only 19 of these sites could be sampled. Consequently 5 additional sites were selected (numbers 27-31) to concentrate sampling at the mouth of the R. Axe channel (Figure 1). Position fixes for these sites are presented in Appendix II.

FIGURE 1 PLOT OF SUBTIDAL AND INTERTIDAL SITES
WESTON-SUPER-MARE Nov.'91 & Jan.'92



Sampling was undertaken using a Day grab, which samples an area of $0.1m^2$ to a maximum depth of 15cm. Two samples were taken at each site , one was retained for infauna and the other subsampled for organic carbon and nitrogen analysis (surface scrape of top 1cm) and full particle size analysis (core of 10cm depth). Notes on the amount of sediment in each grab, sediment type and number of sampling attempts made at each site, were recorded in situ[1].

All samples were handled and analysed as previously mentioned in the intertidal methods (Section 3.2).

## 4.4 Analytical Methods

### 4.4i Invertebrate Samples

Rose Bengal stain was added to samples the day before analysis, to facilitate sorting. Due to the time constraints of working in the field, not all samples were completely seived. Prior to sorting, these samples were reseived through a 0.5mm mesh; all other samples were rinsed through a 0.25mm mesh to remove traces of formaldehyde. Organisms were identified where ever possible down to species level, using binocular and compound microscopes

### 4.4ii Chemical and Physical Analyses

A Malvern Instrumentation 3600 Laser Particle-sizer was used to determine full particle size analysis at I.C.I. Laboratories, Brixham. All sediments were pre-sieved to remove the >2mm fraction.

Organic carbon and nitrogen were analysed at the Welsh N.R.A.'s N.A.M.A.S. accredited Llanelli laboratory. After freeze-drying at 40°C, each sample was seived through a 63µm sieve and acid treated to remove carbonates. The <63µm fraction of the sediment was then analysed for organic carbon and nitrogen using a 'Carlo Erba Strumentazione' Elemental Analyser Model 1106[2].

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[1] This data is not presented in this report but is available from the N.R.A.'s office at Blandford if required.

[2] A detailed account of the methods used is available from the N.R.A.'s Blandford office or the N.A.M.A.S. accredited laboratory at Llanelli.

## 5. RESULTS

### 5.1 Invertebrate Analysis

5.1i Intertidal data

All 24 sites were successfully sampled and a full species list is presented in Appendix III.

A total of 29 species, typical of intertidal estuarine habitats, were recorded across Weston Bay. Species diversity varied, with the total number of species at each site ranging from 4 at site 19, situated towards the centre of the bay, to 11 at site 4, located close to Brean Down. The highest numbers of individuals were recorded from sites 2 and 6, close to Black Rock (1602 and 1156 respectively), while the lowest numbers were sampled from sites 1, 10 and 21.

The most common invertebrates recorded were *Macoma balthica* and *Hydrobia sp.* These molluscs individually contributed over 50% of the total infauna at 11 of the 24 sites. Other abundant organisms included members of the oligochaete family Enchytraeidae, and the polychaete worms *Nereis diversicolor, Pygospio elegans, Streblospio shrubsolii*, *Nephtys hombergii* and *Nephtys* juveniles (the latter probably being young *N. hombergii*).

Of the afore mentioned species, the molluscs and the two polychaetes *Nephtys hombergii* and *Pygospio elegans*, were well distributed throughout the bay. However, the other species exhibited different patterns of distribution. For example, *Nereis diversicolor* was recorded at a total of 11 sites, all of which were located within 860m of the Black Rock outfall; 6 of these sites also contained *Streblospio shrubsolii* which was not recorded from anywhere else in the bay. Conversely *Nephtys* juveniles were not recorded within 860m of Black Rock. Enchytraeids were recorded at a number of sites, but their highest concentrations occurred at sites 2 and 6 (37 & 213 respectively), both of these stations were within 300m of Black Rock.

5.1ii Subtidal Data

A total of 24 sites were sampled for macroinvertebrates. A full species list is presented in Appendix IV.

The subtidal sites were found to be composed of a variety of species. The reef-building polychaete *Sabellaria alveolata* dominated sites to the extreme north and west parts of the survey area (including sites 10, 12 & 13), while sites situated in the south-eastern corner of the survey area (1-4, 27 & 28) were generally found to consist of species typical of softer sediments, *Tharyx sp.* (a sedentary polychaete), *Hydrobia sp.* and members of the Tubificidae (an oligochaete family).

The remaining stations could be divided into 2 groups; one located in the centre of the survey area (sites 14, 15, 29 & 30) containing the interstitial polychaetes *Ophyrotrocha hartmanni* and *Protodriloides chaetifer* and the other containing a mixture of species which were difficult to characterize (5-7, 11, 16 & 31).

### 5.2 Organic Carbon and Nitrogen Analysis

The distribution of organic carbon between sites (both inter- and subtidal) is illustrated in Figure 2.

#### 5.2i Intertidal Data

Results are recorded in Appendix V. To summarise, only site 3 located in the south-western corner of the survey area and site 20 a midshore site, contained >0.2% organic nitrogen (0.21% and 0.206% respectively) all other sites were below the detection limit. The highest levels of organic carbon (3.03%) were recorded at site 17 a low-water station, and the lowest (0.63%) at site 3. Due to the low nitrogen readings C:N ratios could only be calculated for sites 3 and 20 (2.94 and 10.29 respectively).

Low C:N ratios are indicative of sewage derived organic material (Murray et al 1980a), whereas ratios in the region of 7 or 12:1 are typical of marine sediments in shallow waters (Murray et al 1980b). This information suggests that site 3 is receiving sewage derived organic carbon, although the actual level of carbon present suggests that the amount retained is not high.

The majority of C:N ratios were recorded as > figures due to the low levels of organic nitrogen present. Ratios >17:1 reflect the presence of coal dust (Murray et al 1980b) and during sorting, small fragments of coal were observed at a large number of sites.

Examination of these results alongside other known parameters (eg: height on shore, distance from outfall etc.) revealed no clear patterns in the distribution of organic data. It would therefore appear that the presence of coal dust in the intertidal sediments of Weston Bay, is confusing the effects of any sewage derived organic matter.

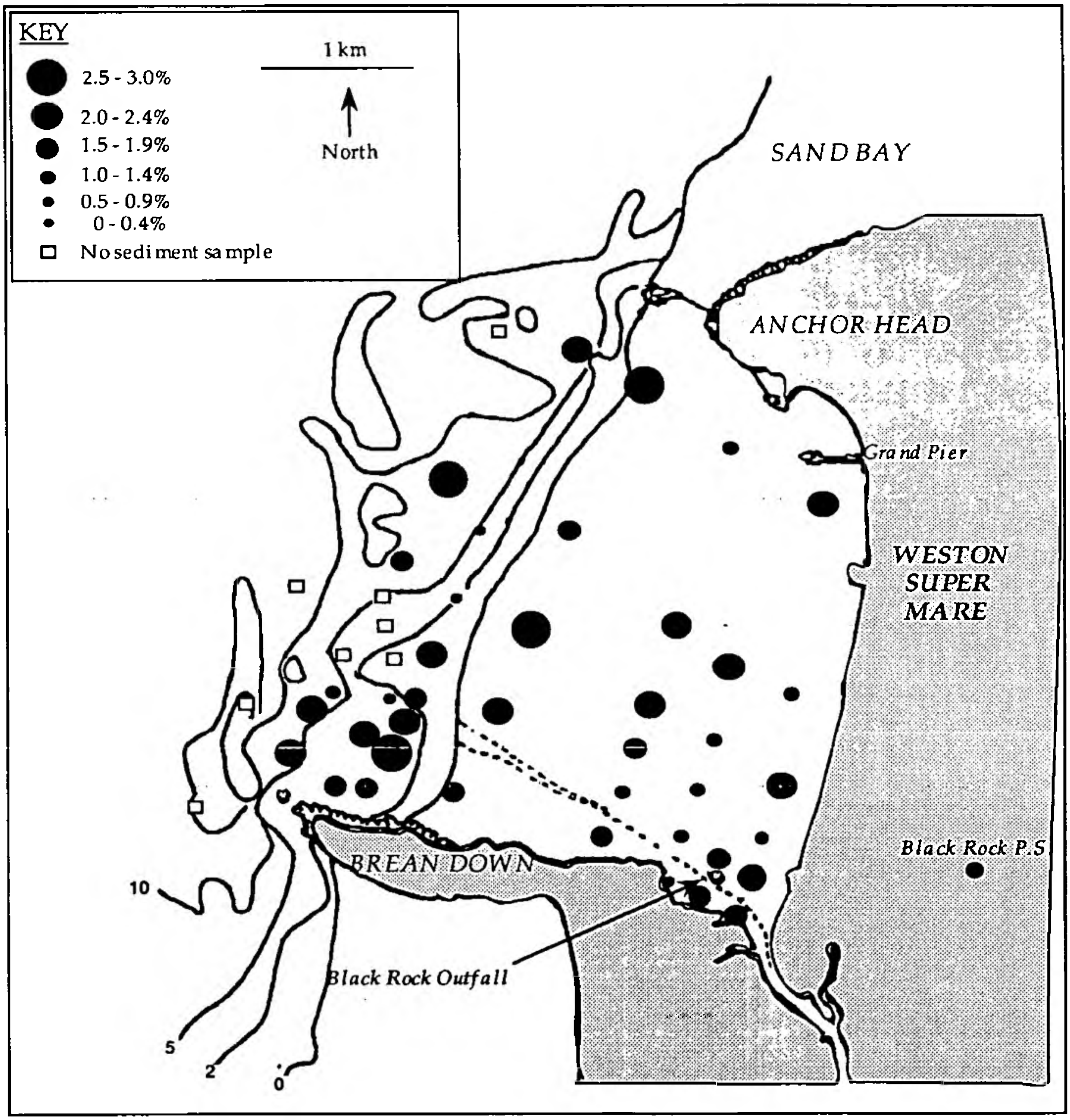
#### 5.2ii Subtidal Data

Results are recorded in Appendix VI. It was observed that only site 6, an inshore station , was found to contain >0.2% organic nitrogen (0.29%). The highest levels of organic carbon were found at two positionally unrelated sites, 2 and 10 (2.84% & 2.64% respectively), while the lowest results were observed at site 29 (0.37%).

As observed at the intertidal sites C:N ratios were generally expressed as >, suggesting that coal-dust was present in these samples.

In general, levels of organic carbon from subtidal sediments, were higher than those recorded from intertidal sites.

FIGURE 2 OVERLAY OF % ORGANIC CARBON PRESENT IN <63micron SEDIMENT FRACTION - WESTON-SUPER-MARE Nov. '91 & Jan. '92



## 5.3 Full Particle Size Analysis

Sediments were classified according to the Wentworth Scale (Buchanan 1984). Figure 4 illustrates the distribution of sediment types within Weston Bay.

5.3i Intertidal Data

Raw data is presented in Appendix V.

Sediments from the intertidal zone were found to be relatively uniform. The majority of sites (1-3, 5-7, 9, 10, 15-17, 21 & 24) were comprised of over 90% silt/clay and of the remainder, 6 stations (4, 8, 11, 13, 19 & 20) contained >80%. These sites were all located towards the south and west of the survey area. Less fine sediments were recorded in the north eastern corner, with sites 18 and 22 consisting of predominantly fine sand (75% & 73.8% respectively), and sites 12, 14 and 23 containing mixed sediment types. From the sediment triangle in Figure 3, it can be seen that the sediment from site 23 could be described as *silty sand* , while sites 12 and 14 contained *sandy silt* .

The intertidal zone of Weston Bay could therefore be described as being predominantly silt with some sandier patches towards the north and along the HW mark.

FIGURE 3 Sediment Triangle For Describing Mixed Sediments Based on the Wentworth Scale

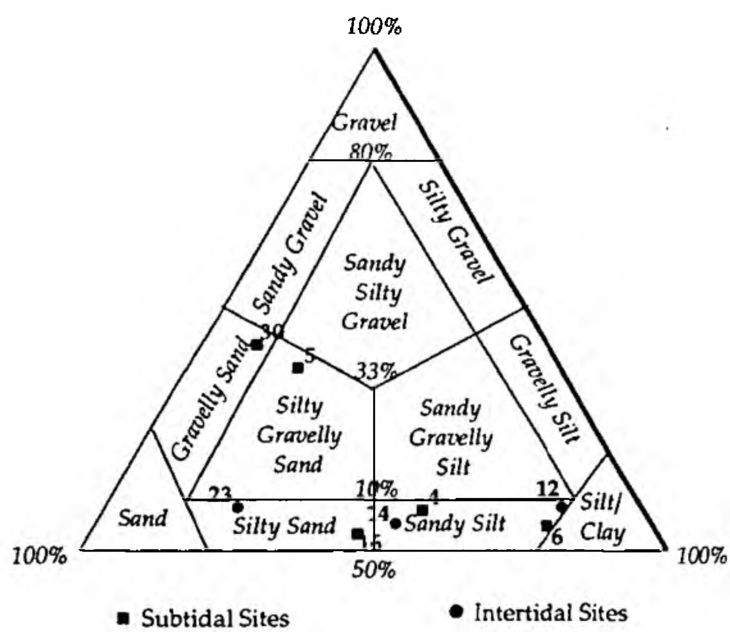
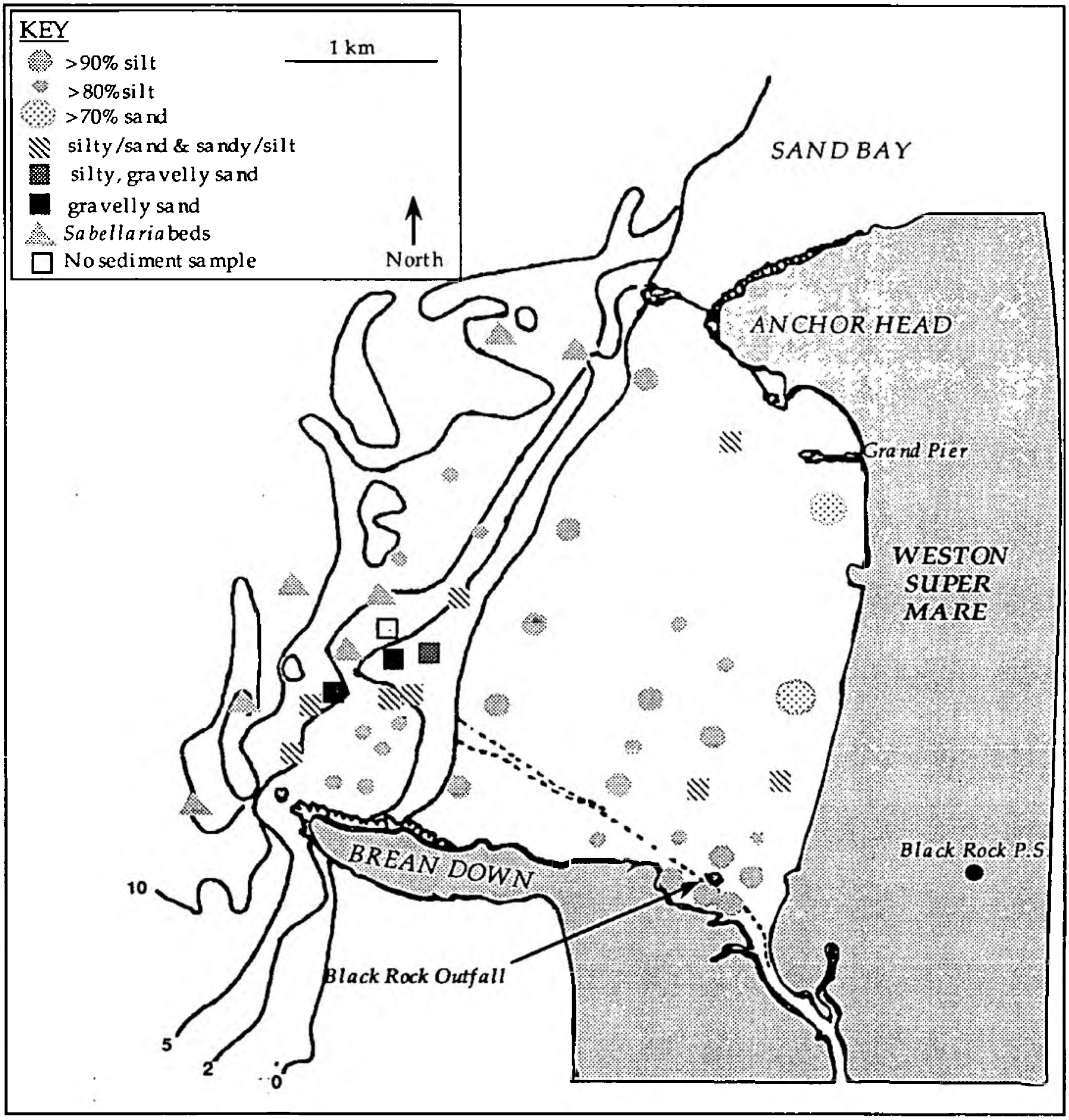


FIGURE 4 OVERLAY OF SEDIMENT TYPES (Based on Wentworth)
WESTON-SUPER-MARE Nov. '91 & Jan. '92



### 5.3ii Subtidal Data

Raw data is presented in Appendix VI.

Due to the substrate type and presence of *Sabellaria* reefs at some sites, not all stations were analysed for particle size. Inorder to form secure reefs, these polychaetes attatch to firm substrates and thus select larger sediment types. Once constructed these reefs trap finer particles. Sediments at these sites could therefore be described as mixed, and were located mostly offshore in deeper waters.

Of the 16 samples analysed, 8 mostly inshore sites, contained >80% silt/clay (1-3, 7, 10, 11, 27 & 28), 3 contained >80% sand (14, 15 and 29) and the remainder were mixed sediments. Using the sediment triangle in Figure 3, sediments from sites 4-5, 16 and 30 could be described as follows:-

| | | |
|---|---|---|
| Sites 4, 6 and 16 | - | *sandy silt /silty sand* |
| Site 5 | - | *silty, gravelly, sand* |
| Site 30 | - | *gravelly, sand* |

## 5.4 Annual Average Concentrations of List I and II Substances

Samples of the effluent at the Black Rock Pumping Station are taken by Water Quality Officers at regular intervals throughout the year. The sample represents the quality of the effluent before it is discharged, ie: after it has passed through the disinfection process. Levels of a few of the substances recorded between January 1991 and 1992 are presented in Table 1.

**TABLE 1 Concentrations of Some Substances Present in the Black Rock Effluent**

| Substance | Unit | Total Maximum | Date of maximum | Total minimum | Date of Minimum | Annual Average | Standard Deviation | No. of samples |
|---|---|---|---|---|---|---|---|---|
| chloride ion | mg/l | 178.00 | 23/05/91 | 87.468 | 08/10/91 | 119.829 | 33.2628 | 12 |
| copper | mg/l | 0.600 | 20/12/91 | 0.054 | 11/01/91 | 0.2735 | 0.2403 | 4 |
| zinc | mg/l | 0.200 | 23/05/91 | 0.099 | 11/01/91 | 0.1647 | 0.0477 | 4 |
| cadmium | µg/l | 20.000 | 20/12/91 | 0.700 | 01/03/91 | 4.8666 | 4.7247 | 3 |
| mercury | µg/l | 0.340 | 20/12/91 | - | - | 0.3400 | 0.0000 | 1 |
| nickel | mg/l | 0.200 | 23/05/91 | 0.100 | 20/12/91 | 0.0750 | 0.0353 | 2 |
| aldrin | µg/l | 20.000 | 20/03/91 | 5.000 | 01/03/91 | 6.2500 | 5.3033 | 2 |
| dieldrin | µg/l | 20.000 | 20/03/91 | 5.000 | 01/03/91 | 6.2500 | 5.3033 | 2 |
| endrin | µg/l | 40.000 | 20/03/91 | 10.000 | 01/03/91 | 12.5000 | 10.6060 | 2 |
| HCB | µg/l | 20.000 | 20/03/91 | 5.000 | 01/03/91 | 6.2500 | 5.3033 | 2 |
| HCBD | ng/l | 20.000 | 20/03/91 | 5.000 | 01/03/91 | 6.2500 | 5.3033 | 2 |

Other substances analysed but not reported here include; pH, temperature, D.O., B.O.D., C.O.D., ammonia, T.O.N., nitrate, nitrite, suspended solids, ortho-phosphorus, lead, chromium, malathion, parathion, D.D.T., trichloroethane, trichloroethane, atrazine, simazine, P.C.P., tetrachloroethylene, chloroform and arsenic.

## 6. MULTIVARIATE AND STATISTICAL ANALYSIS

The aim of analysing ecological data is to find "patterns" which explain the distribution of different organisms within the area surveyed. For small data sets searching for such patterns can be effectively done by eye, but for larger problems, more sophisticated methods are required to organise and summarise the information into a form which is more easily interpreted. Consequently, several multivariate analytical techniques were used to explore the intertidal and subtidal data collected from Weston-Super-Mare, these included TWINSPAN, DECORANA, (indirect methods) CANOCO and PRIMER (direct methods). A brief description of these analyses is presented in Appendix VII. Correlations between environmental variables were also examined and are presented in Appendix VIII.

### 6.1 TWINSPAN

Raw species data is too complex for TWINSPAN to analyse and has to be transformed into an abundance scale. This scale is chosen by the operator to reflect the range of abundances present in the data, and in this instance the following was selected: 0, 1-5, 6-25, 26-125 and >125.

Three analyses were performed:-

i) Intertidal and subtidal combined
ii) Intertidal sites only
iii) Subtidal sites only

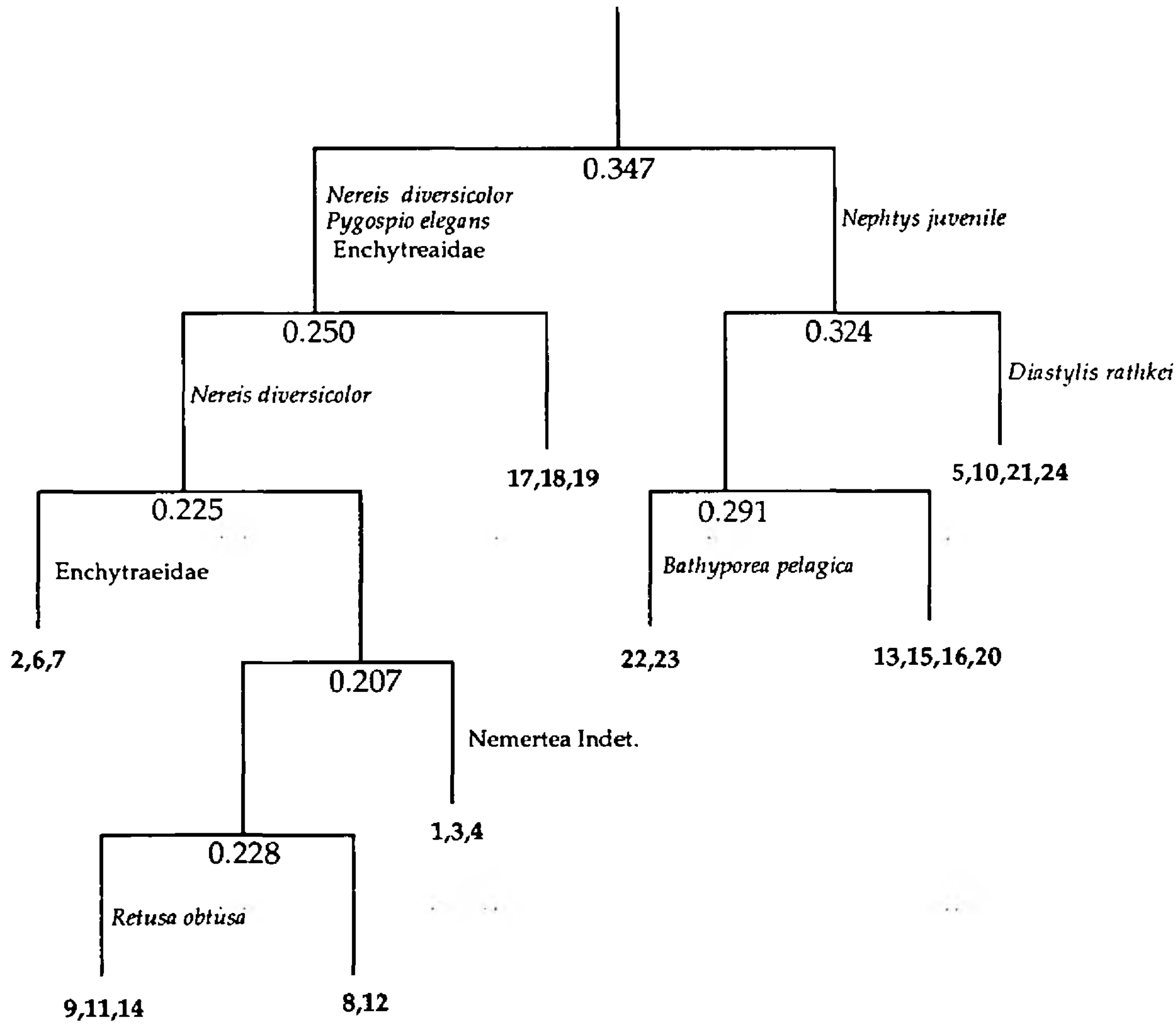
#### 6.1i Intertidal and Subtidal Combined

The combined run generally split intertidal sites away from subtidal sites, as might have been ecologically expected. Some overlap was observed between the two sets of sites with several low-water intertidal stations (5, 10, 21 & 24) being grouped with subtidal sites. However, because of the different environmental conditions prevailing and the largely divergent faunas that they support, subtidal and intertidal sites were examined separately.

#### 6.1ii Intertidal Sites

Eigenvalues for the first and subsequent divisions were relatively low suggesting that the intertidal sites were similar with respect to their faunal assemblages. Eigenvalues are provided at each division, and represent the % variation explained by the site groupings formed. A diagram of this analysis is presented in Figure 5, with eigenvalues and the indicator species responsible for each grouping illustrated. Only the major groupings which are believed to be the most important are discussed here.

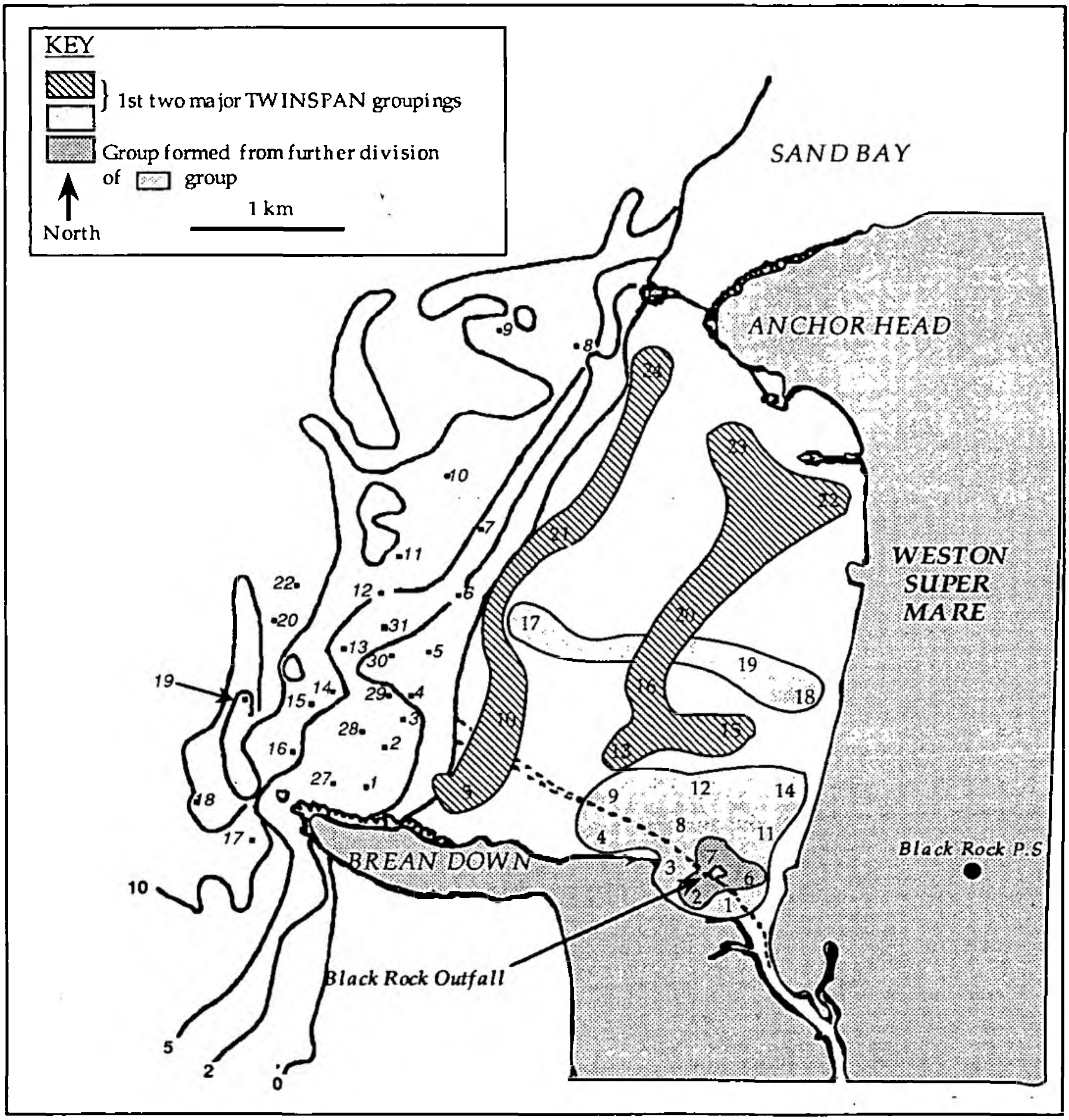
**FIGURE 5 TWINSPAN GROUPING OF INTERTIDAL SITES**
**CUT LEVELS 0,5,25,125**
**Weston-Super-Mare 21/9/91**




**KEY:**

0.789 — Eigenvalue
**1,2,3** — Site Number
*Tharyx sp* — 'Indicator'species

FIGURE 6 OVERLAY OF TWINSPAN INTERTIDAL GROUPINGS
WESTON-SUPER-MARE Nov.'91



The first division produced two major groupings, one of which contained sites 5, 10, 13, 15, 16 and 20-24. This group was split from the other intertidal sites by juveniles of the polychaete *Nephtys*. None of the sites in this group contained *Nereis diversicolor* or Enchytraeidae, both pollution tolerant organisms, and all were located outside 860m of Black Rock (Figure 6). The group was divided further by the cumacean *Diastylis rathkei* splitting away the low-water sites 5, 10, 21 and 24. Cumaceans are generally found burrowing in sand and mud on the lower shore (Jones 1976) and thus reflect the different physical conditions which prevail at the low-water mark when compared to sites located higher up the shore.

The second major group (sites 1-4, 6-9, 11, 12 & 14) was based on the presence of the oligochaete family Encytraeidae and the polychaetes *Nereis diversicolor* and *Pygospio elegans*. These species are recognised as being capable of living in polluted environments (Pearson & Rosenberg 1978) especially with respect to high organic inputs. Of the 14 sites within this group only sites 17-19 lay outside an area 860m from the Black Rock outfall (Figure 6). Further divisions performed on this group revealed that sites 17, 18 and 19 split away.

Generally, TWINSPAN appears to have separated sites primarily into those close to the outfall (ie: within 860m) and those further away. Within the latter group there is a further split based on the relative postion of sites on the shore.

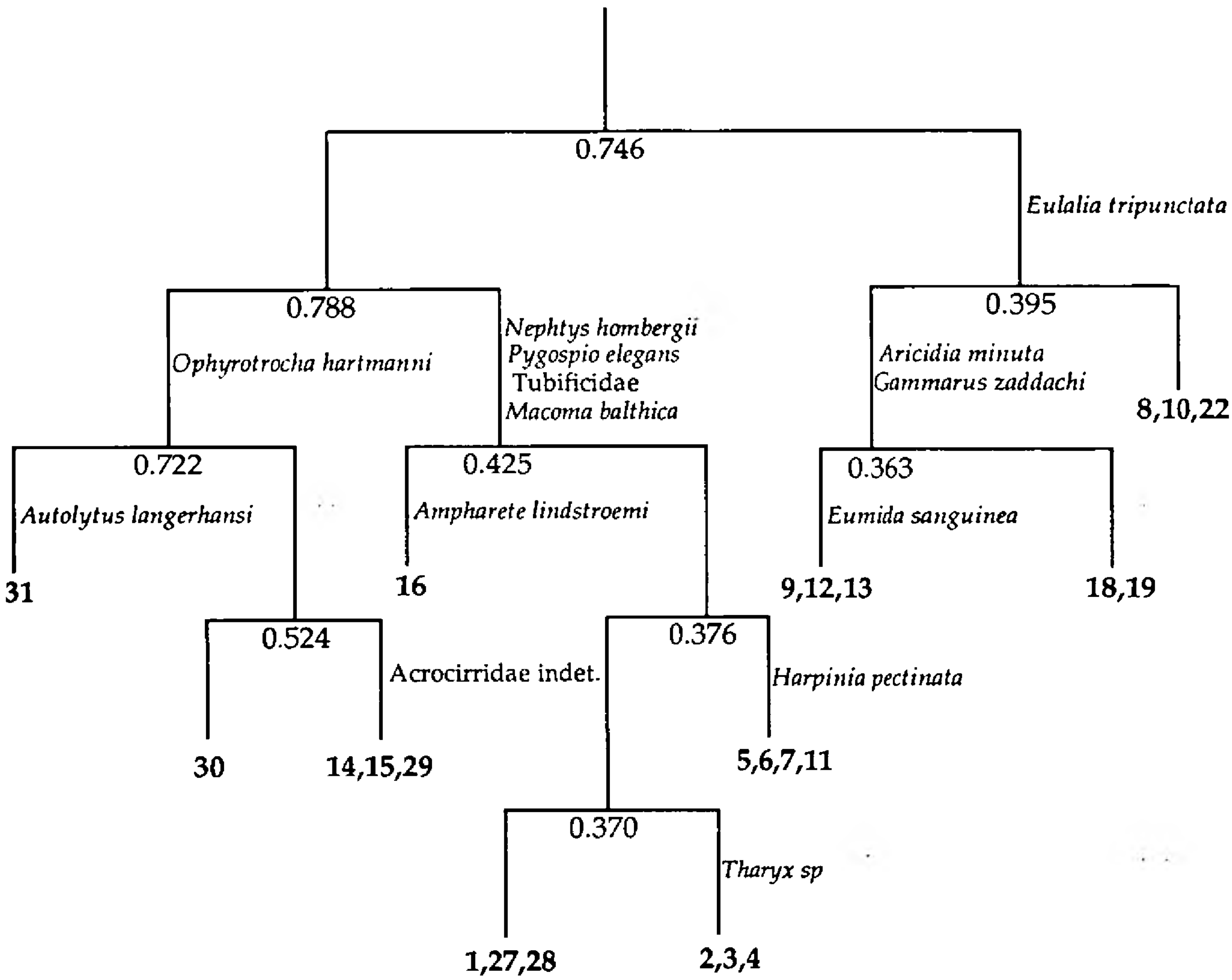
6.1iii Subtidal Sites

Eigenvalues for the earliest divisions were high showing that there were clear differences between the site groupings (Figure 7). Figure 8 illustrates the relative postition of the subtidal TWINSPAN groupings within Weston Bay.

Several clear groups were formed, the largest comprised sites 8-10, 12, 13, 18, 19 and 22 and was based on the presence of the indicator *Eulalia tripunctata*. Examining the species list (Appendix IV) it can be seen that the afore mentioned sites also contain *Sabellaria alveolata*, a reef building polychaete. These reefs provide a variety of ecological niches for other invertebrates. *E. tripunctata* is often found amongst shell gravel, stones and in crevices (Pleijel & Dales 1991), it would thus appear that this grouping is a reflection the substrate present and the presence of *Sabellaria* reefs.

The two other groups formed contained sites 14, 15, 29, 30 and 31 (group X) and stations 1-7, 11, 16, 27 and 28 (group Y). Examining the environmental data (Appendix VI) it was observed that sites within group X generally contained larger particles (pebbles and coarse sand) than group Y (silt and fine sand). This appears to be mirrored by the indicator species selected (*Nephtys hombergii*, *Pygospio elegans*, *Macoma balthica* and Enchytraeids) which are all active burrowers and as such prefer finer substrates. It would therefore appear that this division, like the previous ones, is related to sediment type.

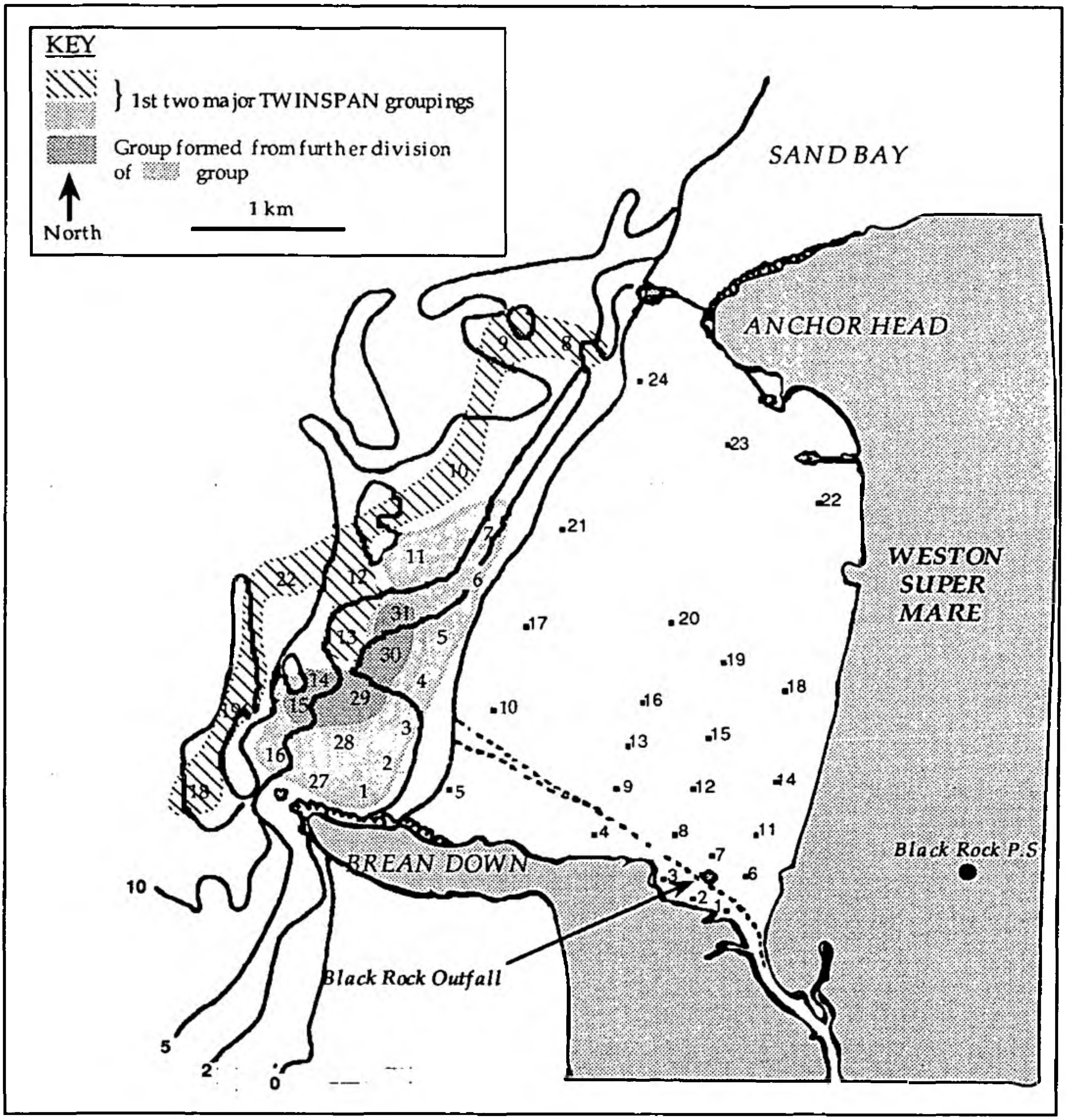
**FIGURE 7 TWINSPAN GROUPING OF SUBTIDAL SITES**
**CUT LEVELS 0,5,25,125**
**Weston-Super-Mare 15-16/1/92**




**KEY:**

0.789 — Eigenvalue
**1,2,3** — Site Number
*Tharyx sp* — 'Indicator' species

FIGURE 8 OVERLAY OF TWINSPAN SUBTIDAL GROUPINGS
WESTON-SUPER-MARE Jan. '92



## 6.2 DECORANA

As with TWINSPAN, three analyses were performed using intertidal and subtidal data separately and combined. Due to the lack of additional information provided by the analysis of combined data (ie: subtidal sites split away from intertidal sites), only groupings from the separate analyses are considered here.

### 6.2i Intertidal Sites

DECORANA was performed on the untransformed data, and produced 4 axes with eigenvalues 0.8558, 0.3192, 0.2326 and 0.0377 respectively. A plot of the first two Axes is shown in Figure 9. These eigenvalues represent the % variation explained by each axis, eg. Axis 1 explains over 85% of the variation seen between samples.

As can be seen site 17 was split away from all the other intertidal sites along Axis 1 (eigenvalue 0.8558). The remaining sites were spread out along the 'weaker' of the two axes (eigenvalue 0.3192), with sites 2, 6 and 7 grouping together at one end and sites 16, 21 and 24 splitting away at the other.

Examining the plot of species scores for these two axes (Figure 10), and the raw data in Appendix III, it can be seen that the species composition of site 17 is significantly different from the other intertidal sites (principally the high abundance of the amphipod*Corophium volulator* ). Correlation of environmental variables with Axis 1 revealed that 21% and 25% of the variance ($r^2$) along that axis could be explained by 'height on shore' and '% organic carbon' respectively. These same parameters have high values at site 17 (Appendix V). As Axis 1 separates site 17 so clearly away from the other stations, it would appear that the majority of species variance along this axis is generated by the organisms present at that site. Consequently the environmental properties of this site are 'dictating' which variables correlate with Axis 1.

Correlation of Axis 2 with environmental parameters showed that 'horizontal distance from the outfall'[1] explained 31% of the total variance along that axis. The second highest amount of variance ($r^2$=25%) was contributed by 'height on shore'. Sites closest to the outfall (2, 6 & 7) were grouped together, based on the presence of pollution tolerant Enchytraeids, *Nereis diversicolor* and *Streblospio shrubsolii* (Figure 10).

[1]The parameter 'horizontal distance' was selected as the measure of outfall distance because of its single vector. The perhaps more logical measurement, direct (ie: site to outfall) distance, contains two vectors, horizontal and vertical distance. Thus any relationship between direct distance and faunal distribution, would also apply to 'height on shore' which is the equivalent of the second 'direct distance' vector, vertical distance. Horizontal distance is a single expression and as such is more representative of outfall distance.

FIGURE 9 PLOT OF DECORANA AXES 1 & 2 (INTERTIDAL SITES)

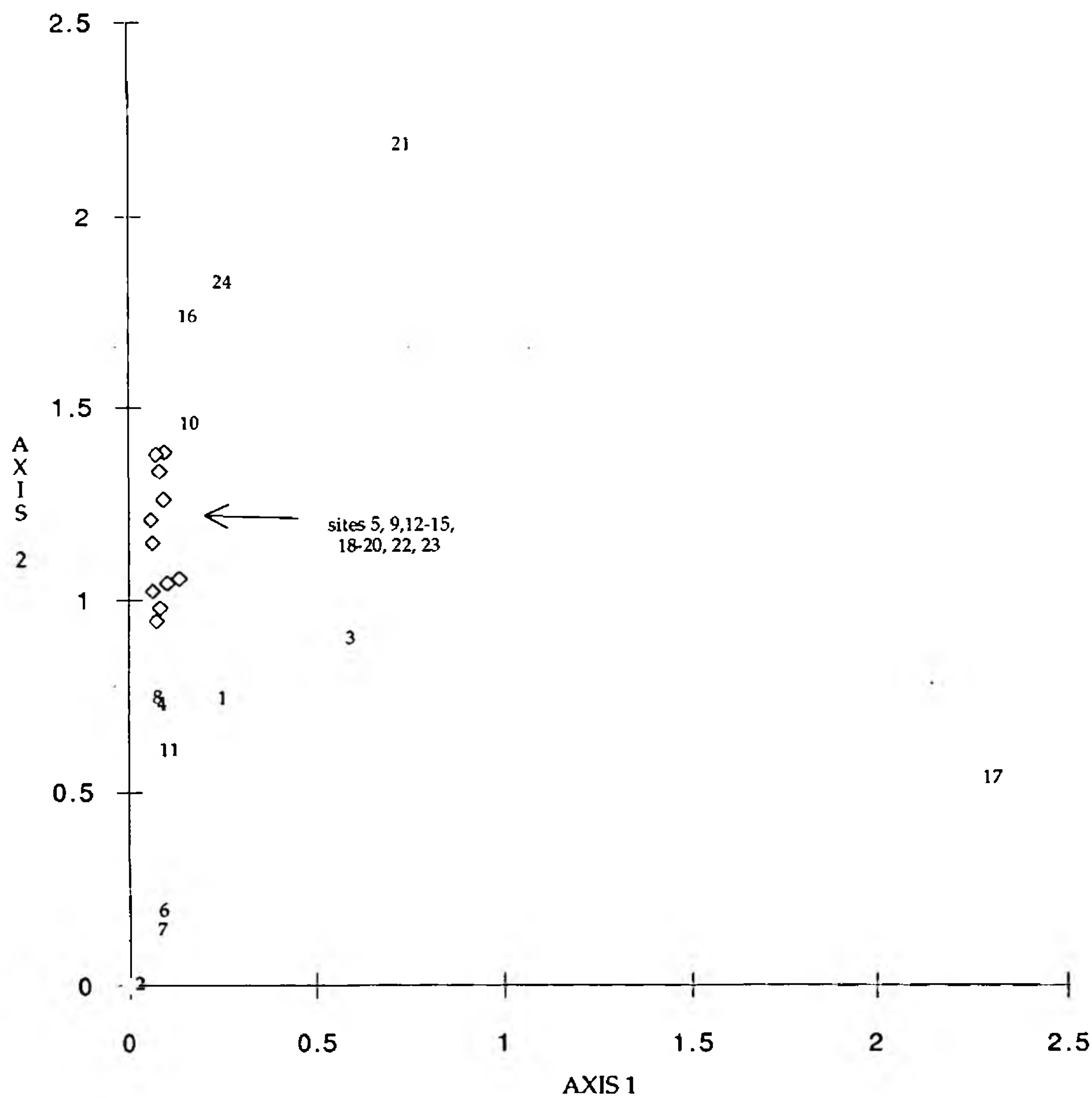


**FIGURE 10 SPECIES SCORES DECORANA AXES 1 & 2 (INTERTIDAL SITES)**

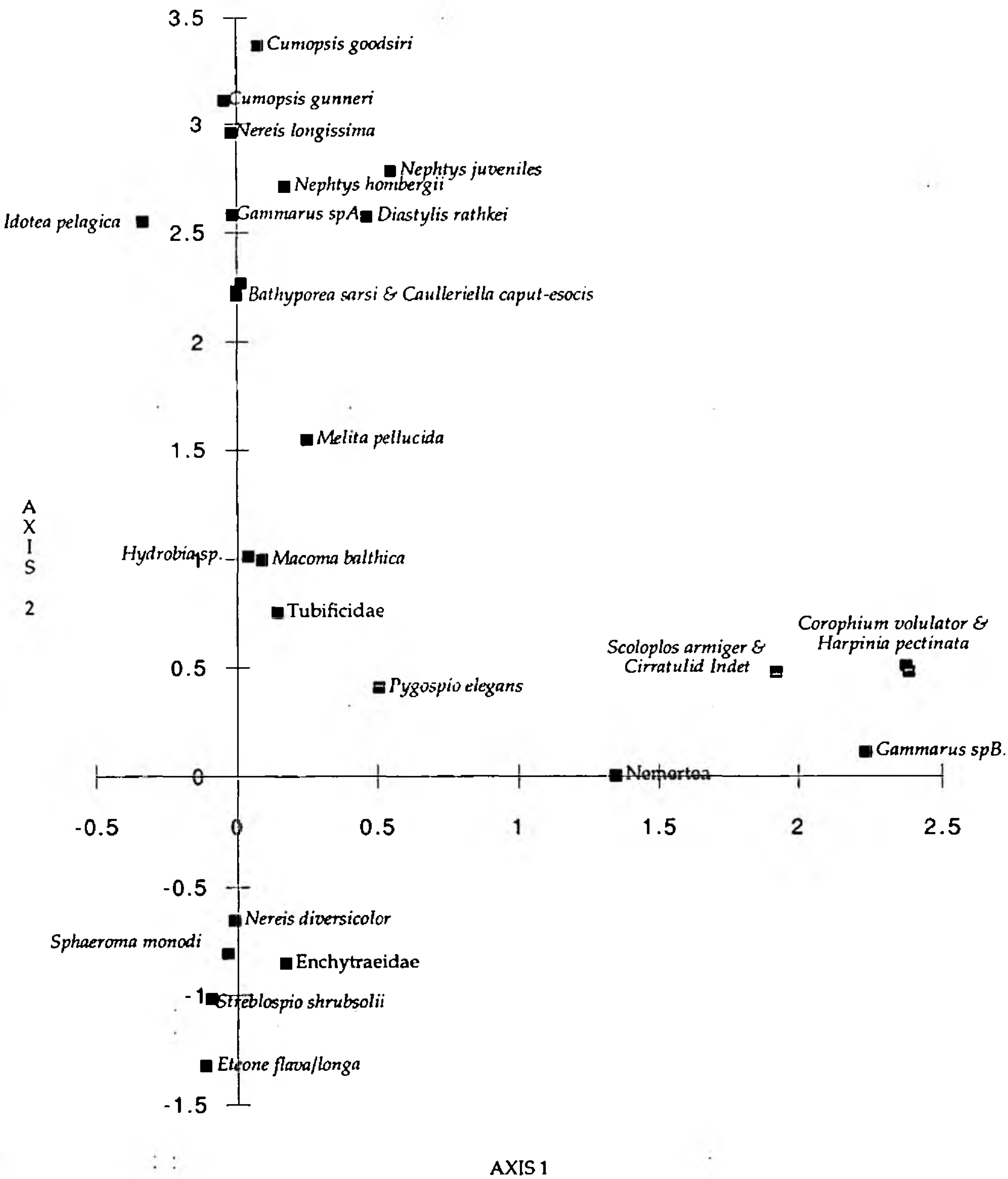
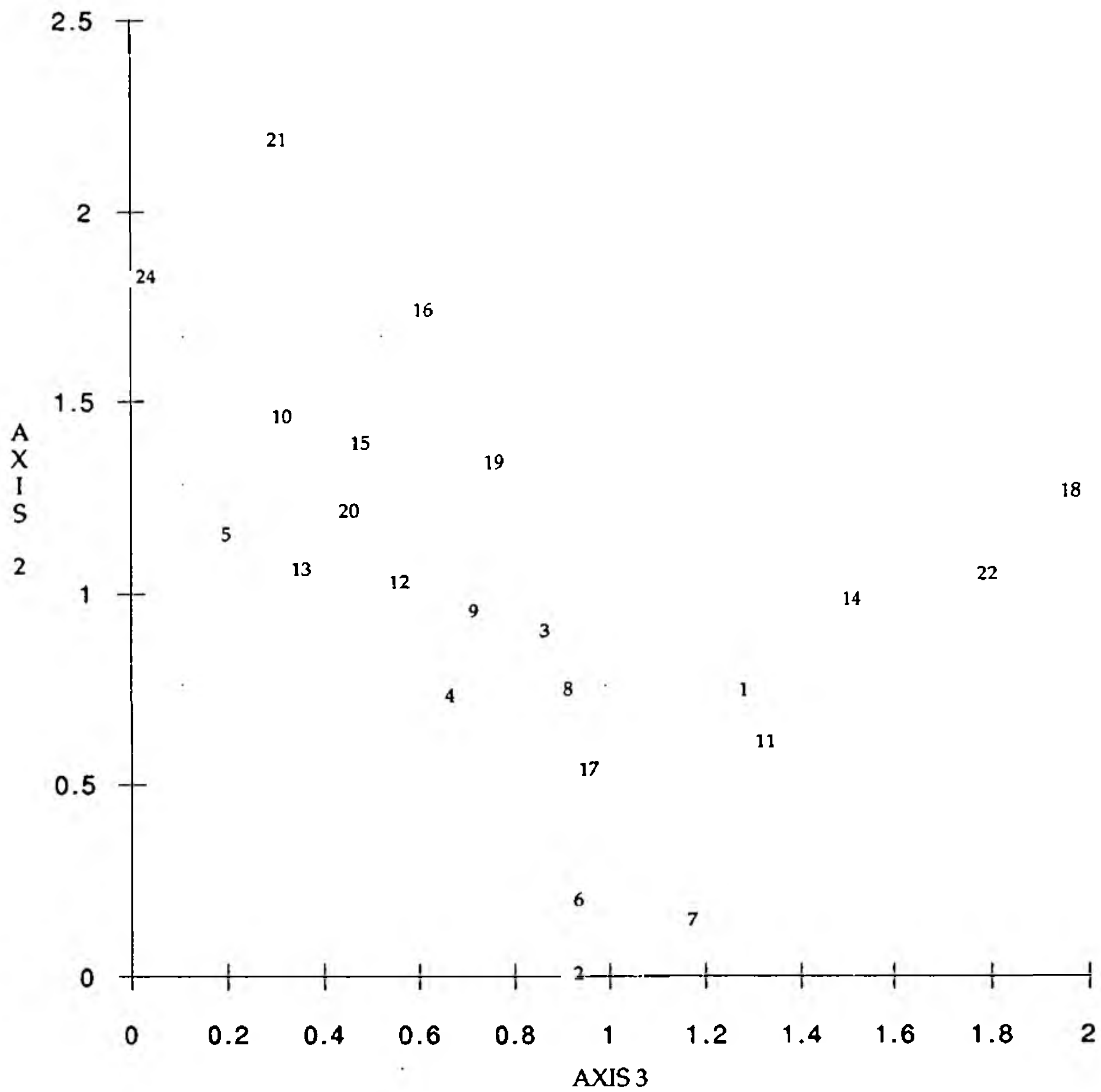


**FIGURE 11 PLOT OF DECORANA AXES 2 & 3 (INTERTIDAL SITES)**



Although Axis 1 is useful in that it shows that site 17 is 'significantly' different from the other intertidal sites, it does not provide much information about the survey area as a whole, consequently Axis 3 was also plotted (Figure 11). The separation of sites along Axis 3 appeared to be based on a combination of sediment type and 'height on the shore'.

Sediment data were recorded as percentages, and are consequently strongly inter-related. Because of this strong intercorrelation the weighted average[2] was taken for each sample and these were used to determine axes correlations (Table 2)

TABLE 2 Pearson Correlations (r values) of Environmental Variables with DECORANA Axes

| | Wtd Av. Whole Sediment | Wtd Av. Silt Component | Ht. on shore | Dist. outfall | %org. carbon |
|---|---|---|---|---|---|
| AXIS 1 | 0.140 | 0.177 | **-0.459** | 0.061 | **0.499** |
| AXIS 2 | -0.136 | -0.125 | **-0.505** | **0.558** | 0.055 |
| AXIS 3 | **-0.599** | **-0.610** | **0.657** | -0.006 | -0.051 |
| AXIS 4 | 0.148 | 0.141 | -0.282 | -0.098 | -0.084 |

**Values of $r^2$ (variance explained) >20% in bold**

DECORANA appears to suggest that, with the exception of site 17, (which appears to be an outlier) 'height on shore' and distance from the Black Rock outfall are playing a significant part in the distribution of species across Weston Bay.

### 6.2ii Subtidal Sites

DECORANA was performed on untransformed data, and produced 4 axes with eigenvalues 0.9522, 0.4389, 0.2431 and 0.141 respectively. A plot of Axes 1 against 2 is presented in Figure 12.

As can be seen, 4 main groups were formed, examining the plot of species scores for Axes 1 and 2 (Figure 13) it can be seen which organisms have been the most influential in the formation of these site groupings:-

1) Sites 1-4, 11, 27 and 28 were grouped together by the presence of active burrowers such as *Tharyx sp. Nephtys hombergii*, Tubificidae and *Hydrobia sp.*

[2] Weighted Average Calculation: the phi value for each sediment type in any one sample is multiplied by its % occurance. These values are added together and divided by 100 to give a weighted average of sediment for that sample. Two such calculations were made, one for whole sediments, and one for the silt component..

2) Sites 8-10, 12, 13, 18 and 22 were linked by the presence of the reef building polychaete*Sabellaria alveolata* and associated fauna eg: *Eulalia tripunctata* .
3) Sites 15 and 30 were paired together partly on the presence of the interstitial polychaete*Ophyrotrocha hartmanni* .
4) Sites 5-7, 14, 16 and 29 seemed to be linked by their common dissimilarity with all the other sites.

Correlation of environmental variables (using weighted averages for sediments) with the DECORANA axes (Table 3) revealed that axis 1 was negatively correlated to sediment type and positively correlated to depth; the variance explained by these variables being 30.25% and 31.81% of the total respectively. Axis 2 was found to have 24.7% ($r^2$) of its total variance explained by organic carbon. This was a negative relationship which on closer examination did not reveal any spatially significant site groupings. This probably reflects the interfering presence of coal dust in the sediments.

DECORANA axis 3 was also plotted (Figure 14), correlation of this axis with environmental variables, revealed a relationship with sediment type. Generally sites positioned high on Axis 3 contained a larger proportion of coarse sand and a smaller proportion of silt.

TABLE 3 Pearson Correlations of Environmental Variables with DECORANA Axes

| | Wtd. Av. Whole Sediment | Wtd. Av. Silt Component | Depth | Dist. outfall | % org. carbon |
|---|---|---|---|---|---|
| AXIS 1 | **-0.550** | -0.373 | **0.564** | 0.355 | -0.015 |
| AXIS 2 | 0.212 | -0.190 | 0.030 | 0.161 | **-0.497** |
| AXIS 3 | **-0.462** | **0.467** | 0.064 | -0.204 | -0.340 |
| AXIS 4 | 0.354 | **0.457** | -0.055 | -0.305 | 0.095 |

**Values of $r^2$ (varience explained) >20% are in bold**

Thus it would appear that the site groupings formed by DECORANA are mainly related to sediment type and depth. Horizontal distance from the outfall was not affecting faunal assemblages, it would therefore appear that the Black Rock outfall was not having an effect subtidally.

FIGURE 12 PLOT OF DECORANA AXIS 1 & 2 (SUBTIDAL SITES)

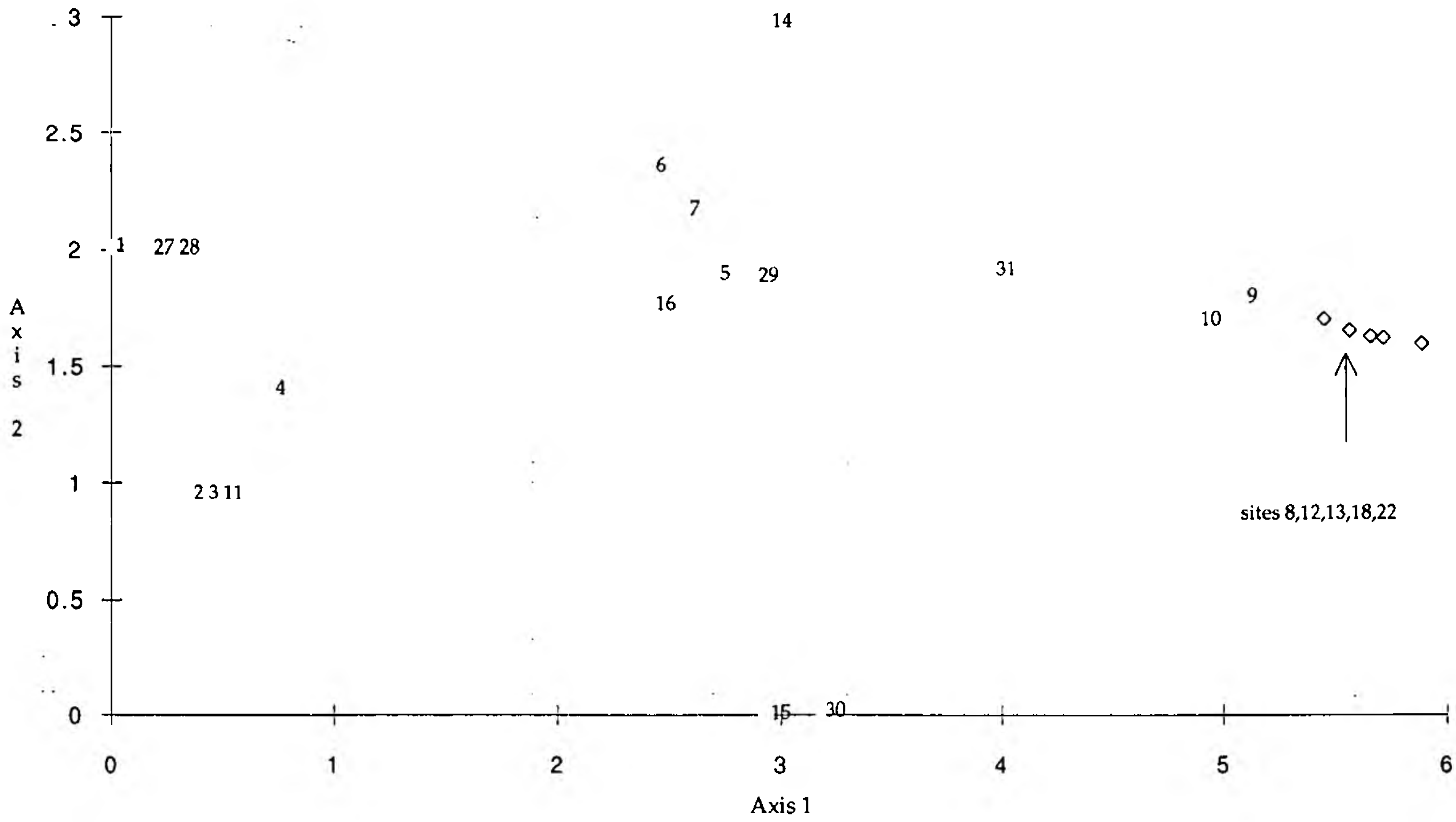


**FIGURE 13 SPECIES SCORES DECORANA AXES 1 & 2 (SUBTIDAL SITES)**

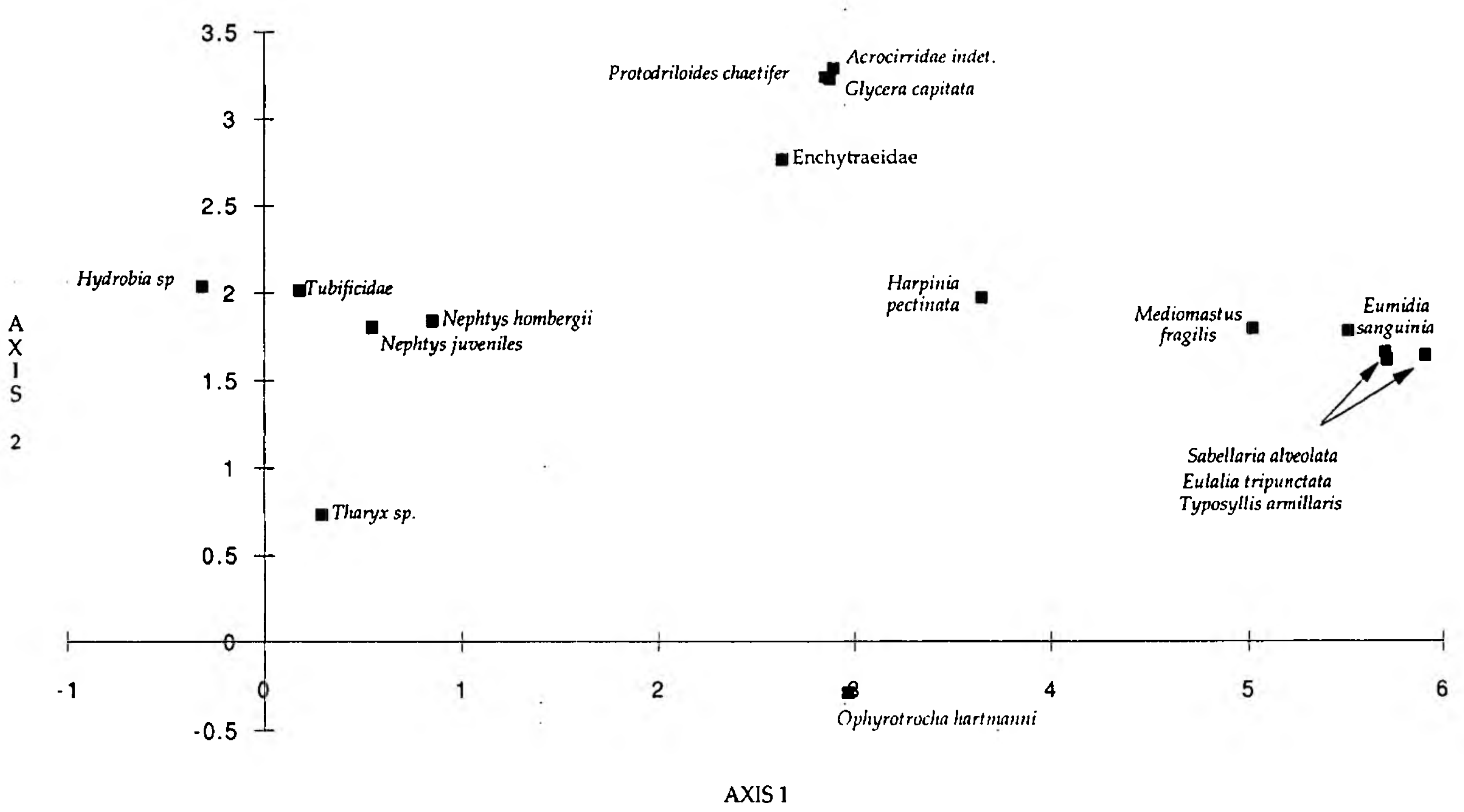
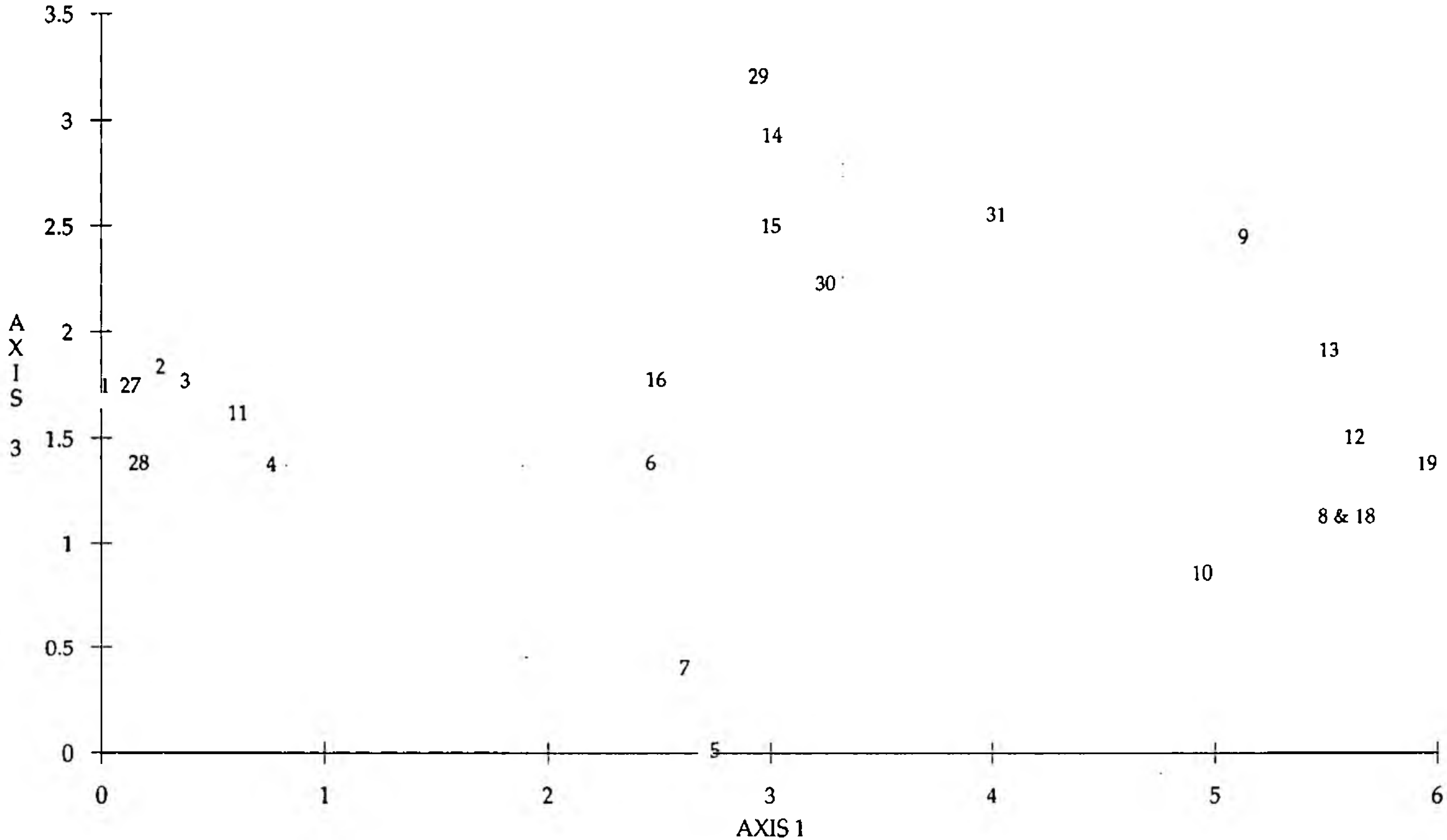


FIGURE 14 PLOT OF DECORANA AXES 1 & 3 (SUBTIDAL SITES)



### 6.3 CANOCO

Two separate analyses were undertaken using subtidal and intertidal data.

#### 6.3i Intertidal Sites

Untransformed data were analysed using CANOCO. Figure 15 shows the site groupings formed and the direction in which the environmental variables were acting. The major indicator species for each group are also illustrated.

As previously seen in DECORANA, site 17 was split away from the other intertidal sites, CANOCO also agreed that this was largely based on the presence of the amphipod *Corophium volulator* . Sites 2, 6 and 7 (and to a certain extent site 4) were split from the main group based on the presence of the polychaetes *Nereis diversicolor* and *Streblospio shrubsolii* , and the oligochaete family Enchytraeidae.

By plotting environmental variables over the site groupings, it can be seen which parameters and indicator species best explain the biological data. Pollution indicator species such as the polychaetes *Streblospio shrubsoli* , *Nereis diversicolor* and the oligochaete family Enchytraeidae, lay at one extreme of the horizontal distance from outfall gradient (ie: close to the outfall) with less 'tolerant' *Nephtys* juveniles at the other (ie: furthest from the outfall). The burrowing amphipod *Bathyporea sarsi* was the key indicator species along the sandy sediment gradient.

Several sites were aggregated around the centre of the plot and could not be clearly separated along any of the environmental gradients. Generally sites in the extreme lower (sites 2, 6, and 7) and upper (sites 18, 21, 23 and 24) parts of the plot followed the distance from outfall vector. Sites 18, 22 and 23 were also influenced by the sand component of the plot. This was not surprising as these sites were the only ones to contain high proportions of coarse sediment. Height on shore tended to most strongly influence low-water sites, with sites 17, 21 and 24 laying at the extreme end of the vector, these sites were quite well separated suggesting that other parameters, such as organic carbon and distance from outfall, were also influencing their positions.

#### 6.3ii Subtidal Sites

Using untransformed data, four distinct groups of sites were observed (Figure 16). Key species involved in these groupings were:

i) sites 14, 15, 29 & 30 - *Protodriloides chaetifer* and*Ophyrotrocha hartmanni*
ii) sites 8, 9, 12, 13, 18, 19, 22 & 31 - *Sabellaria alveolata* , *Melinna cristata* and *Eulalia tripunctata* .

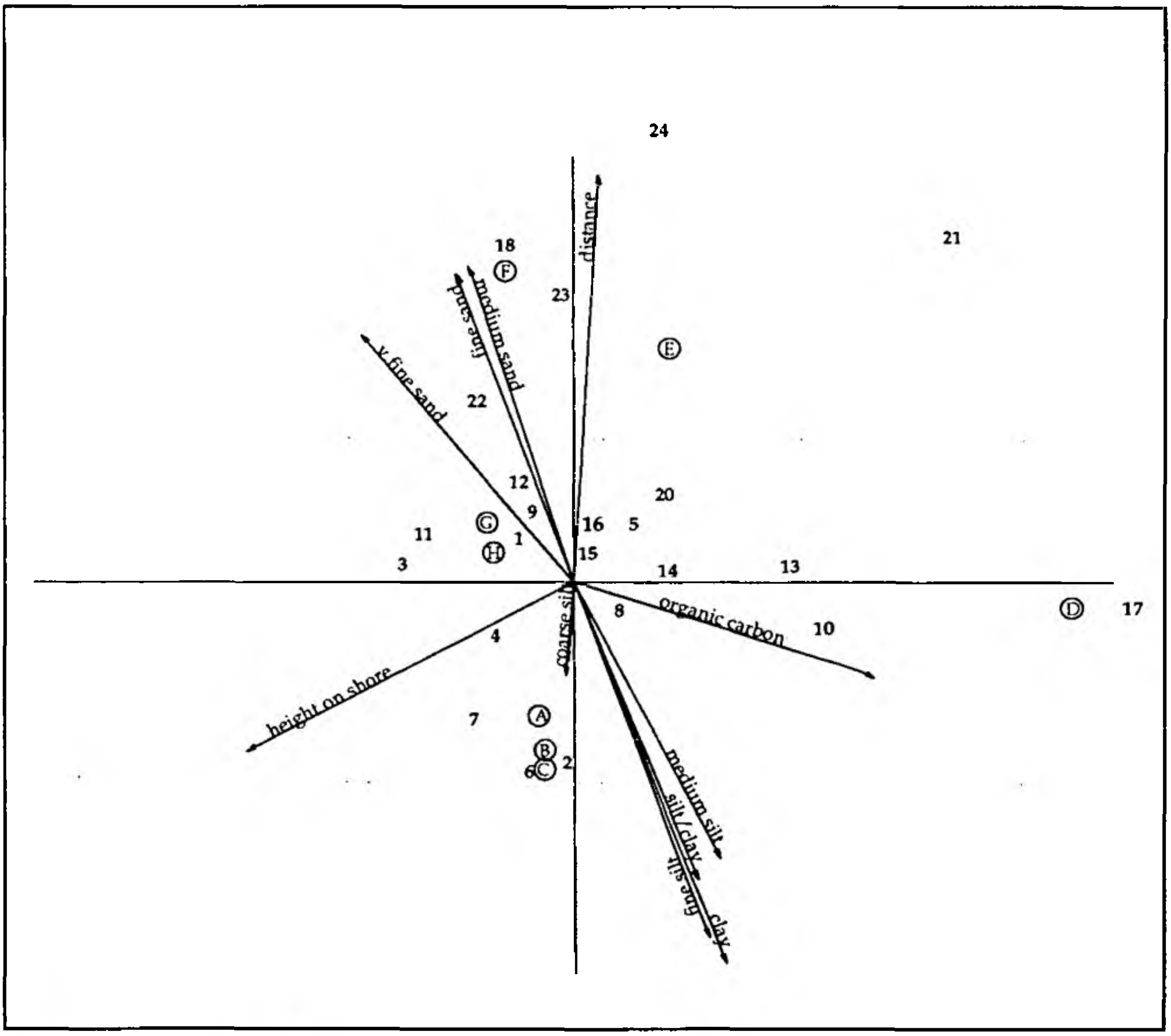
iii) sites 1-7, 10, 11, 27 & 28 - *Tharyx sp. Scoloplos armiger, Macoma balthica,* and *Harpinia pectinata* .

iv) site 16 - *Aricidia minuta*

An overlay of the environmental variables revealed that sites 14, 15, 29 and 30 lie along a sediment gradient of medium and very coarse sand. Group (ii) lies along a gradient of low organic carbon, distance and depth. Closer inspection of the data revealed that there were no results for % organic carbon for these sites, consequently a 'true' organic carbon gradient did not exist.

Sites within group (iii) lay along an increasing silt gradient which was reflected by the burrowing nature of the species found there.

## FIGURE 15 CANOCO - INTERTIDAL DATA



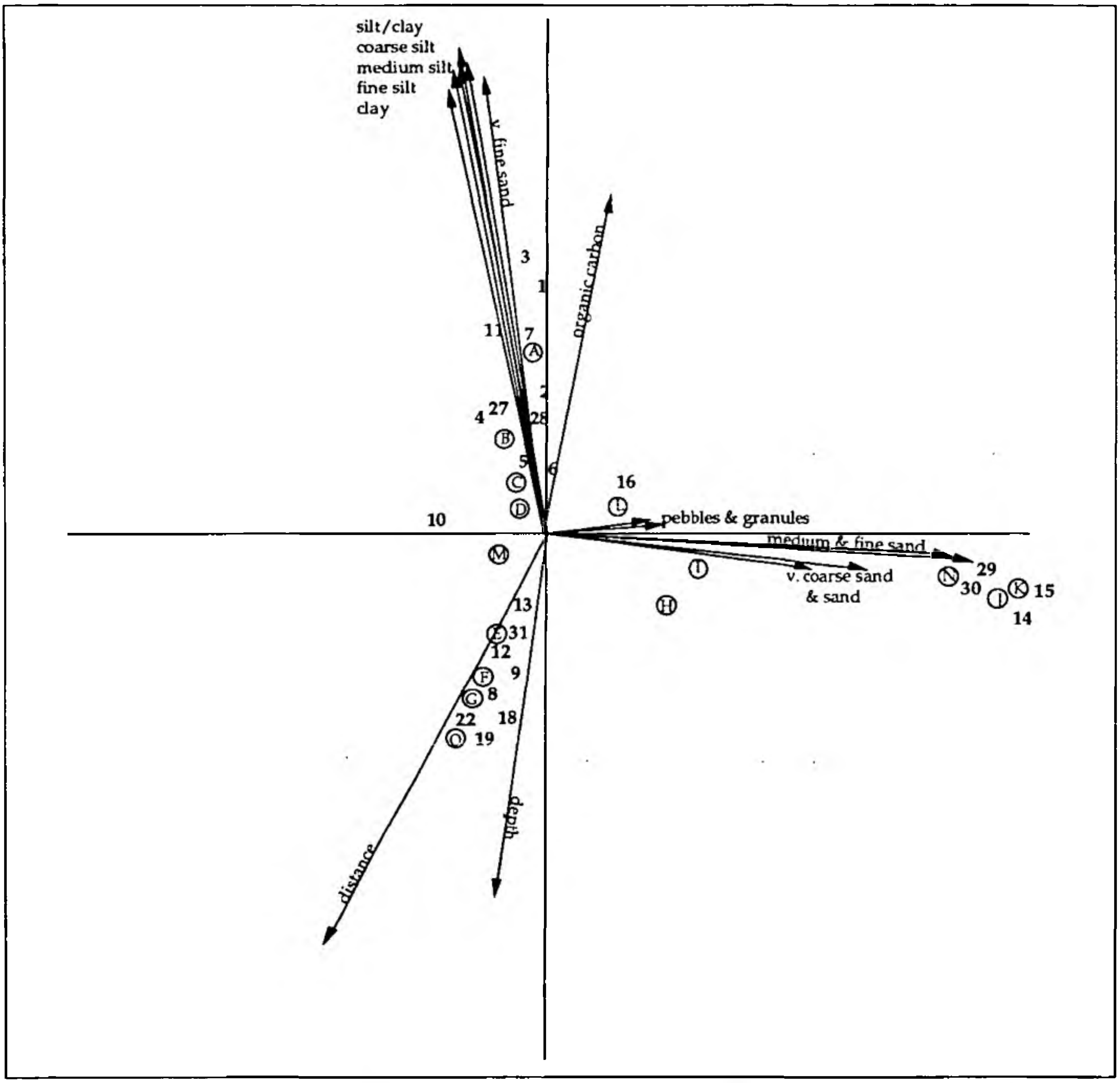

**KEY:**

(A) *Nereis diversicolor*
(B) *Streblospio shrubsolii*
(C) Enchytraeidae
(D) *Corophium volutator*
(E) *Nephtys juvenile*
(F) *Bathyporea sarsi*
(G) *Macoma balthica*
(H) *Pygospio elegans*

——— ENVIRONMENTAL GRADIENTS

22 - SITE NUMBER

## FIGURE 16 CANOCO - SUBTIDAL DATA




**KEY:**

- (A) *Tharyx sp*
- (B) *Macoma balthica*
- (C) *Scoloplos armiger*
- (D) *Harpinia pectinata*
- (E) *Melinna cristata*
- (F) *Eulalia tripunctata*
- (G) *Sabellaria alveolata*
- (H) Nemertea
- (I) Enchytraeidae
- (J) *Protodriloides chaetifer*
- (K) *Ophyrotrocha hartmanni*
- (L) *Aricidia minuta*
- (M) *Nucula sp*
- (N) *Acrocirridae indet.*
- (O) *Typosyllis armalaris*

→ ENVIRONMENTAL GRADIENTS

22 - SITE NUMBER

## 6.4 PRIMER

Several different analyses were performed on the two data sets using this package:-

a) Multidimentional Scaling (M.D.S.)
b) Analysis of Similarity (ANOSIM)
c) Similarity Percentage Analysis (SIMPER)

### 6.4i Intertidal Sites

Species data was converted into an abundance scaling by using a square root root transformation. This scaling reduces the influence of very high abundances on the analysis and thus prevents distortion of the data and presents a more balanced ecological picture.

Figure 17 shows the pattern of sites generated by multidimensional scaling. Overlays of environmental variables showed that 'height on shore' was generating a division of sites, with low water stations separating away from the others (Figure 18). Horizontal distance from the outfall appeared to be an important factor in site distribution, with stations closest to the outfall grouping together (Figure 19). Organic carbon had no obvious influence on site groupings (Figure 20) with the outlier site 17 exhibiting the highest levels. Sediment type, an important factor in determining natural species assemblages, also showed no clear influence on site groupings due to the relative uniformity of the beach (Figure 21), only sites 22, 23 and 18 contained significant proportions of sand (Appendix V).

ANOSIM was used to analyse the significance of the environmental variables (height on shore and distance from outfall) suggested by the MDS plots to be influencing species distribution and thus site groupings. Sites were first grouped according to their height on the shore (Table 4).

**Table 4 Results of ANOSIM Test using 'Height' - values of R (measure of disimmilarity) and levels of significance are shown for each group pairing**

| Ht on Shore | Site Groupings | ANOSIM Groups | 1 | | 2 | |
|---|---|---|---|---|---|---|
| | | | R | % sig. | R | % sig. |
| upper | 1-3, 6-8, 11, 12, 14, 15, 18, 19, 22 | 1 | - | - | - | - |
| middle | 4, 9, 13, 16, 20, 23 | 2 | .15 | ** | - | - |
| lower | 5, 10, 17, 21, 24 | 3 | .66 | *** | .35 | *** |

*** - >99% significant ** - >95% significant * - 95%<n>90% significant

The results of the ANOSIM test (Table 4) not surprisingly revealed that low-water sites were least similar (R tends to 1) to upper shore sites. While mid-

FIGURE 17    SQUARE ROOT ROOT TRANSFORMED INTERTIDAL MDS PLOT

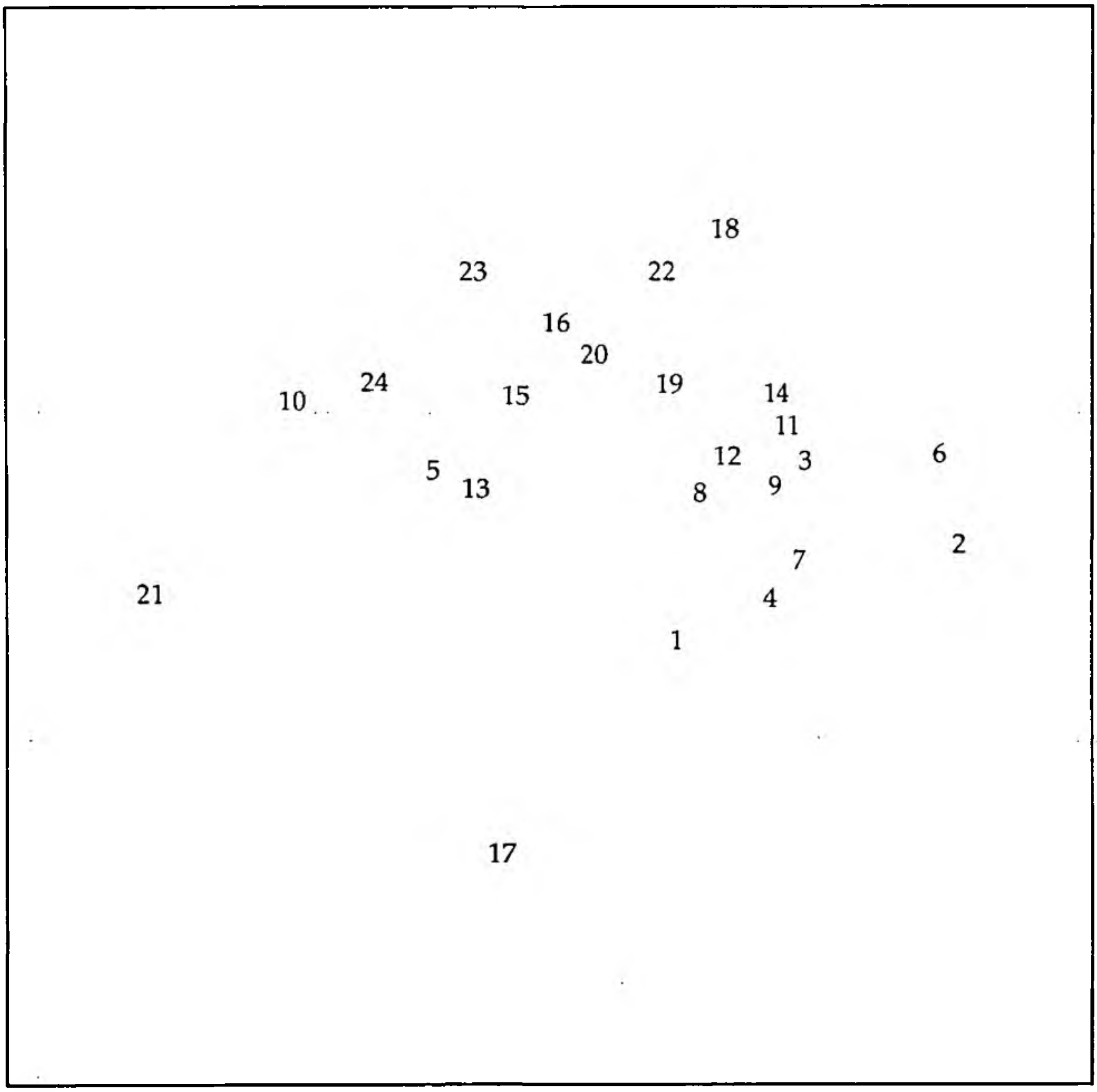


FIGURE 18 OVERLAY OF 'HEIGHT ON SHORE' ON INTERTIDAL MDS PLOT
(Root Root Transformation)

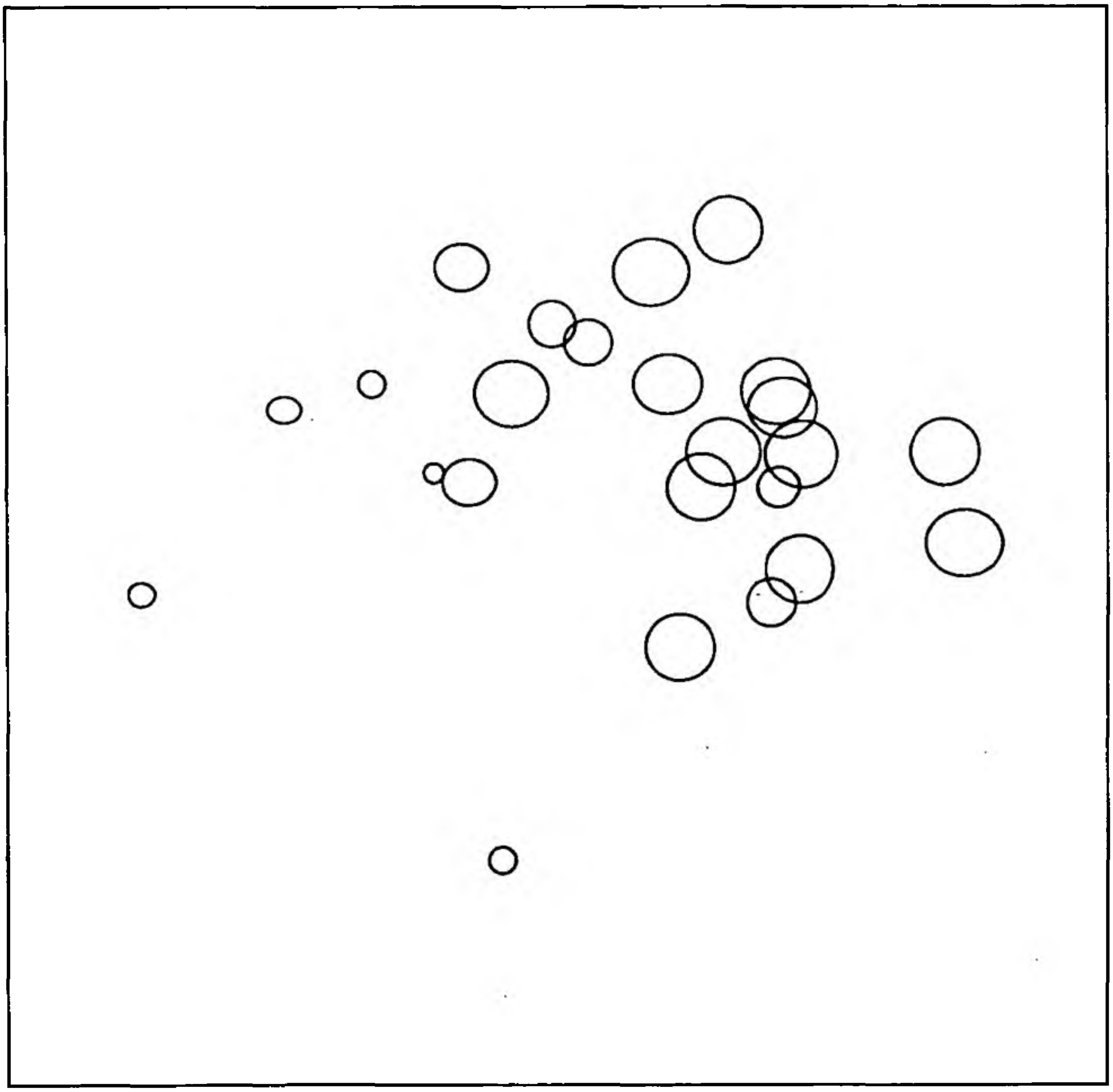


FIGURE 19 OVERLAY OF HORIZONTAL DISTANCE ON INTERTIDAL MDS PLOT (Root Root Transformation)

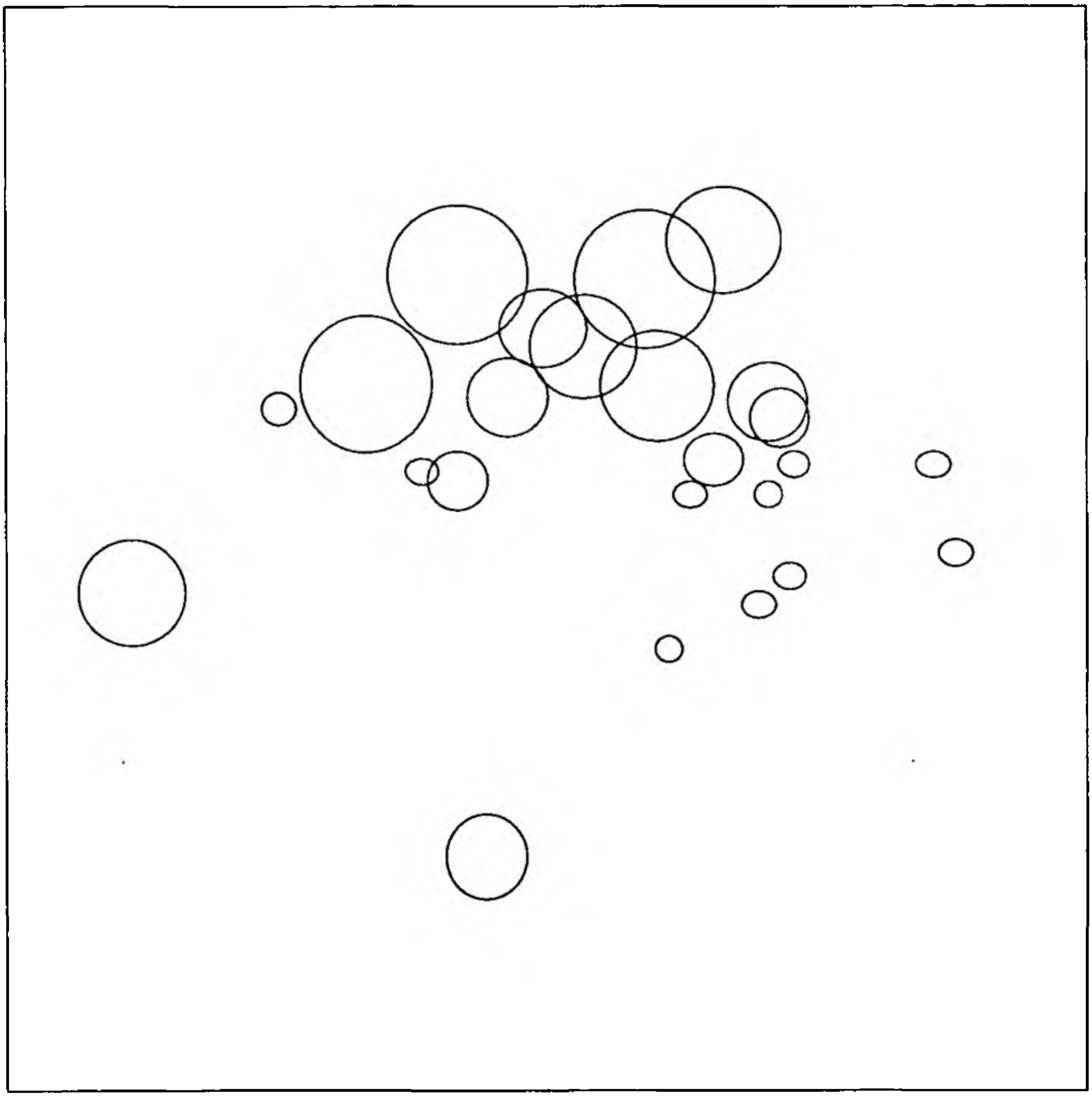


FIGURE 20 OVERLAY OF '% ORGANIC CARBON' ON INTERTIDAL MDS PLOT
(Root Root Transformation)

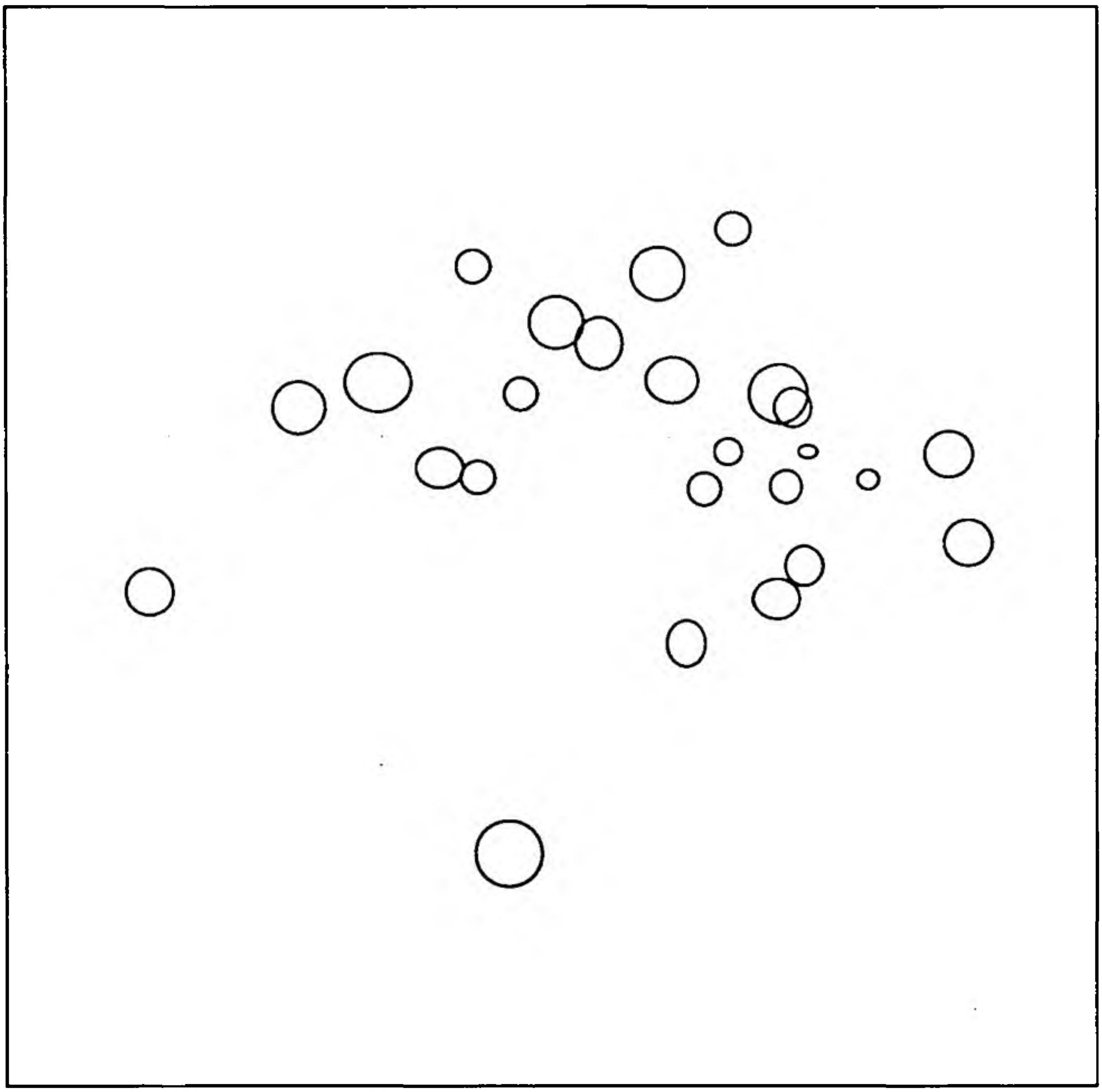
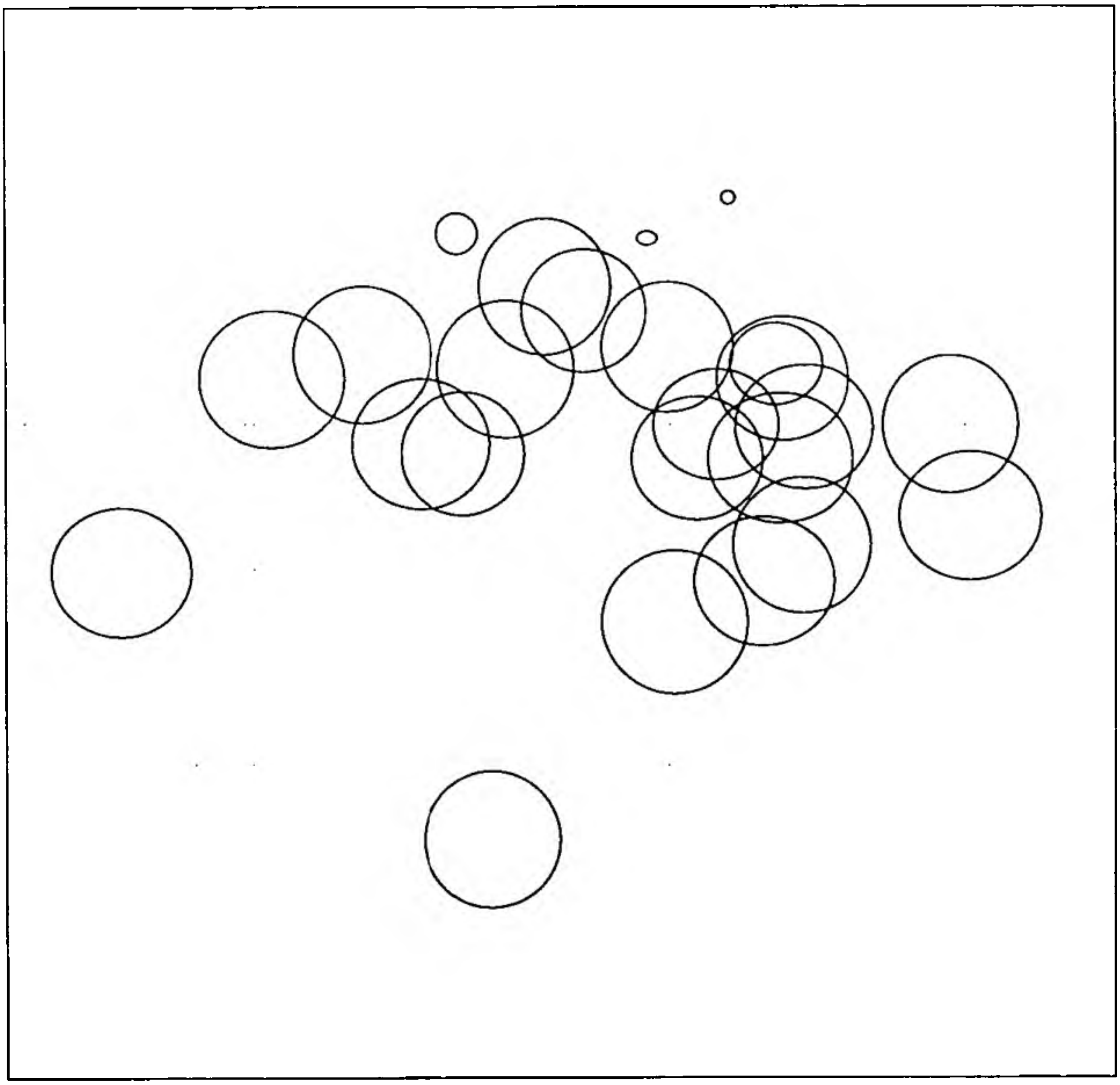


FIGURE 21 OVERLAY OF 'SILT CONTENT' ON INTERTIDAL MDS PLOT
(Root Root Transformation)



shore sites formed an intermediate group, which was most similar (R tends to 0) to the upper shore sites.

SIMPER was used to examine the species responsible for within group similarity (Table 5) and between group dissimilarity (Table 6).

**TABLE 5 Contribution (%) of Species to the Within Group Similarity of 'Height on Shore' Groupings.**

| *SPECIES* | Av. Similarity | Std. Dev. | % contribution |
|---|---|---|---|
| GROUP 1 AVERAGE SIMILARITY 62.06 (S.D. 10.80) | | | |
| *Hydrobia sp* | 19.1 | 4.79 | 30.83 |
| *Macoma balthica* | 17.2 | 2.77 | 27.65 |
| *Pygospio elegans* | 7.8 | 3.88 | 12.58 |
| *Nephtys hombergii* | 7.6 | 5.54 | 12.27 |
| GROUP 2 AVERAGE SIMILARITY 59.09 (S.D. 11.70) | | | |
| *Hydrobia sp* | 24.0 | 4.78 | 40.58 |
| *Macoma balthica* | 14.0 | 2.31 | 23.64 |
| *Nephtys hombergii* | 7.9 | 6.55 | 13.35 |
| *Nephtys* juveniles | 3.1 | 4.07 | 5.32 |
| GROUP 3 AVERAGE SIMILARITY 51.17 (S.D. 16.44) | | | |
| *Nephtys hombergii* | 13.7 | 3.61 | 26.72 |
| *Nephtys* juveniles | 12.0 | 2.79 | 23.38 |
| *Macoma balthica* | 10.6 | 1.72 | 20.66 |
| *Hydrobia sp* | 6.0 | 9.74 | 11.72 |

The species responsible for within group similarities were similar for each group varying only in their % contribution. Both *Macoma* and *Hydrobia* contributed least to the within group similarity of low-water sites. These molluscs are most commonly found on the upper-shore (Tebble 1976 & Graham 1988) although they can be found throughout the intertidal zone. Thus SIMPER suggests that the distribution of these molluscs within the intertidal zone of Weston Bay is 'natural'. Similarly, *Nephtys* juveniles and *N. hombergii* contributed most to the similarity of low-water sites. These polychaetes are found throughout the intertidal zone but are most abundant from mid-tide downwards (Brafield 1978). SIMPER again suggests that the vertical distribution of these polychaetes is 'natural'.

**TABLE 6** **Contribution (%) of Species to the Dissimilarity of 'Height on Shore' Groupings.**

| Group Pairing | Av.dissimilarity | *Species* (top 3) | % contribution |
|---|---|---|---|
| 1 and 2 | 42.21 | ***Nereis diversicolor*** | 13.10 |
| | | *Nephtys hombergii* | 8.53 |
| | | ***Pygospio elegans*** | 7.74 |
| | | *Hydrobia sp.* | 7.63 |
| 1 and 3 | 60.98 | ***Hydrobia sp.*** | 13.94 |
| | | ***Nereis diversicolor*** | 11.17 |
| | | ***Macoma balthica*** | 10.03 |
| | | *Nephtys* juveniles | 9.20 |
| 3 and 2 | 54.03 | ***Hydrobia sp.*** | 17.99 |
| | | *Corophium volutator* | 9.33 |
| | | ***Macoma balthica*** | 7.50 |
| | | ***Nephtys hombergii*** | 6.84 |

***Species in bold represent the first named group***
*Species in plain type represent the second named group*

Owing to the large number of species contributing to between group differences (Table 6), only the top 4 species are presented. The analysis revealed that the polychaete *Nereis diversicolor* and the molluscs *Hydrobia sp.* and *Macoma balthica* provided the largest contribution to the differences between upper and lower-shore sites. As previously mentioned, this appears to reflect the natural distribution of *Hydrobia* and *Macoma* . Similarly, *Nereis diversicolor* , is also normally distributed along the upper to mid-shore zone.

A second ANOSIM was run using the criteria 'horizontal distance from the outfall', to form site groupings (Table 7). Transects 1 and 2 were considered together as their component sites lay either side of the outfall, they were consequently considered as equidistant. The results of this analysis are presented in Table 8.

**Table 7** **'Horizontal Distance' Site Groupings for ANOSIM**

| Transect | Site Groupings | ANOSIM Group |
|---|---|---|
| 1 & 2 | 1 - 10 | 1 |
| 3 | 11 - 13 | 2 |
| 4 | 14 - 17 | 3 |
| 5 | 18 - 21 | 4 |
| 6 | 22 - 24 | 5 |

**Table 8** **Results of ANOSIM Test using 'Horizontal distance'- values of R (measure of dissimilarity) and their significance levels are shown for each group pairing**

| Groups | 1 | | 2 | | 3 | | 4 | |
|---|---|---|---|---|---|---|---|---|
| | **R** | % sig. level | **R** | % sig. level | **R** | % sig. level | **R** | % sig. level |
| 2 | **-.08** | ns | - | - | - | - | - | - |
| 3 | **.19** | * | **-0.16** | ns | - | - | - | - |
| 4 | **.27** | ** | **-0.08** | ns | **-.13** | ns | - | - |
| 5 | **.44** | ** | **.30** | ns | **-.01** | ns | **-.01** | ns |

ns = not significant   * - 95%>n>90% significance
** - >95% significance   *** - >99% significance

As can be seen the only significant results were recorded from pairings with group 1. The dissimilarity measure between these pairings increased with increasing distance, suggesting that a gradual change in faunal assemblages occurs across the beach.

SIMPER was used to examine the species responsible for the within group similarities (Table 9) and between group differences (Table 10).

**TABLE 9** **Contribution (%) of Species to the With Group Similarity of 'Horizontal Distance from Outfall' Groupings.**

| *SPECIES* | Av. Similarity | Std. Dev. | % contribution |
|---|---|---|---|
| **GROUP 1 AVERAGE SIMILARITY 57.03 (S.D. 15.78)** | | | |
| *Hydrobia sp* | 19.2 | 5.33 | 33.70 |
| *Macoma balthica* | 13.5 | 3.09 | 23.70 |
| *Nereis diversicolor* | 8.5 | 7.15 | 14.90 |
| **GROUP 2 AVERAGE SIMILARITY 58.33 (S.D. 13.58)** | | | |
| *Hydrobia sp* | 25.4 | 5.40 | 43.52 |
| *Macoma balthica* | 14.8 | 3.94 | 25.32 |
| *Nephtys hombergii* | 10.0 | 2.89 | 17.10 |
| **GROUP 3 AVERAGE SIMILARITY 50.98 (S.D. 17.62)** | | | |
| *Macoma balthica* | 14.8 | 3.55 | 28.95 |
| *Nephtys hombergii* | 11.0 | 3.86 | 21.60 |
| *Hydrobia sp* | 10.1 | 11.17 | 19.72 |
| *Nephtys* juveniles | 4.9 | 5.77 | 9.69 |
| **GROUP 4 AVERAGE SIMILARITY 46.74 (S.D. 22.61)** | | | |
| *Nephtys hombergii* | 15.4 | 3.27 | 32.88 |
| *Macoma balthica* | 13.2 | 6.21 | 28.16 |
| *Hydrobia sp* | 10.9 | 12.89 | 23.41 |
| **GROUP 5 AVERAGE SIMILARITY 64.03 (S.D. 10.88)** | | | |
| *Hydrobia sp.* | 21.9 | 2.43 | 34.18 |
| *Nephtys hombergiii* | 14.9 | 1.86 | 23.27 |
| *Macoma balthica* | 12.3 | 1.41 | 19.15 |
| *Nephtys* juveniles | 8.1 | 1.79 | 12.59 |

Owing to their widespread distribution, the molluscs *Hydrobia* and *Macoma*, were largely responsible for within group similarities . However other important species were also present. The pollution tolerant polychaete *Nereis diversicolor* only contributed to the similarity of sites within group 1 (ie: sites closest to the outfall), while *Nephtys hombergii* and *Nephtys* juveniles contributed most to groups further from the outfall. As can be seen the average similarity of each group is quite high demonstrating that distance is a good criterion for site groupings.

Inter-group dissimilarities are presented in Table 10, only the top 3 species are presented.

**TABLE 10 Contribution (%) of Species to the Dissimilarity of Anosim 'Horizontal Distance' Groupings'**

| Group Pairing | Av.dissimilarity | *Species* (top 3) | % contribution |
|---|---|---|---|
| 1 and 2 | 39.81 | ***Nereis diversicolor*** | 13.84 |
| | | *Hydrobia sp.* | 9.67 |
| | | ***Streblospio shrubsoli*** | 8.93 |
| 1 and 3 | 49.58 | ***Nereis diversicolor*** | 13.96 |
| | | ***Hydrobia sp.*** | 12.57 |
| | | *Corophium volulator* | 9.37 |
| 1 and 4 | 52.88 | ***Nereis diversicolor*** | 14.36 |
| | | ***Hydrobia sp*** | 12.27 |
| | | *Nephtys hombergii* | 8.81 |
| 1 and 5 | 53.61 | ***Nereis diversicolor*** | 14.52 |
| | | ***Hydrobia sp*** | 8.87 |
| | | *Nephtys* juveniles | 8.82 |
| 2 and 3 | 42.68 | ***Hydrobia sp.*** | 15.39 |
| | | *Corophium volulator* | 12.57 |
| | | ***Nereis diversicolor*** | 11.58 |
| 2 and 4 | 45.52 | ***Hydrobia sp*** | 14.53 |
| | | ***Nereis diversicolor*** | 11.80 |
| | | *Macoma balthica* | 8.54 |
| 2 and 5 | 43.11 | ***Nereis diversicolor*** | 12.79 |
| | | *Nephtys* juveniles | 10.59 |
| | | ***Hydrobia sp*** | 10.38 |
| 3 and 4 | 47.42 | *Hydrobia sp* | 15.28 |
| | | ***Corophium volulator*** | 10.52 |
| | | *Macoma balthica* | 7.95 |
| 3 and 5 | 44.30 | ***Corophium volulator*** | 11.09 |
| | | ***Hydrobia sp*** | 10.00 |
| | | *Macoma balthica* | 9.33 |
| 4 and 5 | 44.65 | ***Hydrobia sp*** | 14.28 |
| | | *Macoma balthica* | 11.95 |
| | | *Pygospio elegans* | 9.46 |

***Species in bold represent the first named group***
*Species in plain type represent the second named group*

As can be seen, the pollution tolerant polychaete *N. diversicolor* and the gastropod *Hydrobia sp.* were the main species involved in the dissimilarity of group 1 with the other sites. Although predominantly occurring on the upper shore, *Hydrobia* was abundant throughout the bay and this was reflected by its contribution to the dissimilarity of all the group pairings. Unlike *Hydrobia*, *Nereis* was exclusive to group 1. The presence of this pollution tolerant polychaete, suggests that 'distance from outfall' is a significant factor in the formation of species assemblages within the intertidal zone of Weston Bay.

As already shown, 'height on shore' is affecting the distribution of species within the intertidal zone, as low-water sites support different faunal assemblages to those recorded further up the shore. Examining the 'horizontal distance' MDS overlay (Figure 19) it can be seen that the low-water sites do not follow the horizontal distance from outfall pattern, suggesting that this parameter applies mainly to upper and mid-shore sites. If this is the case, the exclusion of low-water sites from ANOSIM and SIMPER should increase within group similarity and provide a clearer ecological picture for upper and mid-shore sites. Table 11 shows the results of ANOSIM on the new groups.

**Table 11 Results of ANOSIM Test using 'Horizontal distance with low-water sites removed' - values of R (measure of dissimilarity) and their significance levels are shown for each group pairing**

| Sites | ANOSIM Groups | 1 | | 2 | | 3 | | 4 | |
|---|---|---|---|---|---|---|---|---|---|
| | | R | % sig. | R | % sig. | R | % sig. | R | % sig. |
| 1-4, 6-9 | 1 | - | - | - | - | - | - | - | - |
| 11-13 | 2 | **0.10** | ns | - | - | - | - | - | - |
| 14-16 | 3 | **0.51** | ** | **-0.11** | ns | - | - | - | - |
| 18-20 | 4 | **0.63** | *** | **0.00** | ns | **-0.07** | ns | - | - |
| 22, 23 | 5 | **0.90** | ** | **0.32** | ns | **0.23** | ns | 0.30 | ns |

ns = not significant     * - 95%>n>90% significance
** - >95% significance     *** ->99% significance

As can be seen the R values for each group 1 pairing have increased (cf: Table 8) showing that between group differences are larger. Running SIMPER on these same groups it can be seen that the species contributing to within group similarities (Table 12) did not differ greatly from those previously calculated. However the levels of similarity had increased and the standard deviation greatly decreased, showing that these groupings were more significant.

TABLE 12 **Contribution (%) of Species to the Similarity of 'Horiontal Distance' Groupings Excluding Low-Water Sites.**

| *SPECIES* | Av. Similarity | Std. Dev. | % contribution |
|---|---|---|---|
| GROUP 1 AVERAGE SIMILARITY 66.71 (S.D. 8.46) | | | |
| *Hydrobia sp* | 19.1 | 5.40 | 28.61 |
| *Macoma balthica* | 151 | 2.54 | 22.69 |
| *Nereis diversicolor* | 13.7 | 3.20 | 20.47 |
| *Pygospio elegans* | 7.1 | 0.97 | 10.72 |
| GROUP 2 AVERAGE SIMILARITY 58.33 (S.D. 13.58) | | | |
| *Hydrobia sp* | 25.4 | 5.40 | 43.52 |
| *Macoma balthica* | 14.8 | 3.94 | 25.32 |
| *Nephtys hombergii* | 10.0 | 2.89 | 17.10 |
| GROUP 3 AVERAGE SIMILARITY 65.45 (S.D. 11.81) | | | |
| *Hydrobia sp* | 20.1 | 2.99 | 30.71 |
| *Macoma balthica* | 17.9 | 1.08 | 27.37 |
| *Nephtys hombergii* | 12.9 | 5.08 | 19.77 |
| GROUP 4 AVERAGE SIMILARITY 66.76(S.D. 7.09) | | | |
| *Hydrobia sp* | 21.9 | 7.49 | 32.78 |
| *Macoma balthica* | 18.4 | 3.61 | 27.58 |
| *Nephtys hombergii* | 14.5 | 3.21 | 21.74 |
| GROUP 5 AVERAGE SIMILARITY 74.66 (S.D. -99.0) | | | |
| No species contributions calculated | | | |

Inter-group dissimilarities (Table 13) involved more pollution tolerant species (*Nereis diversicolor. Streblospio shrubsolii* and Enchytraeidae) than in the previous analysis (cf: Table 9) although it should be noted that the levels of dissimilarity were slightly reduced. Species representing group 1 in the pairings were all pollution tolerant and the average dissimilarity increased with increasing distance from the outfall. Thus it would appear that species assemblages above the lower shore gradually change with increasing distance from the outfall, the species present suggesting that a zone of impact exists within a horizontal distance of 300m from the Black Rock outfall, and a radial distance of 860m.

In summary, it would appear that of the environmental parameters examined 'height on shore' and 'horizontal distance from outfall' provide the greatest explanation for the differences in intertidal species assemblages recorded in Weston Bay. The influence of sediment type was removed owing to the relative uniformity of the area examined, and that of organic carbon confused by the presence of coal-dust. From the analysis it would therefore appear that apart from the natural 'height on shore' zonation, Weston Bay could also be divided into two regions which seem to be related to horizontal distance of from the Black Rock outfall, the 'boundary' existing at approximately 300m (equivalent to a radius of 860m). This suggests that the effluent may be influencing the faunal assemblages within the intertidal reaches of Weston Bay.

TABLE 13 Contribution (%) of Species to the Dissimilarity of 'Horizontal Distance' Groupings Excluding Low-Water Sites.

| Group Pairing | Av.dissimilarity | *Species* (top 3) | % contribution |
|---|---|---|---|
| 1 and 2 | 37.69 | ***Nereis diversicolor*** | 14.25 |
| | | ***Streblospio shrubsolii*** | 11.78 |
| | | **Enchytraeidae** | 8.84 |
| 1 and 3 | 44.93 | ***Nereis diversicolor*** | 17.75 |
| | | *Nephtys hombergii* | 10.48 |
| | | **Streblospio shrubsoli** | 9.31 |
| 1 and 4 | 45.31 | ***Nereis diversicolor*** | 19.80 |
| | | *Nephtys hombergii* | 11.21 |
| | | **Streblospio shrubsoli** | 9.36 |
| 1 and 5 | 55.23 | ***Nereis diversicolor*** | 17.03 |
| | | **Streblospio shrubsoli** | 8.03 |
| | | ***Hydrobia sp*** | 7.47 |
| 2 and 3 | 36.75 | ***Nereis diversicolor*** | 13.17 |
| | | *Nephtys* juvenile | 11.35 |
| | | ***Hydrobia sp.*** | 10.56 |
| 2 and 4 | 37.80 | ***Nereis diversicolor*** | 13.34 |
| | | *Nephtys hombergii* | 9.80 |
| | | *Macoma balthica* | 7.84 |
| 2 and 5 | 40.83 | ***Nereis diversicolor*** | 13.01 |
| | | *Macoma balthica* | 10.72 |
| | | *Bathyporea sarai* | 10.54 |
| 3 and 4 | 33.85 | ***Nephtys* juveniles** | 12.09 |
| | | *Hydrobia sp.* | 10.83 |
| | | *Pygospio elegans* | 9.33 |
| 3 and 5 | 34.56 | ***Bathyporea sarsi*** | 12.40 |
| | | *Macoma balthica* | 11.97 |
| | | *Pygo spio elegans* | 11.26 |
| 4 and 5 | 35.58 | ***Bathyporea sarsi*** | 12.42 |
| | | *Macoma balthica* | 11.46 |
| | | *Pygospio elegans* | 11.00 |

***Species in bold represent the first named group***
*Species in plain type represent the second named group*

## 6.2 Subtidal Sites

MDS was performed on untransformed subtidal data, the resulting plot is illustrated in Figure 22. To examine the influence of various environmental factors on these site groupings, several sets of data were overlaid. An overlay of the silt content of sediments (Figure 23) showed that this was partly contributing to the species assemblages present. Sites to the left of the plot had no sediment data due to the presence of *Sabellaria* beds and large stones, which prevent accurate samples from being taken with the Day grab. Site 10 was the only *Sabellaria* site to be sampled for particle size analysis, because of the higher proportion of silt present. Consequently this station supported a mixture of burrowing organisms and *Sabellaria* associations, which explains its tendancy to group with the other *Sabellaria* sites. The overlay of coarse silt (Figure 24), clearly explains the faunal assemblages observed in sites 14, 15, 29 and 30. As observed in DECORANA, horizontal distance from the outfall did not appear to be influencing site groupings (Figure 25).

Sediment type thus appeared to be the greatest influencing factor on site groupings from MDS. ANOSIM was used to test the significance of sediment on the site groupings. The groups were formed based on the % of silt and sand present at each site (Table 14).

**TABLE 14 Results of ANOSIM Test using 'Sediment Type' - values of R (measure of dissimilarity) and their significance levels are shown for each group pairing.**

| Sediment | Site Groupings | Anosim Groups | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|---|---|
| | | | R | % sig. | R | % sig. | R | % sig. |
| >80% silt | 1-3, 7,10, 11, 27, 28 | 1 | - | - | - | - | - | - |
| >80% sand | 14, 15, 29 | 2 | .76 | *** | - | - | - | - |
| No Sediment Sample (ground too hard) | 8, 9, 12, 13, 18, 19, 22, 31 | 3 | .71 | *** | .81 | *** | - | - |
| 'mixed sediments' | 4-6, 16, 30 | 4 | .08 | ns | .33 | ns | .60 | *** |

ns - no significance *** - >99% significant

As can be seen all groups with the exception of group 4 (mixed sediments), were significantly dissimilar This supports the hypothesis that the main criteria involved in the distribution of species within the subtidal zone was sediment type.

SIMPER was used to examine the species involved in the similarity of sites within groups (Table 15) and the dissimilarity between groups (Table 16).

FIGURE 22   SUBTIDAL MDS PLOT (No Transformantion)

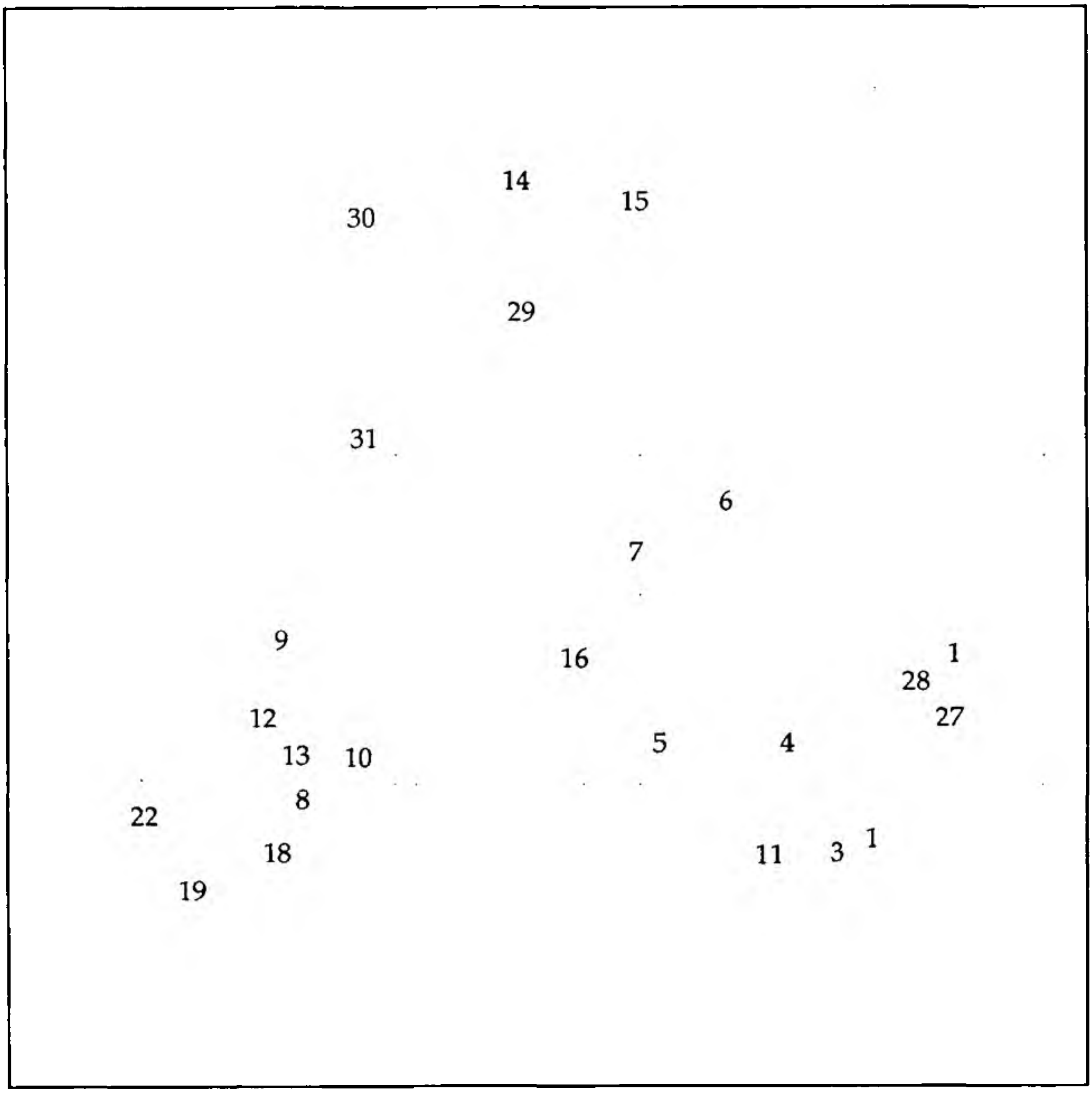


FIGURE 23   OVERLAY OF 'SILT CONTENT' ON SUBTIDAL MDS PLOT

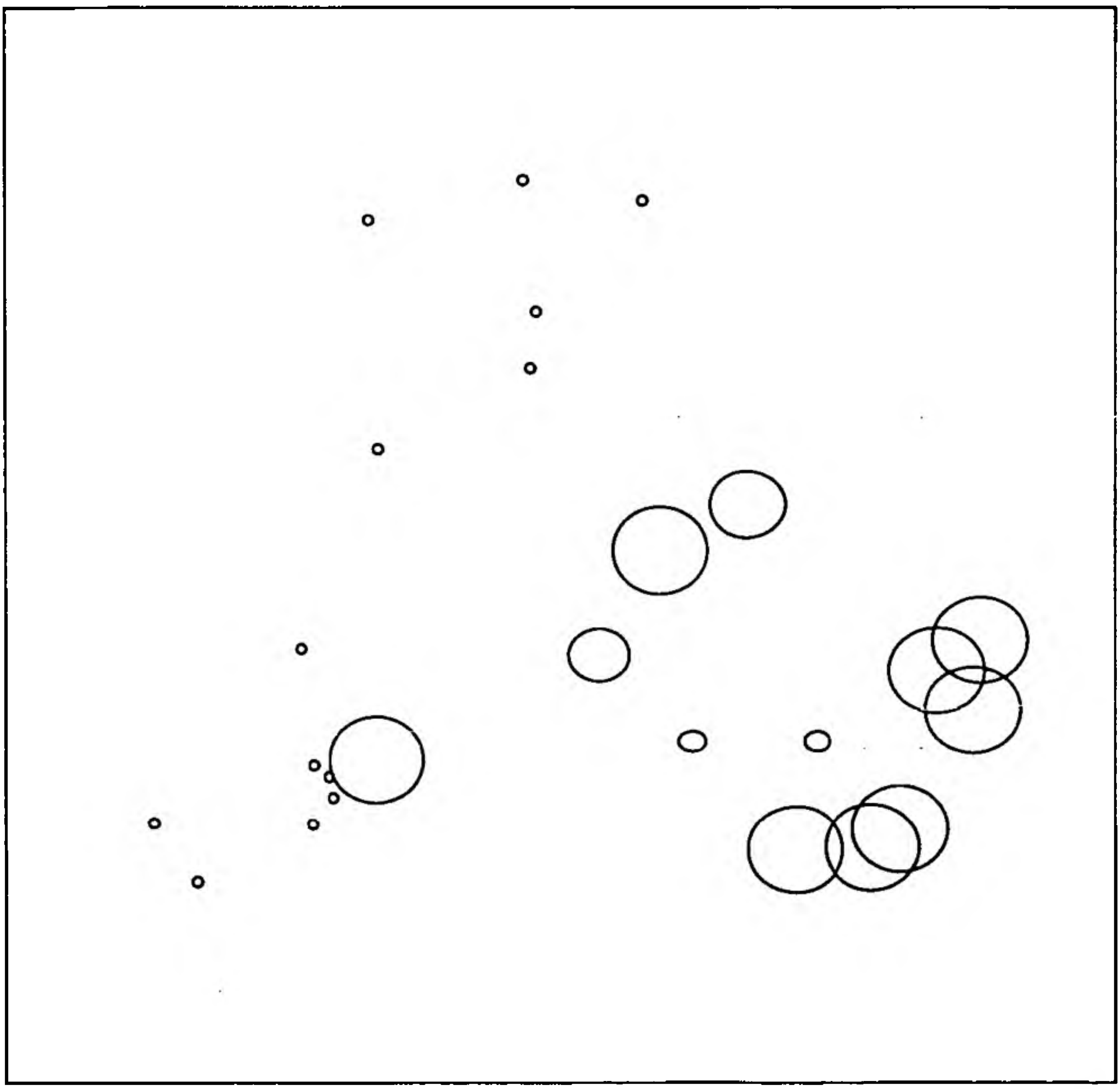


FIGURE 24 OVERLAY OF 'COARSE SAND' ON SUBTIDAL MDS PLOT

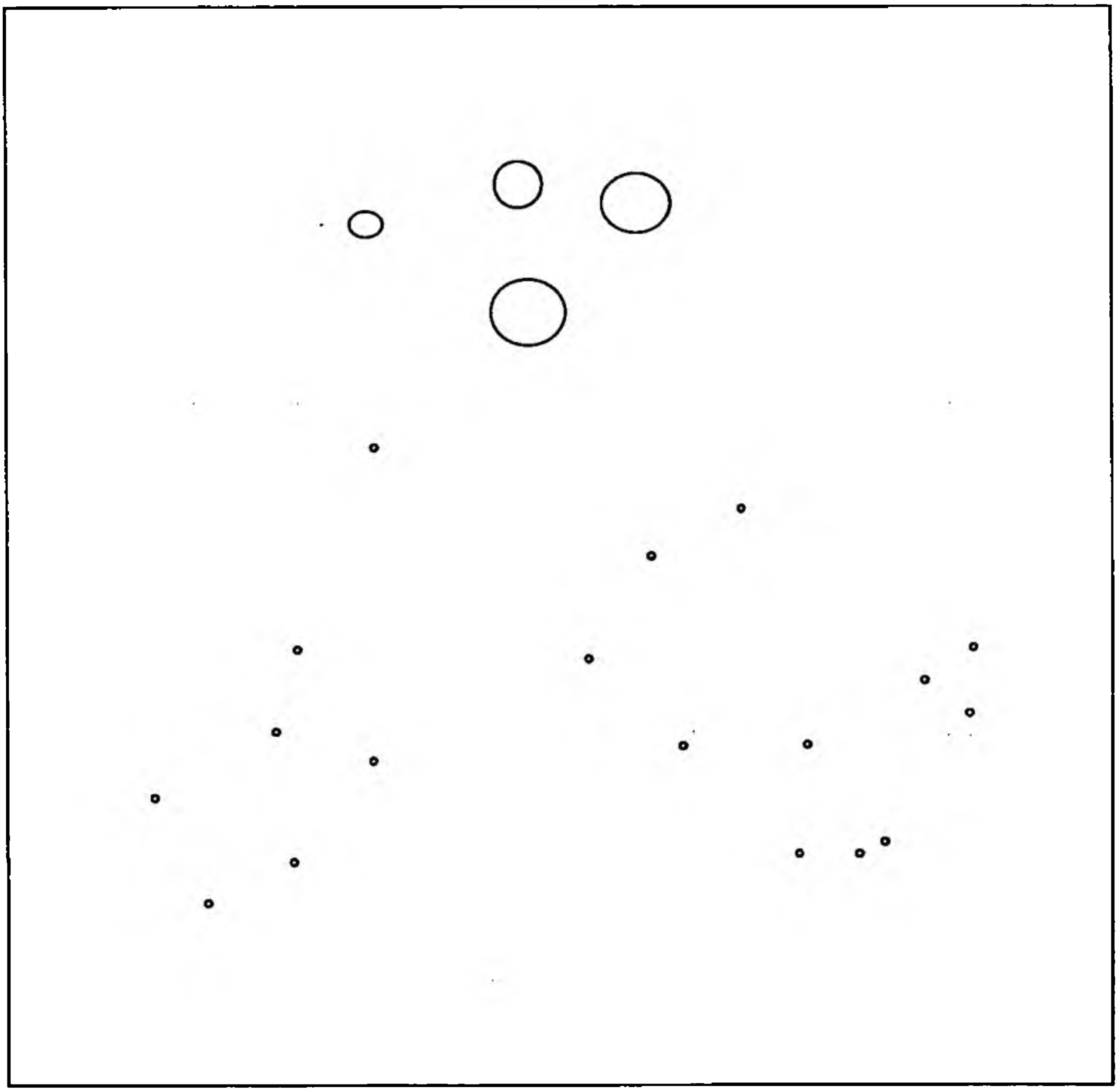


FIGURE 25 OVERLAY OF 'HORIZONTAL DISTANCE' ON SUBTIDAL MDS PLOT

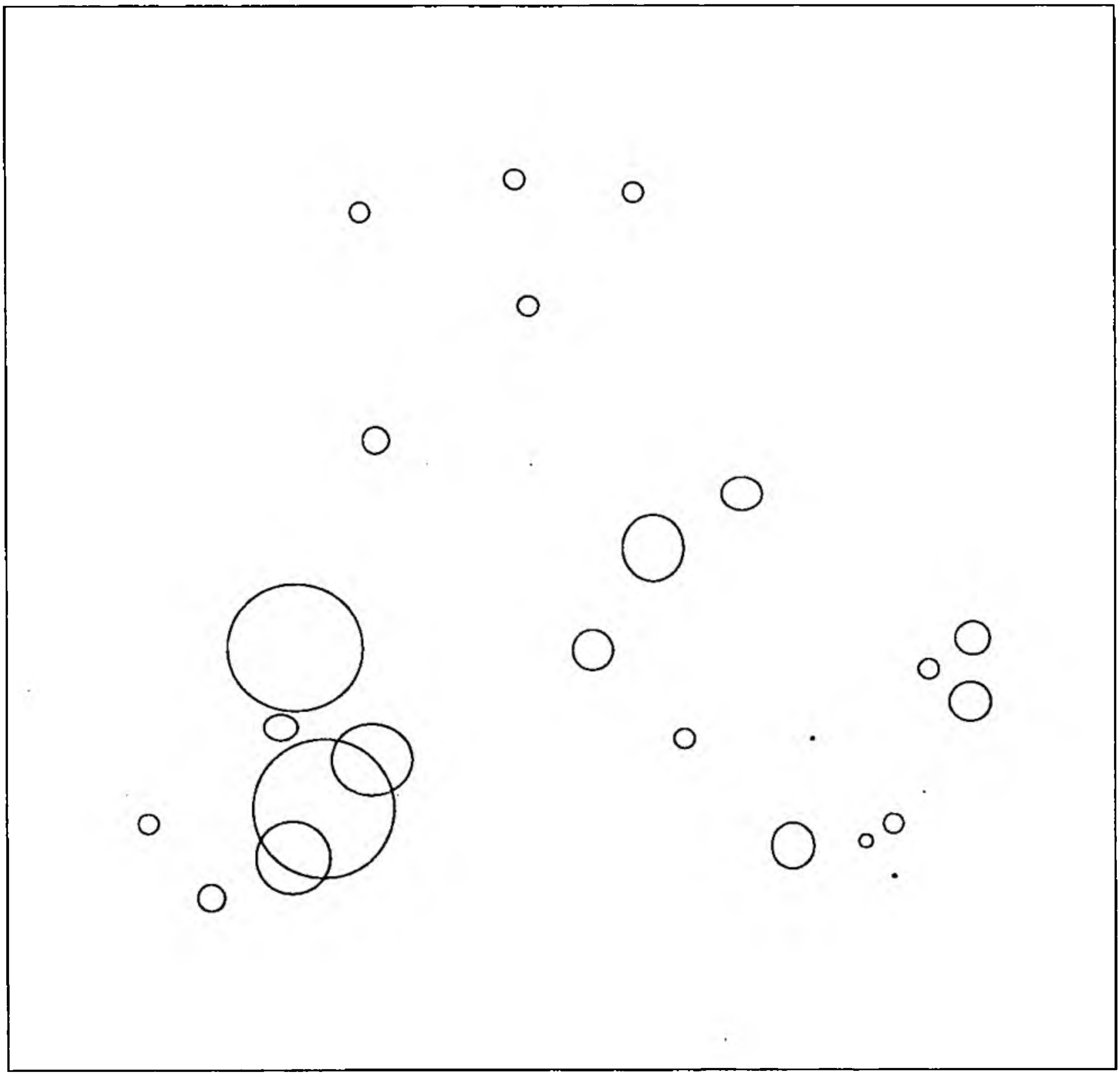


FIGURE 26 OVERLAY OF 'DEPTH' ON SUBTIDAL MDS PLOT

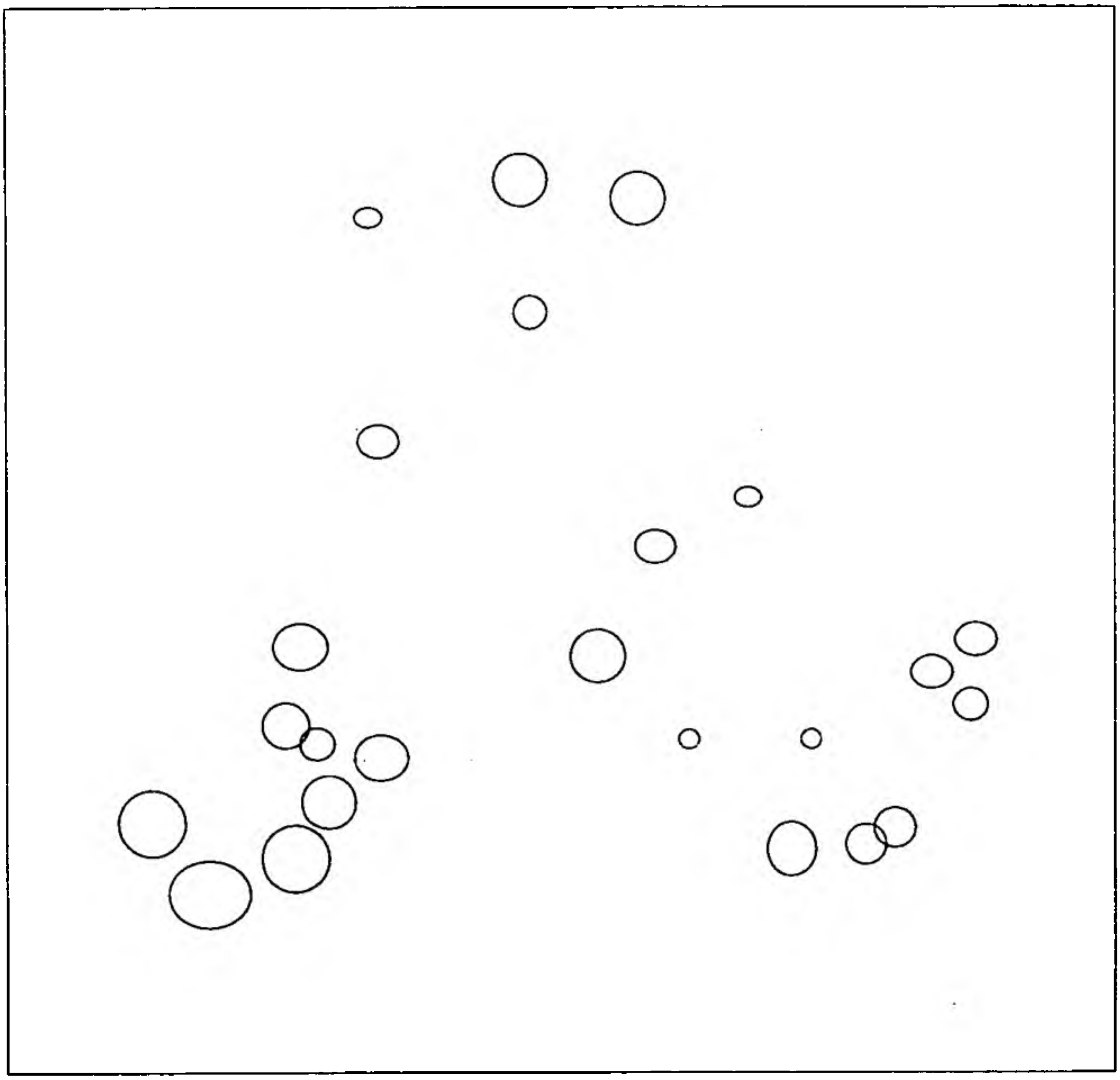


**TABLE 15 Contribution (%) of Species to the Similarity of Anosim 'Sediment Type' Groupings.**

| *SPECIES* | Av. Similarity | Std. Dev. | % contribution |
|---|---|---|---|
| **GROUP 1 AVERAGE SIMILARITY 22.01 (S.D. 29.739)** | | | |
| *Tharyx sp* | 8.1 | 23.46 | 36.69 |
| *Hydrobia sp* | 5.1 | 11.00 | 23.33 |
| Tubificidae | 4.4 | 7.63 | 20.15 |
| *Nephtys hombergii* | 2.6 | 2.37 | 11.95 |
| **GROUP 2 AVERAGE SIMILARITY 29.01(S.D. 14.219)** | | | |
| *Protodriloides chaetifer* | 15.1 | 10.6 | 51.90 |
| *Ophyrotrocha hartmanni* | 9.0 | 8.93 | 31.08 |
| **GROUP 3 AVERAGE SIMILARITY 34.40(S.D. 24.940)** | | | |
| *Sabellaria alveolata* | 26.2 | 22.75 | 76.07 |
| *Typosyllis armillaris* | 2.8 | 3.01 | 8.21 |
| **GROUP 4 AVERAGE SIMILARITY 11.72(S.D. 13.19)** | | | |
| *Scoloplos armiger* | 4.4 | 7.17 | 37.62 |
| Tubificidae | 1.5 | 1.83 | 12.56 |
| *Pygospio elegans* | 1.3 | 2.22 | 10.90 |
| *Tharyx sp* | 1.1 | 2.00 | 9.32 |

As can be seen ,within group similarities were not as high as those observed for the intertidal groupings. This low similarity may be due to the smaller abundances recorded at subtidal sites Consequently sites within a group may contain species common to each other (ie; be similar), but due to the lower abundances and the interfering presence of species unique to each site, the 'within group' similarity is low.

The strongest within group similarities (>25%) were exhibited by groups 2 and 3. The higher similarity within these groups can be expained by the fauna supported by their sediments. For example group 2 sites contained >80% sand, such sediments can provide harsh environments especially where there is a strong tidal regime like in the Severn Estuary. Consequently only a few individuals will persist such as the interstitial species *Ophyrotrocha* . Conversely, group 3 sites were comprised of reefs formed by the polychaete *Sabellaria alveolata* . Such reefs provide a variety of ecological niches which would not exist otherwise; they thus support a wide range of organisms which, because of their ecological preferences do not inhabit the other substrates present within Weston Bay.

Despite the relatively weak 'within group' similarities,'between group' dissimilarities were high (Table 16). This suggests that the species from each group are significantly different from each other to enable us to say that sediment type is a good criterion for this group separation.

**TABLE 16 Contribution (%) of Species to the Dissimilarity of ANOSIM 'Sediment Type' Groupings**

| Group Pairing | Av.dissimilarity | *Species* (top 50%) | % contribution |
|---|---|---|---|
| 1 and 2 | 99.05 | ***Tharyx sp*** | 21.32 |
| | | *Ophyrotrocha hartmanni* | 20.15 |
| | | ***Hydrobia sp*** | 12.67 |
| | | ***Tubificidae*** | 12.46 |
| 1 and 3 | 94.21 | *Sabellaria alveolata* | 31.66 |
| | | ***Tharyx sp*** | 15.97 |
| | | **Tubificidae** | 9.89 |
| 1 and 4 | 89.44 | ***Tharyx sp*** | 28.15 |
| | | ***Hydrobia sp*** | 15.60 |
| | | **Tubificidae** | 15.44 |
| 2 and 3 | 98.49 | *Sabellaria alveolata* | 39.86 |
| | | ***Ophyrotrocha hartmanni*** | 19.44 |
| 2 and 4 | 92.71 | ***Ophyrotrocha hartmanni*** | 35.16 |
| | | ***Protodriloides chaetifer*** | 15.09 |
| 3 and 4 | 96.81 | ***Sabellaria alveolata*** | 45.26 |
| | | ***Mediomastus fragilis*** | 8.68 |

***Species in bold represent the first named group***
*Species in plain type represent the second named group*

## 7. DISCUSSION

### 7.1 Intertidal Survey

Multivariate analyses have shown that species assemblages within Weston Bay appear to be strongly correlated to 'distance from outfall'. Pollution tolerant species such as *Nereis diversicolor, Streblospio shrubsolii* and Enchytraeids (Pearson & Rosenberg 1978) were only recorded within a radius of 860m from the outfall. Different species assemblages were recorded outside of this area and were generally represented in the analyses by *Nephtys* juveniles and *N. hombergii*.

The distribution pattern of *Nephtys* may have arisen as a result of an avoidance strategy adopted by the juveniles. The mode of reproduction used by *Nephtys hombergii* is settlement. Spawning is believed to occur around July and the first juvenile settlement is observed around September (Warwick 1975). Juveniles settle on the low-water mark and then migrate upshore. It is possible that some avoidance strategy may be adopted by the immature worms during this migration, which might explain their absence from sites within 860m of the outfall. Increased mortality may be another possible explanation for the absence of juveniles and reduced incidence of adult *Nephtys* within this area.

A smaller area consisting of sites 2, 6 and 7, was located within a 300m radius of the outfall. This group was recognised by 3 of the 4 multivariate techniques used, although in TWINSPAN the formation of this sub-group was 'weak' suggesting that it was not significantly different from other sites within the same group. This area contained the highest numbers of *Nereis* and organic 'loving' Enchytraeids, and also the highest numbers of total individuals (>1000 at sites 2 and 6). From this information it would appear that this area is the most affected by the Black Rock outfall.

Considering the high organic content of any sewage effluent, the correlation of % organic carbon with 'distance from outfall' was unusual in that levels were highest at sites some distance from the presumed source of input. This apparent anomaly may be explained by the presence of coal dust which is known to contaminate sediments from the Severn Estuary (Murray et al 1980a).

It would thus appear that the zonation of species within the intertidal zone of Weston Bay, cannot be confidently attributed to organic enrichment. However, as previously mentioned multivariate techniques have shown that 'distance from outfall' is an important factor in the distribution of species within the bay. This suggests that one or more components of the effluent are influencing the observed species assemblages. It is possible that one of these components could be the disinfection process, which is performed between May and September each year.

The by-products of disinfection are known to be potentially toxic to marine life. Levels of residual chlorine at the outfall have in the past been recorded as high as 34-39mg/l (Wessex Water 1985) and levels as low as 0.21-0.81mg/l (DOE 1988) have been recorded as having a toxic effect on invertebrate organisms, infact the US Environmental Protetion Agency proposed that levels in saltwater should not exceed 13μg/l (DOE 1988).

Another possible cause of this zonation could be the high levels of List I and II substances discharged from the outfall. A number of substances including copper, zinc, dieldrin, aldrin and hexaclorobenzene (HCB), were recorded as having higher annual averages in the Black Rock effluent than those laid down by the nationally agreed Environmental Quality Standards for estuarine waters (DOE circular). Although these standards apply to 'open' waters and the Black Rock effluent will obviously be diluted by the receiving waters, there are times when the effluent forms a large proportion of the flow of the R.Axe. At such times dilution of the effluent within the river channel is greatly reduced (DOE 1988), in such instances it may be possible that these quality standards are breached. Levels of these substances in the sediments of Weston Bay were not recorded in this study, but would be an important part of any future work.

It should be noted that this study cannot clarify whether disinfection or industrial waste are impacting the bay, and that between January and December 1991 the effluent did not breach its consent for cadmium. The bioaccumation studies of chlorinated compounds in limpets and seaweeds carried out in November 1991 and June & July of 1992, should provide information on the effects of disinfection on the the fauna of Weston Bay.

### 7.2 Subtidal Survey

Unlike the intertidal data, a zone of impact generated by the Black Rock outfall was difficult to establish subtidally. Multivariate techniques revealed distinct site groupings based on the species assemblages present. These were found to be related to sediment type and depth. There was no correlation with 'horizontal distance' and therefore the outfall cannot be shown to be exerting an effect on the subtidal fauna. This was believed to due to the overall distance separating the subtidal sites from the discharge source and the greater dilution afforded to the effluent by subtidal waters.

Levels of organic carbon were generally higher at subtidal stations, but there were no distinct patterns in the data. As already discussed coal dust may be confusing the effects of any organic input.

## 7.3 Conclusions and Recommendations

The data analyses used in this report have repeatedly shown a distinct correlation between the intertidal species assemblages within Weston Bay and distance from the Black Rock outfall. It would thus appear that effluent discharged from this outfall is having an effect on species distribution within the intertidal zone. The component of the discharge largely responsible could not be ascertained from this study and remains unclear. However, further work which could include the collection of sediments for metal and organic chemical analyses, may provide more information. Subtidally it appears that species distribution is not effected by the Black Rock outfall.

The proposed improvements in the treatment of effluent from Weston Super Mare would mean that the Black Rock outfall would only be used for the discharge of disinfected storm-water. Future work could include a repeat survey of the Bay to examine whether these improvements have resulted in any significant changes in the marine fauna.

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## APPENDIX I INTERTIDAL POSITION FIXES

### Weston Bay - Nov' 91

| Site No. | Latitude | Longitude |
|---|---|---|
| 1 | 51° 19.29 | 02° 59.67 |
| 2 | 19.32 | 59.84 |
| 3 | 19.41 | 03° 00.00 |
| 4 | 19.56 | 00.38 |
| 5 | 19.78 | 01.21 |
| 6 | 19.41 | 02° 59.60 |
| 7 | 19.47 | 59.77 |
| 8 | 19.54 | 59.94 |
| 9 | 19.71 | 03° 00.30 |
| 10 | 20.00 | 00.98 |
| 11 | 19.56 | 02° 59.54 |
| 12 | 19.70 | 59.87 |
| 13 | 19.82 | 03° 00.21 |
| 14 | 19.73 | 02° 59.44 |
| 15 | 19.87 | 59.79 |
| 16 | 20.00 | 03° 00.22 |
| 17 | 20.30 | 00.77 |
| 18 | 20.07 | 02° 59.34 |
| 19 | 20.20 | 59.63 |
| 20 | 20.31 | 59.93 |
| 21 | 20.58 | 03° 00.51 |
| 22 | 20.72 | 02° 59.05 |
| 23 | 20.94 | 59.52 |
| 24 | 21.16 | 03° 00.04 |

APPENDIX II SUBTIDAL POSITION FIXES

Weston Bay - Jan. '92

| Site No. | Latitude | Longitude |
|---|---|---|
| 1 | 51° 19.78 | 03° 01.68 |
| 2 | 19.91 | 01.59 |
| 3 | 20.02 | 01.47 |
| 4 | 20.09 | 01.42 |
| 5 | 20.22 | 01.31 |
| 6 | 20.41 | 01.14 |
| 7 | 20.69 | 00.92 |
| 8 | 21.27 | 00.39 |
| 9 | 21.38 | 00.08 |
| 10 | 20.85 | 01.15 |
| 11 | 20.56 | 01.47 |
| 12 | 20.43 | 01.59 |
| 13 | 20.28 | 01.76 |
| 14 | 20.16 | 01.84 |
| 15 | 20.06 | 01.95 |
| 16 | 19.91 | 02.08 |
| 18 | 19.75 | 02.65 |
| 19 | 20.06 | 02.36 |
| 22 | 20.47 | 02.07 |
| 27 | 19.82 | 01.87 |
| 28 | 19.96 | 01.67 |
| 29 | 20.08 | 01.64 |
| 30 | 20.24 | 01.49 |
| 31 | 20.32 | 01.36 |

APPENDIX III WESTON-SUPER-MARE INTERTIDAL INFAUNAL DATA - 21st November 1991

| *SPECIES (Infauna)* | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nemertean (indet.) | 5 | 1 | 1 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Eteone flava/longa* | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Nereis diversicolor* | 11 | 352 | 24 | 98 | 0 | 315 | 203 | 98 | 19 | 0 | 66 | 11 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Nereis longissima* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Nephtys hombergii (spp, complex)* | 9 | 0 | 56 | 4 | 46 | 0 | 0 | 17 | 0 | 3 | 2 | 25 | 13 | 4 | 63 | 123 | 3 | 14 | 146 | 74 | 19 | 15 | 16 | 27 |
| *Nephtys juvenile* | 0 | 0 | 0 | 0 | 21 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 3 | 0 | 18 | 17 | 2 | 0 | 0 | 1 | 7 | 1 | 2 | 43 |
| *Scoloplos armiger* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| *Pygospio elegans* | 2 | 11 | 11 | 5 | 0 | 32 | 5 | 1 | 3 | 0 | 14 | 22 | 0 | 5 | 0 | 1 | 5 | 22 | 12 | 1 | 0 | 27 | 0 | 0 |
| *Streblospio shrubsoli* | 3 | 469 | 62 | 27 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Caulleriella caput-esocis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cirratulidae (indet.) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Enchytraeidae | 0 | 37 | 1 | 0 | 0 | 213 | 9 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Tubificidae | 2 | 0 | 0 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Gammarus sp.A* | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| *Gammarus sp.B* | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Melita pellucida* | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| *Bathyporea pelagica* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| *Bathyporea sarsi* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 61 | 0 | 0 | 0 | 5 | 1 | 0 |
| *Harpinia pectinata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Parapleustes bicuspis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Corophium volulator* | 1 | 0 | 0 | 4 | 1 | 0 | 4 | 1 | 6 | 0 | 0 | 0 | 17 | 0 | 1 | 0 | 387 | 0 | 0 | 0 | 4 | 0 | 0 | 0 |
| *Sphaeroma monodoni* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Idotea pelagica* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Cumopsis goodsiri* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| *Cumopsis gunneri* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| *Diastylis rathkei* | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| *Retusa obtusa* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 3 | 3 | 1 | 0 | 7 | 0 | 1 | 0 | 4 | 1 | 0 |
| *Hydrobia sp.* | 11 | 617 | 381 | 553 | 777 | 509 | 128 | 250 | 406 | 15 | 104 | 633 | 409 | 46 | 256 | 152 | 0 | 71 | 425 | 536 | 0 | 103 | 70 | 75 |
| *Macoma balthica* | 17 | 113 | 151 | 75 | 19 | 86 | 63 | 92 | 102 | 2 | 100 | 75 | 9 | 77 | 39 | 57 | 8 | 195 | 155 | 48 | 1 | 365 | 14 | 5 |
| *TOTAL NUMBER OF SPECIES* | 9 | 8 | 9 | 11 | 8 | 6 | 9 | 6 | 7 | 5 | 7 | 7 | 6 | 8 | 6 | 8 | 9 | 9 | 4 | 9 | 7 | 8 | 8 | 6 |
| *TOTAL NUMBER OF INDIVIDUALS* | 61 | 1602 | 688 | 778 | 870 | 1156 | 421 | 448 | 555 | 23 | 288 | 768 | 452 | 141 | 380 | 493 | 412 | 373 | 738 | 664 | 36 | 521 | 107 | 152 |

## APPENDIX IV WESTON-SUPER-MARE SUBTIDAL INFAUNAL DATA - 15-16th January 1992

| *SPECIES (Infauna)* | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 18 | 19 | 22 | 27 | 28 | 29 | 30 | 31 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Burrowing Anthozoan (indet) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 |
| Nemertean (indet.) | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 2 | 0 | 1 | 5 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 4 | 2 | 2 |
| *Gattyana cirrosa* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Harmothoe impar* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Lepidonotus squamatus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Eteone flava/longa* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Eulalia tripunctata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 3 | 8 | 0 | 3 | 18 | 0 | 0 | 0 | 14 | 16 | 3 | 0 | 0 | 0 | 0 | 0 |
| *Eumida sanguinea* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Phyllodoce maculata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Glycera capitata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 |
| *Autolytus sp.A* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Autolytus langerhansi* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| *Exogone (naidina)* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 |
| *Sphaerosyllis hystrix* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Typosyllis armillaris* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 0 | 2 | 0 | 17 | 24 | 0 | 0 | 0 | 12 | 24 | 11 | 0 | 0 | 0 | 0 | 0 |
| *Nereis juvenile* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Nereis longissima* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Nereis pelagica* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Nereis virens* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Nephtys cirrosa* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Nephtys hombergii (spp, complex)* | 19 | 6 | 10 | 1 | 5 | 0 | 1 | 0 | 0 | 1 | 11 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 22 | 47 | 0 | 0 | 0 |
| *Nephtys juvenile* | 0 | 7 | 10 | 12 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 22 | 16 | 0 | 0 | 0 |
| *Ophyrotrocha (hartmanni)* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 195 | 0 | 0 | 0 | 0 | 0 | 0 | 28 | 21 | 0 |
| *Scoloplos armiger* | 0 | 0 | 0 | 11 | 15 | 0 | 0 | 3 | 0 | 8 | 2 | 0 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Aricidea minuta* | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Polydora caeca* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Pygospio elegans* | 0 | 1 | 0 | 0 | 2 | 3 | 3 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 8 | 1 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| Spionidae (indet.) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Streblospio shrubsoli* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cirratulidae (indet.) | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Tharyx sp.* | 2 | 189 | 151 | 35 | 2 | 0 | 0 | 0 | 0 | 0 | 170 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Acrocirridae (indet.) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Mediomastus fragilis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 66 | 8 | 0 | 8 | 90 | 0 | 0 | 5 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 14 |
| *Protodriloides chaetifer* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 0 | 0 |
| *Sabellaria alveolata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 277 | 28 | 150 | 0 | 94 | 173 | 0 | 0 | 6 | 408 | 240 | 76 | 0 | 0 | 0 | 0 | 0 |
| *Ampharete grubei/acutifrons* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Ampharete lindstoemi* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Melinna cristata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24 | 3 | 14 | 0 | 0 | 10 | 0 | 0 | 0 | 15 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |

## APPENDIX IV (cont.) WESTON-SUPER-MARE SUBTIDAL INFAUNAL DATA - 15th - 16th January 1992

| *SPECIES (Infauna)* | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 18 | 19 | 22 | 27 | 28 | 29 | 30 | 31 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Neoamphitrite figilus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Polycirrus sp.* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 |
| *Thelpus cincinnatus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Enchytraeidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 9 | 0 | 0 | 0 | 1 | 0 | 7 | 0 | 9 |
| Tubificidae | 13 | 17 | 8 | 14 | 1 | 1 | 0 | 0 | 0 | 0 | 10 | 2 | 1 | 0 | 2 | 5 | 0 | 0 | 0 | 194 | 42 | 2 | 0 | 0 |
| *Nymphon rubrum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Pycnogonum littorale* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ostracoda (indet.) | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gammaridae (indet.) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Gammarus sp.A* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Gammarus zaddachi* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 |
| *Melita obtusata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Melita palmata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Melita pellucida* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30 | 0 | 0 | 0 | 0 | 0 |
| *Harpinia pectinata* | 0 | 0 | 0 | 0 | 33 | 4 | 8 | 23 | 8 | 68 | 5 | 0 | 3 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Para pleustes bicuspis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Corophium volulator* | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Sphaeroma monodoni* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Janira maculosa* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 6 | 0 | 0 | 4 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Diastylis sp.* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Diastylis rathkei* | 1 | 0 | 2 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 |
| *Retusa obtusa* | 0 | 0 | 0 | 0 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| *Hydrobia sp.* | 137 | 13 | 2 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 99 | 98 | 0 | 0 | 1 |
| *Nucula sp.* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 44 | 4 | 42 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Macoma balthica* | 1 | 0 | 1 | 4 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 6 | 2 | 0 | 0 | 0 |
| *Abra tenuis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Sphenia binghami* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *TOTAL NUMBER OF SPECIES* | 7 | 6 | 7 | 9 | 9 | 8 | 8 | 14 | 9 | 22 | 11 | 11 | 13 | 8 | 8 | 16 | 12 | 9 | 6 | 7 | 7 | 7 | 4 | 7 |
| *TOTAL NUMBER OF INDIVIDUALS* | 274 | 233 | 184 | 81 | 76 | 14 | 19 | 416 | 121 | 344 | 209 | 132 | 332 | 13 | 115 | 84 | 475 | 288 | 126 | 349 | 208 | 77 | 31 | 41 |

APPENDIX V PHYSICAL AND CHEMICAL DATA - INTERTIDAL SURVEY - Weston-Super-Mare

21st November 1991 (All sediment data expressed as %)

| Site | 500-250µm med. sand | 250-125µm fine sand | 125-62.5µm v.fine sand | <62.5µm siltclay | 65-30µm *coarse silt* | 30-15µm *med. silt* | 15-7.2µm *fine silt* | 7.2-0µm *clay* | Ht. on shore | Horz. Dist. outfall (m) | Direct Dist. outfall (m) | % organic carbon | % organic nitrogen |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.0 | 0.2 | 2.5 | 97.3 | 15.0 | 33.3 | 22.8 | 26.6 | 3 | 107 | 250 | 1.81 | <0.2 |
| 2 | 0.3 | 3.5 | 4.7 | 91.5 | 15.7 | 32.0 | 20.6 | 23.8 | 3 | 179 | 143 | 1.94 | <0.2 |
| 3 | 0.1 | 1.7 | 6.6 | 91.5 | 24.5 | 33.8 | 16.8 | 17.2 | 3 | 179 | 246 | 0.63 | 0.21 |
| 4 | 0.3 | 4.8 | 7.5 | 87.4 | 21.1 | 30.4 | 17.7 | 18.9 | 2 | 179 | 786 | 1.75 | <0.2 |
| 5 | 0.0 | 0.8 | 3.9 | 95.3 | 20.6 | 37.1 | 19.5 | 18.6 | 1 | 500 | 1857 | 1.74 | <0.2 |
| 6 | 0.1 | 1.4 | 2.6 | 95.9 | 12.7 | 34.0 | 23.2 | 26.4 | 3 | 179 | 286 | 2.08 | <0.2 |
| 7 | 0.1 | 1.5 | 5.9 | 92.5 | 21.2 | 31.7 | 18.9 | 21.6 | 3 | 179 | 179 | 1.68 | <0.2 |
| 8 | 0.3 | 5.0 | 8.0 | 86.6 | 19.4 | 29.6 | 17.4 | 21.0 | 3 | 179 | 357 | 1.19 | <0.2 |
| 9 | 0.0 | 0.7 | 2.9 | 96.4 | 12.2 | 34.1 | 23.6 | 26.7 | 2 | 250 | 857 | 1.26 | <0.2 |
| 10 | 0.0 | 0.2 | 2.3 | 97.5 | 15.3 | 35.6 | 22.1 | 25.1 | 1 | 250 | 1857 | 2.32 | <0.2 |
| 11 | 0.4 | 5.0 | 7.4 | 87.5 | 21.0 | 30.0 | 17.6 | 19.3 | 3 | 571 | 464 | 1.45 | <0.2 |
| 12 | 1.6 | 13.2 | 7.0 | 78.2 | 16.5 | 28.1 | 16.2 | 18.0 | 3 | 571 | 607 | 1.14 | <0.2 |
| 13 | 1.2 | 6.1 | 4.8 | 87.9 | 17.5 | 32.1 | 17.9 | 20.9 | 2 | 571 | 1000 | 1.57 | <0.2 |
| 14 | 3.4 | 30.5 | 8.6 | 57.5 | 12.0 | 20.9 | 1.8 | 13.1 | 3 | 1000 | 821 | 2.39 | <0.2 |
| 15 | 0.7 | 2.5 | 3.2 | 93.6 | 11.7 | 30.7 | 22.6 | 28.8 | 3 | 1000 | 786 | 1.41 | <0.2 |
| 16 | 0.0 | 0.4 | 3.0 | 96.6 | 16.0 | 35.0 | 22.0 | 24.0 | 2 | 1035 | 1250 | 2.11 | <0.2 |
| 17 | 0.0 | 0.2 | 2.5 | 97.3 | 13.9 | 36.2 | 21.8 | 25.8 | 1 | 1035 | 2036 | 3.03 | <0.2 |
| 18 | 10.9 | 75.0 | 10.8 | 3.3 | 2.3 | 0.3 | 0.0 | 1.1 | 3 | 1856 | 1357 | 1.24 | <0.2 |
| 19 | 1.0 | 5.0 | 7.1 | 86.9 | 21.9 | 32.4 | 16.7 | 16.5 | 3 | 1856 | 1393 | 2.12 | <0.2 |
| 20 | 1.4 | 5.4 | 6.1 | 87.1 | 23.5 | 31.6 | 15.6 | 16.9 | 2 | 1856 | 1500 | 2.12 | 0.206 |
| 21 | 0.6 | 4.2 | 3.3 | 91.9 | 14.3 | 33.2 | 20.2 | 24.7 | 1 | 1892 | 2500 | 1.76 | <0.2 |
| 22 | 13.9 | 73.8 | 6.7 | 5.6 | 2.4 | 1.4 | 0.9 | 1.2 | 3 | 3570 | 2571 | 2.33 | <0.2 |
| 23 | 11.3 | 55.4 | 6.3 | 27.1 | 6.2 | 9.0 | 5.3 | 6.9 | 2 | 3570 | 2821 | 1.28 | <0.2 |
| 24 | 0.0 | 0.9 | 3.8 | 95.2 | 19.0 | 37.0 | 20.4 | 19.4 | 1 | 3570 | 3250 | 2.61 | <0.2 |

sand - Sediment type as defined by Wentworth Scale *fine silt* - Sediment type loosely based on Wentworth Scale

Due to the absence of accurate data, a scale for height on shore was constructed based on Admiralty Chart No. L(D1)1152: 1=lower shore, 2=mid-shore and 3=upper shore.

## APPENDIX VI PHYSICAL AND CHEMICAL DATA - SUBTIDAL SURVEY - Weston-Super-Mare

**15-16th January 1992** (All sediment data expressed as %)

| Site | 64-4mm pebbles | 4-2mm granules | 2-1mm v.coarse sand | 1-0.5mm coarse sand | 500-250µm medium sand | 250-125µm fine sand | 125-62.5µm v.fine sand | <62.5µm siltclay | 65-30µm *coarse silt* | 30-15µm *med. silt* | 15-7.2µm *fine silt* | 7.2-0µm *clay* | Depth | Horiz Dist. (m) | Direct Dist. (m) | % org. carbon | % org. nitrogen |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ***** | ***** | ***** | ***** | ***** | 0.2 | 3.0 | 96.8 | 20.5 | 37.1 | 19.7 | 20.0 | 5 | 857 | 2720 | 1.69 | <0.2 |
| 2 | ***** | ***** | ***** | ***** | 0.5 | 1.2 | 2.9 | 95.5 | 15.8 | 35.0 | 21.3 | 23.7 | 5 | 464 | 2686 | 2.84 | <0.2 |
| 3 | ***** | ***** | ***** | ***** | 0.1 | 1.1 | 5.3 | 93.5 | 20.2 | 36.3 | 18.9 | 18.7 | 5 | 250 | 2640 | 2.13 | <0.2 |
| 4 | ***** | ***** | ***** | ***** | 10.4 | 26.7 | 4.0 | 58.9 | 12.1 | 22.1 | 12.8 | 12.4 | 4 | 36 | 2680 | 1.76 | <0.2 |
| 5 | 12.3 | 16.1 | 9.2 | 2.2 | 16.4 | 23.7 | 2.8 | 17.2 | 3.4 | 6.2 | 3.9 | 3.9 | 4 | 428 | 2720 | 2.15 | <0.2 |
| 6 | ***** | ***** | ***** | ***** | 5.0 | 12.1 | 4.8 | 78.2 | 17.0 | 28.4 | 15.9 | 17.3 | 4 | 964 | 2840 | 0.94 | 0.294 |
| 7 | ***** | ***** | ***** | ***** | 1.1 | 7.6 | 2.8 | 88.5 | 11.8 | 31.6 | 20.5 | 25.0 | 5 | 1571 | 3080 | 0.98 | <0.2 |
| 8 | | | *N o* | | *S a m p l e* | | | | *N o* | | *S a m p l e* | | 6 | 3356 | 4000 | 2.30 | <0.2 |
| 9 | | | *N o* | | *S a m p l e* | | | | *N o* | | *S a m p l e* | | 6 | 3106 | 4280 | *No* | *Sample* |
| 10 | ***** | ***** | ***** | ***** | 1.2 | 5.7 | 3.0 | 90.1 | 13.6 | 31.9 | 20.8 | 24.2 | 6 | 1821 | 3560 | 2.64 | <0.2 |
| 11 | ***** | ***** | ***** | ***** | ***** | ***** | 1.8 | 98.2 | 10.1 | 32.0 | 22.9 | 33.4 | 6 | 1000 | 3320 | 1.74 | <0.2 |
| 12 | | | *N o* | | *S a m p l e* | | | | *N o* | | *S a m p l e* | | 6 | 643 | 3280 | *No* | *Sample* |
| 13 | | | *N o* | | *S a m p l e* | | | | *N o* | | *S a m p l e* | | 5 | 71 | 3280 | *No* | *Sample* |
| 14 | ***** | 10.5 | 47.2 | 33.9 | 5.6 | 1.5 | 0.8 | 0.5 | ***** | ***** | ***** | ***** | 6 | 287 | 3200 | 1.15 | <0.2 |
| 15 | ***** | ***** | 5.9 | 45.5 | 48.2 | 0.2 | 0.2 | ***** | ***** | ***** | ***** | ***** | 6 | 464 | 3320 | 2.16 | <0.2 |
| 16 | ***** | ***** | ***** | ***** | 29.0 | 24.3 | 5.0 | 41.7 | 9.7 | 15.1 | 8.5 | 8.8 | 6 | 928 | 3360 | 2.37 | <0.2 |
| 18 | | | *N o* | | *S a m p l e* | | | | *N o* | | *S a m p l e* | | 7 | 1749 | 3520 | *No* | *Sample* |
| 19 | | | *N o* | | *S a m p l e* | | | | *N o* | | *S a m p l e* | | 7 | 714 | 4000 | *No* | *Sample* |
| 22 | | | *N o* | | *S a m p l e* | | | | *N o* | | *S a m p l e* | | 7 | 179 | 3840 | *No* | *Sample* |
| 27 | ***** | ***** | ***** | ***** | ***** | 0.4 | 3.8 | 95.8 | 17.3 | 35.1 | 20.8 | 23.1 | 5 | 964 | 3000 | 1.83 | <0.2 |
| 28 | ***** | ***** | ***** | ***** | ***** | 0.3 | 2.7 | 97.0 | 15.3 | 35.6 | 21.8 | 24.7 | 5 | 464 | 2880 | 2.13 | <0.2 |
| 29 | ***** | 1.2 | 13.3 | 54.0 | 30.7 | 0.5 | 0.2 | 0.2 | ***** | ***** | ***** | ***** | 5 | 214 | 2840 | 0.37 | <0.2 |
| 30 | 29.5 | 14.8 | 22.3 | 21.7 | 7.5 | 1.6 | 0.3 | 2.3 | ***** | ***** | ***** | ***** | 4 | 179 | 2960 | No Result | <0.2 |
| 31 | | | *N o* | | *S a m p l e* | | | | *N o* | | *S a m p l e* | | 5 | 571 | 3000 | *No* | *Sample* |

sand - Sediment type as defined by Wentworth Scale *fine silt* - Sediment type loosely based on Wentworth Scale

Due to the absence of accurate data, a scale for depth was constructed based on Admiralty Chart No. L(D1)1152 : 4=0-2m, 5=2-5m, 6=5-10m, 7=>10m.
(all values are expressed in metres below chart datum)

APPENDIX VII

**A Brief Description of the Multivariate Techniques Used in the Analysis of Data Collected from Weston Bay**

A total of four analyses were used: TWINSPAN & DECORANA (indirect methods), and CANOCO & PRIMER (direct methods). Indirect methods only handle species data, the environmental data has to be examined separately, while direct methods analyse the species data and environmental data together.

## 1. TWINSPAN

TWINSPAN (Two Way Indicator Species Analysis) is a classification technique, which groups sites according to their species similarity and will highlight 'indicator species' which best explain the groupings formed.

Raw data is too complex for TWINSPAN to handle and therefore has to take the form of an abundance scale (cut-levels). This scale is chosen by the operator to reflect the range and distribution of abundances present in the data-set. TWINSPAN can then use this scale in its analysis.

The analysis in brief can be explained as follows: The samples are classified in a divisive heirarchy according to the species present. Repeated dichotomies are produced eventually forming a sample classification. This is then converted into an ordering and used to classify the species scores. The latter are then used to reclassify the samples through repeated dichotomization.

The eigenvalues produced represent the % variance explained by the samples forming each group, that is the higher the eigenvalue the 'stronger' the grouping. For a more detailed account see Hill (1979a).

## 2. DECORANA

DECORANA (Detrended Correspondence Analysis) is an ordination technique which positions samples/species along a series of axes by a form of of reciprocal averaging. The species/sample scores resulting form the first axis. Subsequent axes are derived by detrending the sample scores such that they have no systematic relation to the previously formed axis.

A process of rescaling is applied to all the axes, details of this and a further explanation of the procedures involved in DECORANA can be found in Hill (1979b).

## 3. CANOCO

CANOCO (Canonical Community Ordination) consists of a variety of canonical ordination techniques for relating species communities to their environments. It is an extension of DECORANA, using reciprocal averaging to produce a direct analysis of species and environmental data. This is done by introducing an additional constraint on the axes formed by species data, which is they must be a linear combination of environmental variables.

Further information on CANOCO can be found in Ter Braak (1988).

## 4. PRIMER

PRIMER (Plymouth Routines In Multivariate Ecological Research) was developed by the Plymouth Marine Laboratory and is currently being assessed as an analytical technique by the National Rivers Authority. It analyses species data by a process of multidimentional scaling (MDS). MDS attempts to constuct a sample map based on the 'distance' of one sample from another, ie: the difference in species composition of each sample is calculated (Bray-Curtis similarity measure) and then used to produce a 2-dimensional plot. Environmental variables can then be overlayed onto this map and thus species/environment relationships can be determined.

The statistical validity of environmental influences can be tested using ANOSIM (Analysis of Similarity). This produces a measure of intra-group species similarity and inter-group dissimilarity, when any environmental variable is used to define groups of samples. SIMPER examines the contribution of different species to the measures of group similarity/dissimilarity. Further details of these techniques are available from Wessex N.R.A's Blandford Laboratory, where the lecture notes accompanying the relevant P.M.L. workshop are held.

APPENDIX VIII PEARSON CORRELATION COEFFICIENTS - only r values giving an $r^2$ of >20% are shown

**TABLE A** **INTERTIDAL DATA - Weston Super Mare - November 1991**

| | Med. Sand | Fine Sand | V.Fine Sand | Silt | *Coarse Silt* | *Med. Silt* | *Fine Silt* | *Clay* | Ht. on shore |
|---|---|---|---|---|---|---|---|---|---|
| Med. Sand | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| Fine Sand | 0.982 | *** | *** | *** | *** | *** | *** | *** | *** |
| V.Fine Sand | 0.494 | 0.586 | *** | *** | *** | *** | *** | *** | *** |
| Silt | -0.978 | -0.988 | -0.628 | *** | *** | *** | *** | *** | *** |
| *Coarse Silt* | -0.779 | -0.786 | none | 0.754 | *** | *** | *** | *** | *** |
| *Med. Silt* | -0.969 | -0.989 | -0.632 | 0.992 | 0.768 | *** | *** | *** | *** |
| *Fine Silt* | -0.873 | -0.920 | -0.763 | 0.933 | 0.564 | 0.913 | *** | *** | *** |
| *Clay* | -0.884 | -0.906 | -0.754 | 0.922 | 0.465 | 0.885 | 0.940 | *** | *** |
| Ht. on shore | none | none | 0.519 | none | none | none | none | none | *** |
| Horiz. Dist. | 0.677 | 0.609 | none | -0.604 | none | -0.552 | -0.540 | -0.618 | none |

**TABLE B** **SUBTIDAL DATA - Weston Super Mare - January 1992**

| | Horiz. Distance | Pebbles | Granules | V.C. Sand | Coarse Sand | Med. Sand | Fine Sand | V.Fine Sand | *V.Fine Silt* |
|---|---|---|---|---|---|---|---|---|---|
| Pebbles | -1.000 | *** | *** | *** | *** | *** | *** | *** | *** |
| Granules | 0.453 | -1.000 | *** | *** | *** | *** | *** | *** | *** |
| V.C. Sand | -0.441 | 1.000 | none | *** | *** | *** | *** | *** | *** |
| Coarse Sand | -0.216 | 1.000 | -0.941 | none | *** | *** | *** | *** | *** |
| Med. Sand | -0.244 | -1.000 | -0.737 | -0.715 | 0.570 | *** | *** | *** | *** |
| Fine Sand | -0.008 | -1.000 | 0.575 | none | -0.832 | none | *** | *** | *** |
| V.F. Sand | 0.258 | -1.000 | 0.591 | none | -0.833 | none | 0.458 | *** | *** |
| Silt | 0.513 | -1.000 | 0.615 | -0.549 | -0.845 | -0.617 | none | 0.566 | none |
| *Coarse.silt* | -0.038 | N.E Data | N.E Data | N.E Data | N.E Data | -0.650 | -0.765 | none | none |
| *Med. Silt* | 0.193 | N.E Data | N.E Data | N.E Data | N.E Data | -0.840 | -0.905 | none | none |
| *Fine Silt* | 0.328 | N.E Data | N.E Data | N.E Data | N.E Data | -0.851 | -0.887 | none | none |
| *V.F. Silt* | 0.414 | N.E Data | N.E Data | N.E Data | N.E Data | -0.826 | -0.856 | -0.506 | none |
| Org. Carbon | 0.206 | none | 0.977 | none | -0.605 | none | none | none | none |
| Depth | 0.343 | none | none | none | 0.681 | none | none | none | 0.500 |

**KEY:** none = '$r^2$' values<20%, N.E. Data = not enough data to calculate 'r' values