APPENDIX No. 4

Intertidal Habitat Assessment at Renmore, Galway Bay
June 2018

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Intertidal Habitat Assessment,

Renmore, Galway Bay

Produced by

AQUAFACT International Services Ltd

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1. Introduction

AQUAFACT undertook a survey of the intertidal habitats at Renmore where it is proposed to expand the port of Galway to allow 24hr use of the harbour as it is currently restricted to operating only at high water. The expansion will require infilling an area of both intertidal and subtidal habitats of the Galway Bay cSAC. In the National Parks and Wildlife Service (NPWS, 2015) site synopsis for the Galway Bay cSAC, a complex of 2 intertidal habitats *i.e.* sand and mud flats exposed at low water (1140) and reefs (1170) is listed for the area in question.

2. Materials and Methods

2.1. Sampling Procedure

Sampling took place on the 28th and 29th October 2015. An intertidal walk over survey was carried out by three experienced marine ecologists to document the intertidal habitat types within the proposed development area. The surveyors determined biological zones based on differences in substrata and biological communities. A 0.25m^2 quadrat was used to record the species present, their abundance (using the SACFOR scale) and the substrate type. Specimens that could not be identified in the field were bought back to the laboratory for microscopic examination. Photographs within each habitat were also taken. Where substrate allowed, 15cm diameter cores (to a depth of 15cm) were collected for faunal and sedimentary analysis. At each of the core stations, two replicate faunal samples were collected and a third was collected for grain size and organic carbon analysis.

The samples collected for faunal analysis were carefully and gently sieved on a 1mm mesh sieve as a sediment water suspension for the retention of fauna. Great care was taken during the sieving process in order to minimise damage to taxa such as spionids, scale worms, phyllodocids and amphipods. The sample residue was carefully flushed into a pre-labelled (internally and externally) container from below. Each label contained the sample code and date. The samples were stained with Eosin-briebrich scarlet and fixed in 4% w/v buffered formaldehyde solution upon returning to the laboratory. These samples were ultimately preserved in 70% alcohol prior to processing.

The sediment samples were stored in labelled plastic containers and these samples were frozen (<-18ºC) as soon as possible after acquisition.

Figure 2.1 shows the intertidal survey area and the locations of the 10 core stations. Table 2.1 provides the coordinates of the core stations.

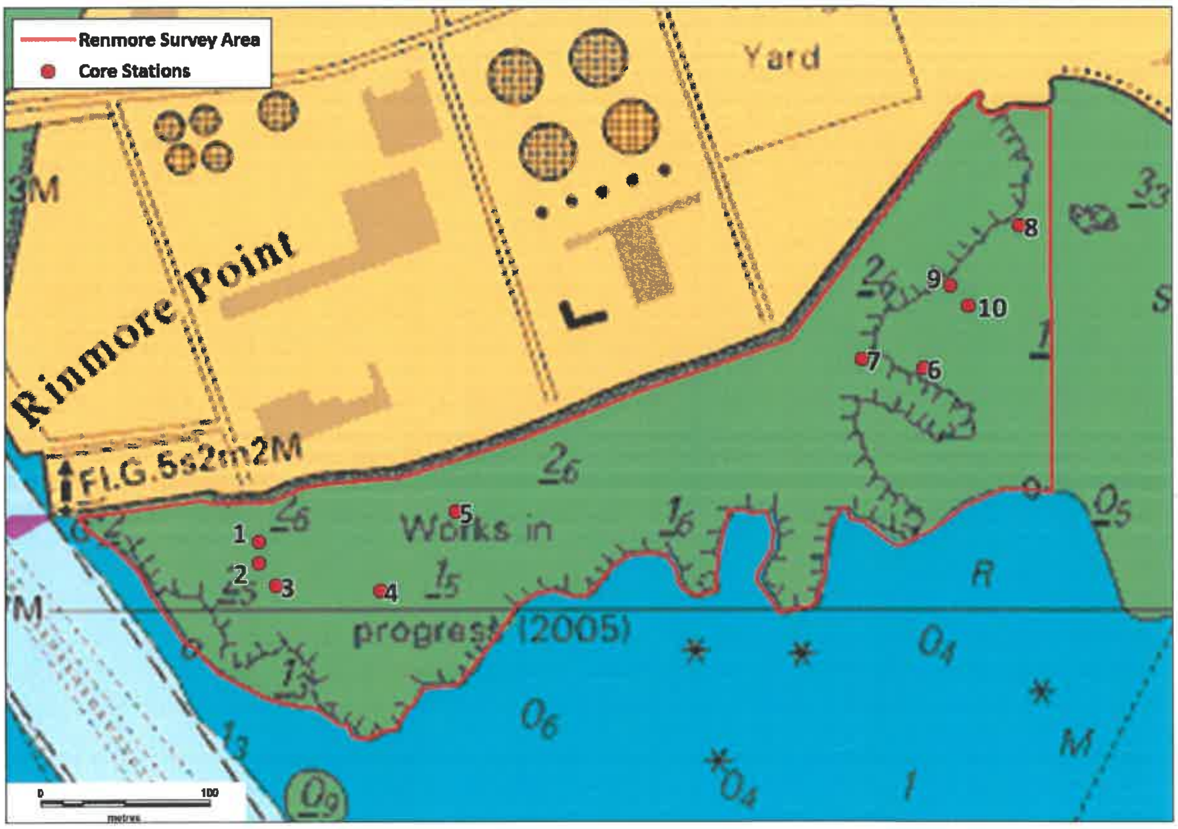

Figure 2.1: Renmore survey area and core station locations.

Table 2.1: Coordinates of core stations.

Station	Longitude	Latitude
1	-9.04264	53.26704
2	-9.04264	53.26692
3	-9.04248	53.2668
4	-9.04155	53.26677
5	-9.04088	53.2672
6	-9.0367	53.26796
7	-9.03724	53.26801
8	-9.03584	53.26872
9	-9.03646	53.2684
10	-9.0363	53.26829

2.2. Sample Processing

All faunal samples were placed in an illuminated shallow white tray and sorted first by eye to remove large specimens and then sorted under a stereo microscope (x 10 magnification). Following the removal of larger specimens, the samples were placed into Petri dishes, approximately one half teaspoon at a time and sorted using a binocular microscope at x25 magnification.

The fauna was sorted into four main groups: Polychaeta, Mollusca, Crustacea and others. The 'others' group consisted of echinoderms, nematodes, nemerteans, cnidarians and other lesser phyla. The fauna were maintained in stabilised 70% industrial methylated spirit (IMS) following retrieval and identified to species level where practical using a binocular microscope, a compound microscope and all relevant taxonomic keys. After identification and enumeration, specimens were separated and stored to species level. The faunal specimens were then identified to species level where possible using all relevant taxonomic keys and BEQUALM/NAMBQC guides.

The granulometric analysis was carried out by AQUAFACT using the traditional granulometric approach. Traditional analysis involved the dry sieving of approximately 100g of sediment using a series of Wentworth graded sieves. The process involved the separation of the sediment fractions by passing them through a series of sieves. Each sieve retained a fraction of the sediment, which were later weighed and a percentage of the total was calculated. Table 2.2 shows the classification of sediment particle size ranges into size classes. Sieves, which corresponded to the range of particle sizes (Table 2.2), were used in the analysis. Appendix 3-1 provides the detailed granulometric methodology.

Table 2.2.2: The classification of sediment particle size ranges into size classes (adapted from Buchanan, 1984).

Range of Particle Size	Classification	Phi Unit
<63µm	Silt/Clay	>4 Ø
63-125 µm	Very Fine Sand	4 Ø, 3.5 Ø
125-250 µm	Fine Sand	3 Ø, 2.5 Ø
250-500 µm	Medium Sand	2 Ø, 1.5 Ø
500-1000 µm	Coarse Sand	1 Ø, 1.5 Ø
1000-2000 µm (1 – 2mm)	Very Coarse Sand	0 Ø, -0.5 Ø
2000 – 4000 µm (2 – 4mm)	Very Fine Gravel	-1 Ø, -1.5 Ø
4000 -8000 µm (4 – 8mm)	Fine Gravel	-2 Ø, -2.5 Ø
8 -64 mm	Medium, Coarse & Very Coarse Gravel	-3 Ø to -5.5 Ø
64 – 256 mm	Cobble	-6 Ø to -7.5 Ø

Range of Particle Size	Classification	Phi Unit
>256 mm	Boulder	< -8 Ø

Organic carbon analysis was carried out by ALS laboratories using the Loss on Ignition (LOI) technique. This method involves oven drying the sediment sample in a muffle furnace (450°C for a period of 6 hours) after which time the organic content of the sample is determined by expressing as a percentage the weight of the sediment after ignition over the initial weight of the sediment.

2.3. *Data Analysis*

Statistical evaluation of the faunal data was undertaken using PRIMER v.6 (Plymouth Routines in Ecological Research). The faunal returns from both replicate samples were totalled prior to analysis. Univariate statistics in the form of diversity indices are calculated. Numbers of species and numbers of individuals per sample will be calculated and the following diversity indices will be utilised:

1) Margalef's species richness index (D) (Margalef, 1958):

$$D = \frac{S-1}{\log_2 N}$$

where: N is the number of individuals

S is the number of species

2) Pielou's Evenness index (J) (Pielou, 1977):

$$J = \frac{H'(\text{observed})}{H'_{max}}$$

where: H'_{max} is the maximum possible diversity, which could be achieved if all species were equally abundant (= $\log_2 S$)

3) Shannon-Wiener diversity index (H') (Pielou, 1977):

$$H' = -\sum_{i=1}^{S} p_i(\log_2 p_i)$$

where: p_i is the proportion of the total count accounted for by the i^{th} taxa

4) Simpson's Diversity Index (Simpson, 1949)

$$1-\lambda' = 1-\{\Sigma_i N_i(N_i-1)\} / \{N(N-1)\}$$

where N is the number of individuals of species i.

Species richness is a measure of the total number of species present for a given number of individuals. Evenness is a measure of how evenly the individuals are distributed among different species. The Shannon-Wiener index incorporates both species richness and the evenness component of diversity (Shannon & Weaver, 1949) and Simpson's index is a more explicit measure of the latter, *i.e.* the proportional numerical dominance of species in the sample (Simpson, 1949).

The PRIMER programme (Clarke & Warwick, 2001) was used to carry out multivariate analyses on the station-by-station faunal data. All species/abundance data from the core survey was fourth root transformed and used to prepare a Bray-Curtis similarity matrix in PRIMER. The fourth root transformation was used in order to allow the intermediate abundant and rarer species to play a part in the similarity calculation (other transformations *e.g.* square root, square root-1, were tested but had little effect on the spatial relationships between stations).

The similarity matrix was then used in classification/cluster analysis. The aim of this analysis was to find "natural groupings' of samples, i.e. samples within a group that are more similar to each other, than they are similar to samples in different groups (Clarke & Warwick, *loc. cit.*). The PRIMER programme CLUSTER carried out this analysis by successively fusing the samples into groups and the groups into larger clusters, beginning with the highest mutual similarities then gradually reducing the similarity level at which groups are formed. The result was represented graphically in a dendrogram, the x-axis representing the full set of samples and the y-axis representing similarity levels at which two samples/groups are said to have fused. SIMPROF (Similarity Profile) permutation tests were incorporated into the CLUSTER analysis to identify statistically significant evidence of genuine clusters in samples which are *a priori* unstructured.

The Bray-Curtis similarity matrix was also subjected to a non-metric multi-dimensional scaling (MDS) algorithm (Kruskal & Wish, 1978), using the PRIMER programme MDS. This programme produced an ordination, which is a map of the samples in two- or three-dimensions, whereby the placement of samples reflects the similarity of their biological communities, rather than their simple geographical location (Clarke & Warwick, 2001). With regard to stress values, they give an indication of how well the multi-dimensional similarity matrix is represented by the two-dimensional plot. They are calculated by comparing the interpoint distances in the similarity matrix with the corresponding interpoint distances on the 2-d plot. Perfect or near perfect matches are rare in field data, especially in the absence of a single overriding forcing factor such as an organic enrichment gradient. Stress values increase, not only with the reducing dimensionality (lack of clear forcing structure), but also with increasing quantity of data (it is a sum of the squares type regression coefficient). Clarke & Warwick (*loc. cit.*) have provided a classification of the reliability of MDS plots based on stress values, having compiled simulation studies of stress value behaviour and archived empirical data.

This classification generally holds well for 2-d ordinations of the type used in this study. Their classification is given below:

- Stress value < 0.05: Excellent representation of the data with no prospect of misinterpretation.
- Stress value < 0.10: Good representation, no real prospect of misinterpretation of overall structure, but very fine detail may be misleading in compact subgroups.
- Stress value < 0.20: This provides a useful 2-d picture, but detail may be misinterpreted particularly nearing 0.20.
- Stress value 0.20 to 0.30: This should be viewed with scepticism, particularly in the upper part of the range, and discarded for a small to moderate number of points such as < 50.
- Stress values > 0.30: The data points are close to being randomly distributed in the 2-d ordination and not representative of the underlying similarity matrix.

Each stress value must be interpreted both in terms of its absolute value and the number of data points. In the case of this study, the moderate number of data points indicates that the stress value can be interpreted more or less directly. While the above classification is arbitrary, it does provide a framework that has proved effective in this type of analysis.

The species, which are responsible for the grouping of samples in cluster and ordination analyses, were identified using the PRIMER programme SIMPER (Clarke & Warwick, 1994). This programme determined the percentage contribution of each species to the dissimilarity/similarity within and between each sample group.

In order to determine what role (if any) sediment characteristics has on the faunal groupings, Principal Component Analysis (PCA) was carried out on the sediment grain size and organic carbon data. PCA is a 2D/3D ordination similar to that of non-metric MDS. The data was transformed to prevent any outliers having a disproportionate influence on the results. The grain size characteristics were arcsin transformed and the organic carbon results were $\log_{10}$ transformed as is standard practice. if any significant (pairwise correlations >0.95) correlations existed between variables, only one variable from that correlated group was included in the analysis, to prevent the correlation being exaggerated in the analysis. Following transformation, the data was normalised to equalise the variance and standardise the contributory importance of each variable. The resulting data matrix was subjected to a correlation based PCA using Primer v6 programme PCA (Clarke & Warwick, 1994), to identify the parameters that accounted for the variance in the original dataset. The SIMPROF groupings assigned to the stations based on their faunal make-up (using CLUSTER) were added to the dataset to allow a comparison to be made between the faunal and sediment groupings.

In order to assess the benthic ecological quality of the community, the AZTI Marine Biotic Index (AMBI) was calculated on each replicate sample. AMBI offers a 'pollution or disturbance classification' which represents the benthic community health (*sensu* Grall & Glémarec, 1997). All epifauna and planktonic taxa are removed prior to analysis. Individuals are put into one of five ecological sensitivity groups (Group I - very sensitive to disturbance/pollution; Group II - indifferent to disturbance/pollution; Group III - tolerant to disturbance/pollution; Group IV - second-order opportunists and Group V - first order opportunists) and the AMBI score is calculated as a weighted average of the sensitivity scores of each replicate sample. Assemblages with high proportions of sensitive taxa are indicative of areas with low levels of disturbance/pollution and stations dominated by opportunistic taxa reflect impacted areas. Table 2.3 shows the AMBI values and their equivalences (after Borja *et al.*, 2000).

Table 2.3: Summary of the AMBI values and their equivalences (after Borja *et al.*, 2000 modified from Grall & Glémarec, 1997).

AMBI Value (BC = Biotic Coefficient)	Dominating Ecological Group	Benthic Community Health	Site Pollution Classification
$0.0 < BC \le 0.2$	I	Normal	Unpolluted
$0.2 < BC \le 1.2$		Impoverished	
$1.2 < BC \le 3.3$	III	Unbalanced	Slightly Polluted
$3.3 < BC \le 4.3$	IV - V	Transitional to Polluted	Moderately Polluted
$4.3 < BC \le 5.0$		Polluted	
$5.0 < BC \le 5.5$	V	Transitional to Heavy Pollution	Heavily Polluted
$5.5 < BC \le 6.0$		Heavily Polluted	
7.0	Azoic	Azoic	Extremely Polluted

3. Results

3.1. Walkover

Lichen species (*Verrucaria maura, Lichina pygmaea, Xanthoria parietina* and *Caloplaca marina*) were recorded at High Water. Algal species recorded at the site included *Pelvetia canaliculata* in the highest parts of the upper shore, *Fucus spiralis* in the upper shore, *Ascophyllum nodosum* and its epiphytic red alga, *Vertebrata lanosa* along with *Fucus vesiculosus* in the mid shore area and *Fucus serratus* in the lower shore. Some red algae crusts were recorded from mid shore to lower shores areas. Figures 3.1 and 3.2 show representative photographs of the intertidal area.

Figure 3.1: Representative imagery from Renmore intertidal.

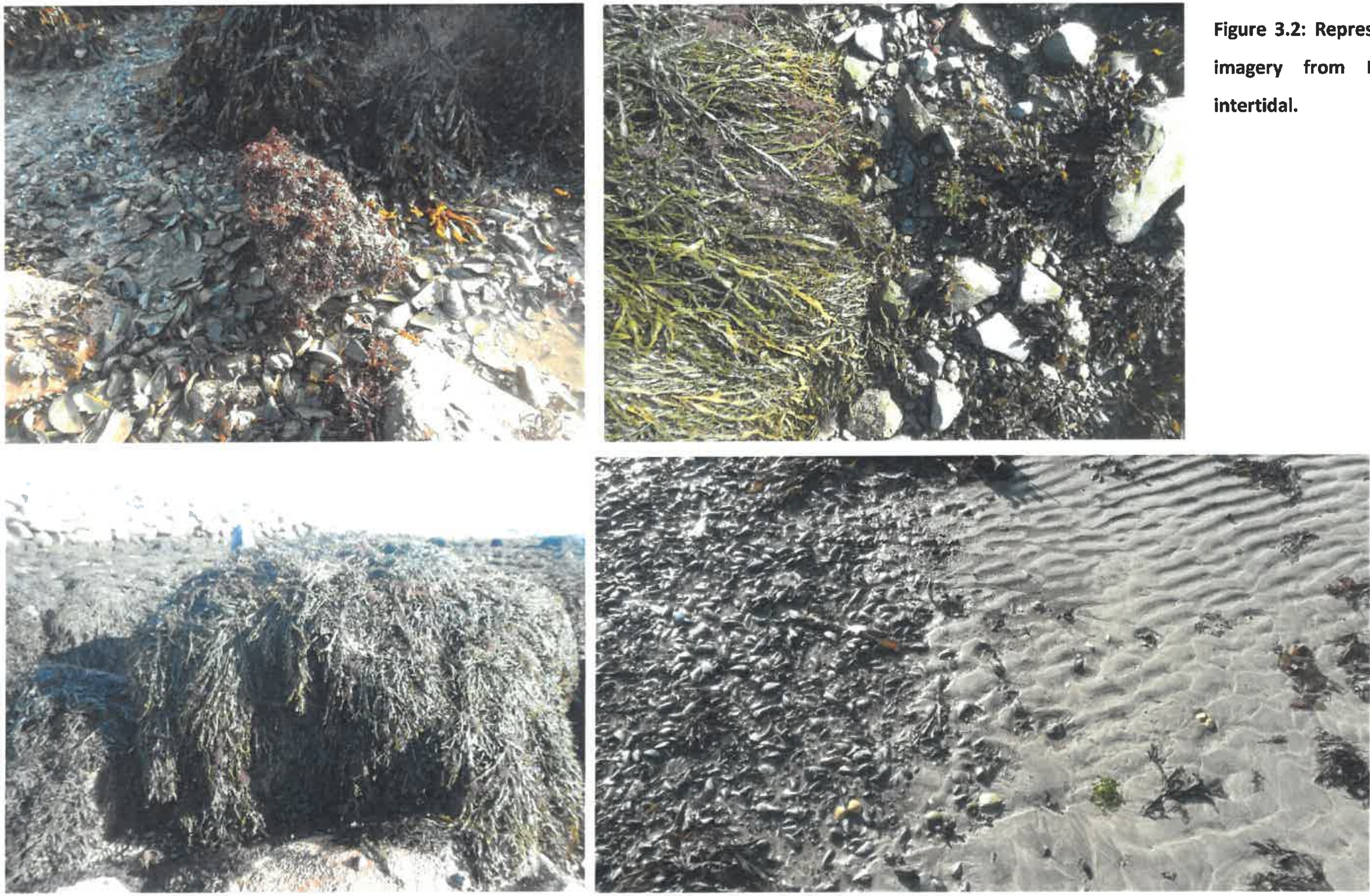

Figure 3.2: Representative imagery from Renmore intertidal.

3.2. *Sediment*

Table 3.1 presents the results of the granulometric analyses on the ten sediment samples collected at Renmore.

Station 6 contained the highest percentage of fine gravel (38.6%) and Station 1 contained the highest percentage of very fine gravel (23.5%). Stations 4 contained the highest percentage of very coarse sand (36%) and coarse sand (20.4%). Station 2 contained the highest percentage of medium sand (12.2%). Station 8 contained the highest percentage of fine sand (74.1%). Station 5 had the highest percentage of very fine sand (61.2%) and silt-clay (17.5%). The sediment sampled was classified according to Folk (1954) as sand, muddy sand, gravelly sand, sandy gravel. Figure 3.3 shows the grain size distribution at each station. Figure 3.4 shows the sediment type according to Folk (1954).

Except for Station 5 where very fine sands predominated, sediments in the area are characterised gravels and coarse sand with low percentages of fine, very fine and silt-clay fractions. Another characteristic aspect of the area surveyed was the presence of large numbers of mussel shells and shell debris particularly in the western half of the site. Many live mussels were also recorded and small number of juvenile native oysters, *Ostrea edulis.* Three bottom shells of the non-native Pacific Oyster *Magallana (Crassostrea) gigas* were also seen. Sediments throughout the area smelled strongly of hydrogen sulphide.

Table 3.1: Sediment grain size results from Renmore.

Station	Fine Gravel (>4mm)	Very Fine Gravel (2-4mm)	Very Coarse Sand (1-2mm)	Coarse Sand (0.5-1mm)	Medium Sand (0.25-0.5mm)	Fine Sand (125-250mm)	Very Fine Sand (62.5-125mm)	Silt-Clay (<63mm)	Folk (1954)
1	23.5	23.5	24.6	11	6.1	4.4	4.1	2.8	Sandy gravel
2	13.80	15.30	22.30	15.40	12.20	12.40	5.80	2.80	Gravelly sand
3	7.90	15.10	25.50	15.60	7.60	12.30	12.00	4.10	Gravelly sand
4	3	15.4	36	20.4	6.9	11.8	5.4	1	Gravelly sand
5	0.3	0.3	0.3	1.1	1.6	17.8	61.2	17.5	Muddy sand
6	38.6	21.3	10.3	4.5	5.9	12.5	5.6	1.4	Sandy gravel
7	21.5	23.3	16.2	8	9.3	13	7.5	1.3	Sandy gravel
8	0	0.1	0.1	0.8	3.7	74.1	21	0.3	Sand
9	0	0	0.1	0.8	2.6	62.1	34	0.5	Sand
10	0.2	0.3	0.7	1.6	3.6	45.8	47.2	0.7	Sand

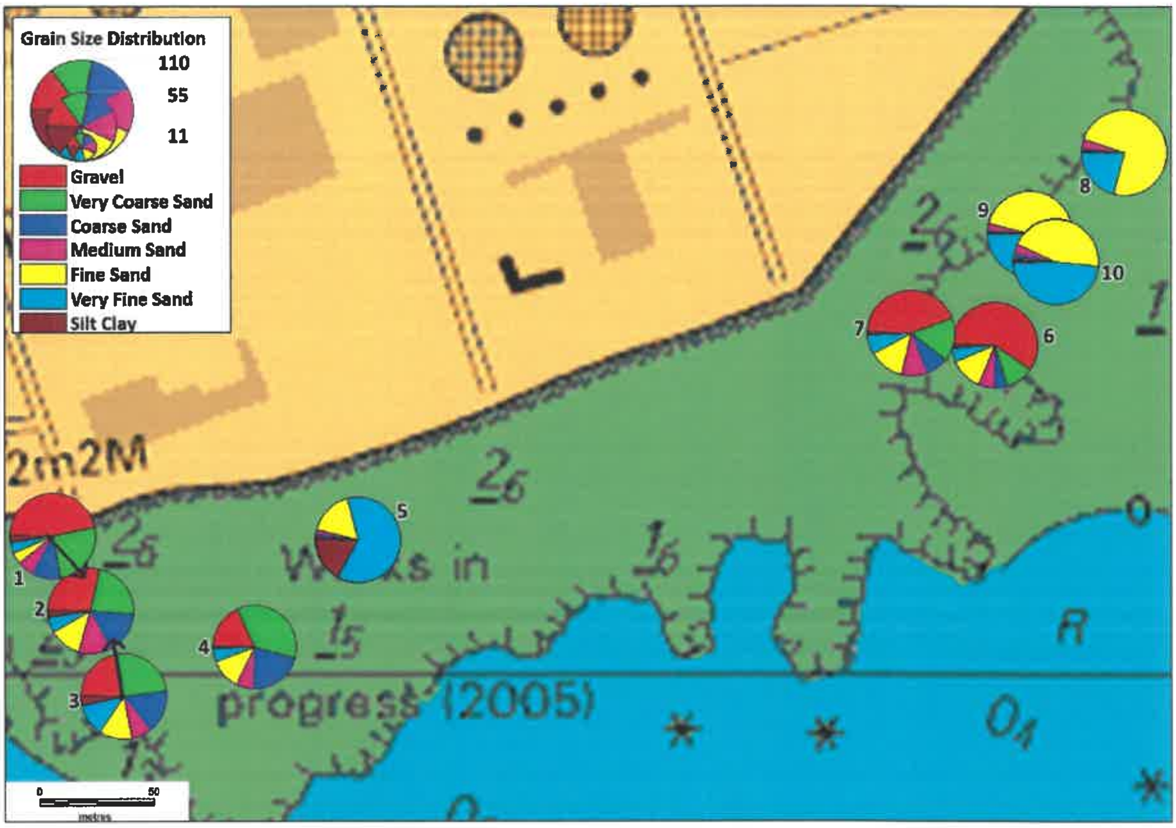

Figure 3.3: Grain size distribution from Renmore.

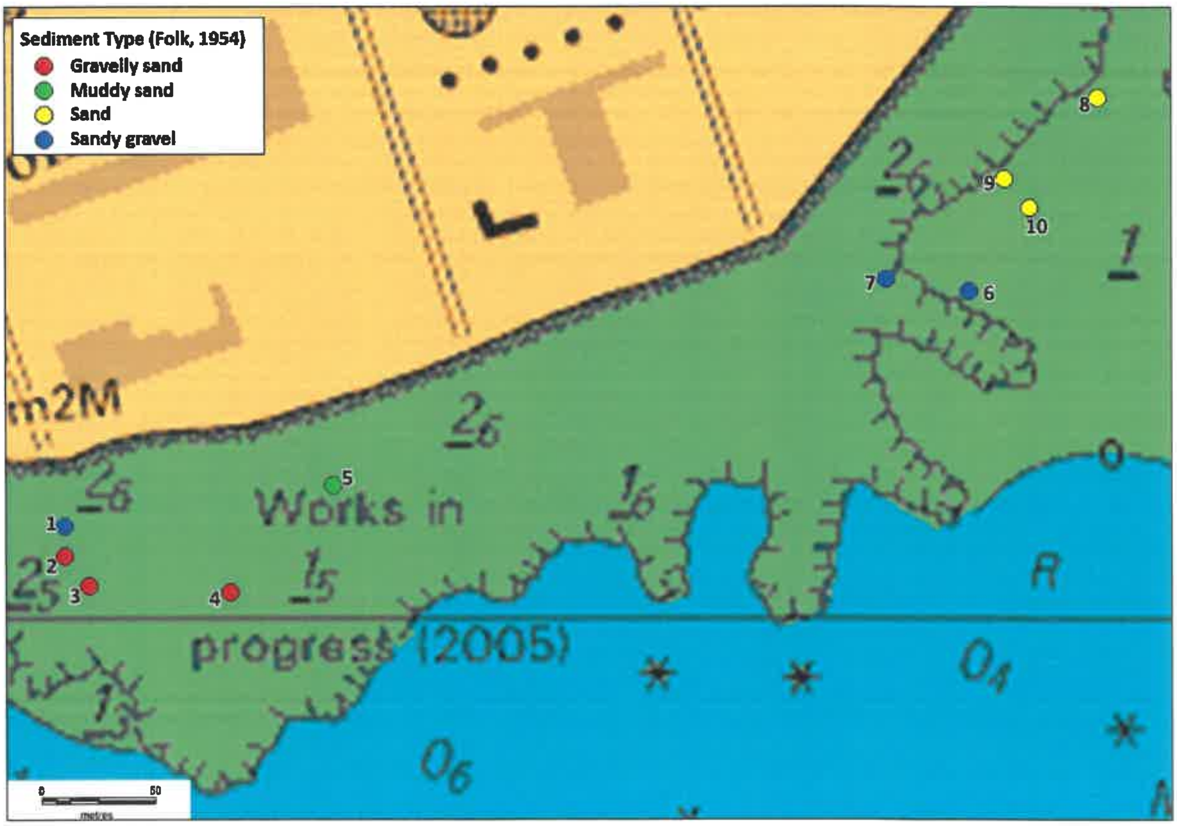

Figure 3.4: Sediment type according to Folk (1954) in Renmore.

Organic carbon levels ranged from 1.12 % at Station 9 to 8.16% at Station 1. The results can be seen in Table 3.2.

Table 3.2: Organic carbon results from the Renmore survey area.

Station	% LOI
1	8.16
2	4.28
3	4.26
4	3.96
5	2.24
6	3.36
7	2.18
8	1.15
9	1.12
10	1.22

3.3. Infauna

The taxonomic identification of the benthic infauna across all 10 core stations sampled at Renmore yielded a total count of 67 taxa, consisting of 4,386 individuals ascribed to 6 phyla. Of the 67 taxa recorded, 45 were identified to species level. The remaining 22 could not be identified to species level as they were either juveniles, partial/damaged or indeterminate. Appendix 3-2 shows the faunal abundances from the sampled sites.

Of the 67 taxa present, 1 was a cnidarian (corals, anemones, jellyfish *etc*), 1 was a nematode (roundworm), 2 were nemerteans (ribbon worms), 35 were annelids (segmented worms), 14 were crustaceans (crabs, shrimps, prawns) and 14 were molluscs (mussels, cockles, snails etc.

3.3.1. Univariate Analysis

Univariate statistical analyses were carried out on the combined station-by-station faunal data. The following parameters were calculated and can be seen in Table 3.3: taxon numbers, number of individuals, richness, evenness, Shannon-Weiner diversity and Simpson's Diversity. Stations 8, 9 and 10 returned the lowest number of taxa (8) while Station 4 returned the highest number (28). The lowest number of individuals was recorded at Stations 8 and 10 (45) and the highest number of individuals was recorded at Station 1 (1,623). Species richness was lowest at Station 9 (1.7) and highest at Station 4 (4.57) while evenness was lowest at Station 3 (0.45) and highest at Station 7 (0.79). Shannon-Weiner diversity ranged from 1.21 at Station 3 to 2.51 at Station 7. Simpson's diversity ranged from 0.50 at Station 3 to 0.88 at Station 7. Figure 3.5 shows these community indices in graphical form.

Table 3.3: Univariate measures of community structure.

Stations	No. Taxa	No. Individuals	Richness	Evenness	Shannon-Weiner Diversity	Simpson's Diversity
1	26	1623	3.38	0.49	1.59	0.64
2	20	1022	2.74	0.48	1.45	0.57
3	15	511	2.24	0.45	1.21	0.50
4	28	369	4.57	0.75	2.50	0.87
5	14	85	2.93	0.75	1.98	0.78
6	25	310	4.18	0.73	2.34	0.87
7	24	314	4.00	0.79	2.51	0.88
8	8	45	1.84	0.70	1.46	0.70
9	8	62	1.70	0.66	1.36	0.68
10	8	45	1.84	0.76	1.58	0.71

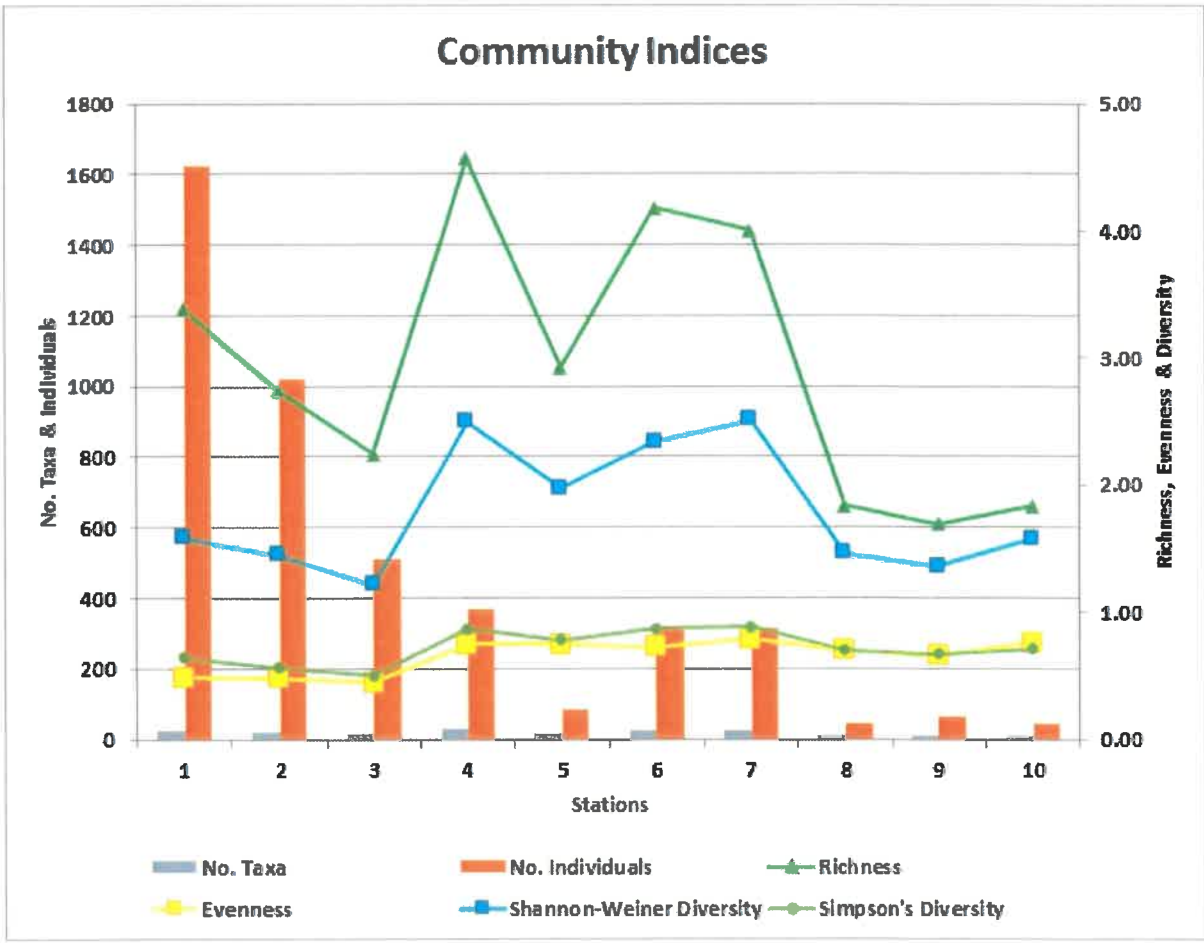

Figure 3.5: Community diversity indices.

3.3.2. Multivariate Analysis

The same data set used above for the univariate analyses was also used for the multivariate analyses. The dendrogram and the MDS plot can be seen in Figures 3.6 and 3.7 respectively. SIMPROF analysis revealed 3 statistically significant groupings between the 10 stations (the samples connected by red lines cannot be significantly differentiated). The stress level on the MDS plot indicates a good representation of the data.

Group a separated from Groups b and c at a 20.37% similarity level and Groups b and c separated from each other at a 34.35% similarity level.

Group a contained stations 1 and 2 and SIMPER analysis revealed that it had a within group similarity of 72.64%. This group contained 30 taxa comprising 2,645 individuals. Of the 30 taxa, 10 were present twice or less. Three species accounted for just over 77% of the faunal abundance of this group; the oligochaetes *Tubificoides benedii* (1,588 individuals, 60.04% abundance), *Baltidrilus costata* (262 individuals, 9.91% abundance) and *Tubificoides pseudogaster* agg. (195 individuals, 7.37% abundance). Species richness was above average for this group but diversity was low due to the over-abundance of 1 species. These oligochaetes are first order opportunistic species that proliferate in reduced sediments. The stations in this group had a high gravel content.

Group b contained stations 3, 4, 6 and 7 and SIMPER analysis revealed that it had a within group similarity of 57.46%. This group contained 43 taxa comprising 1,504 individuals. Of the 43 taxa, 13 were present twice or less. Three species accounted for just over 55% of the faunal abundance of this group; the oligochaetes *Tubificoides* sp. (461 individuals, 30.65% abundance) and the polychaetes *Heteromastus filiformis* (210 individuals, 13.96% abundance) and *Eteone longa agg.* (163 individuals, 10.84% abundance). SIMPER analysis revealed that the polychaetes *Pygiospio elegans, Heteromastus filiformis* and the nemertean *Cerebratulus* sp. were the characterising species of this group. Table 3.4 shows the full SIMPER results. Species richness was relatively high for this group but diversity was average. *Tubificoides* sp. is first order opportunistic species that proliferate in reduced sediments and *Heteromastus filiformis* is a 2nd order opportunistic species present in slight to pronounced unbalanced situations. *Eteone longa agg., Cerebratulus* sp. and *Pygiospio elegans* are tolerant to excess organic matter enrichment but their populations are stimulated by organic enrichment. The stations in this group had a high gravel content.

Group c contained stations 5, 8, 9 and 10 and SIMPER analysis revealed that it had a within group similarity of 53.65%. This group contained 20 taxa comprising 237 individuals. Of the 20 taxa, 9 were present twice or less. Three species accounted for just over 72% of the faunal abundance of this group; the polychaetes *Eteone longa* agg. (100 individuals, 42.19% abundance) and *Capitella* sp. complex (54 individuals, 22.78% abundance) and the bivalve *Fabulina fabula* (17 individuals, 7.17% abundance). SIMPER analysis revealed that the polychaetes *Pygiospio elegans* and *Eteone longa* agg. were the characterising species of this group. Table 3.4 shows the full SIMPER results. Species richness and diversity were low for this group. *Capitella* sp. complex is a first order opportunistic species that proliferate in reduced sediments *Eteone longa agg.* is tolerant to excess organic matter enrichment but their populations are stimulated by organic enrichment. *Fabulina fabula* however is a species that is very sensitive to organic enrichment and only occurs under unpolluted conditions. All of the stations in this group were of a similar sedimentary make-up (sand and muddy sand).

The occurrence of the pioneering polychaete genus *Capitella* and high numbers of tubificid oligochaetes, in Group a (Stations 1 and 2 which are closest to the plume of the River Corrib) indicates a high level of organic carbon and a low level of oxygen in the sediment.

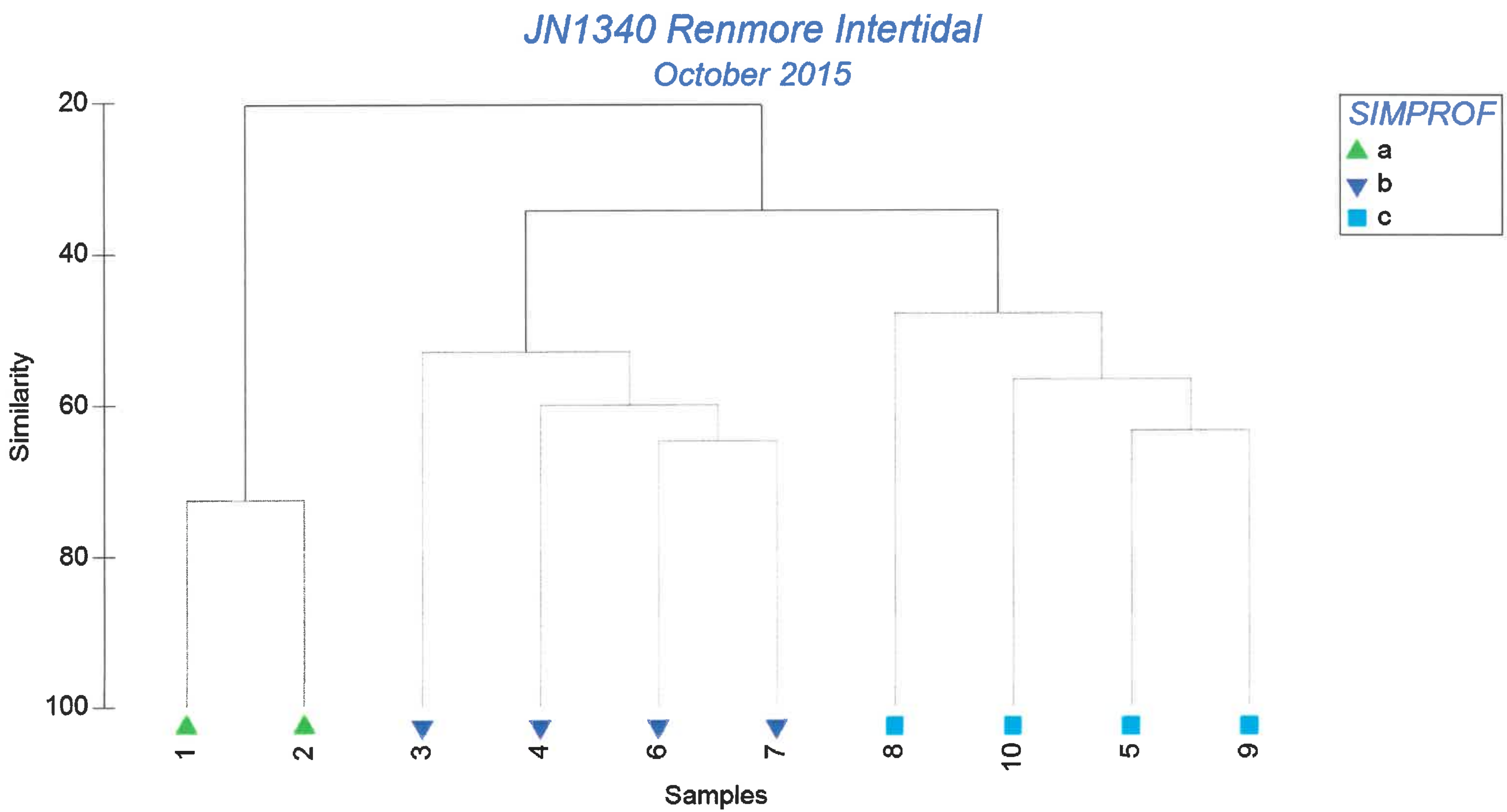

Figure 3.6: Cluster analysis of quantitative faunal data from ten intertidal stations at Renmore.

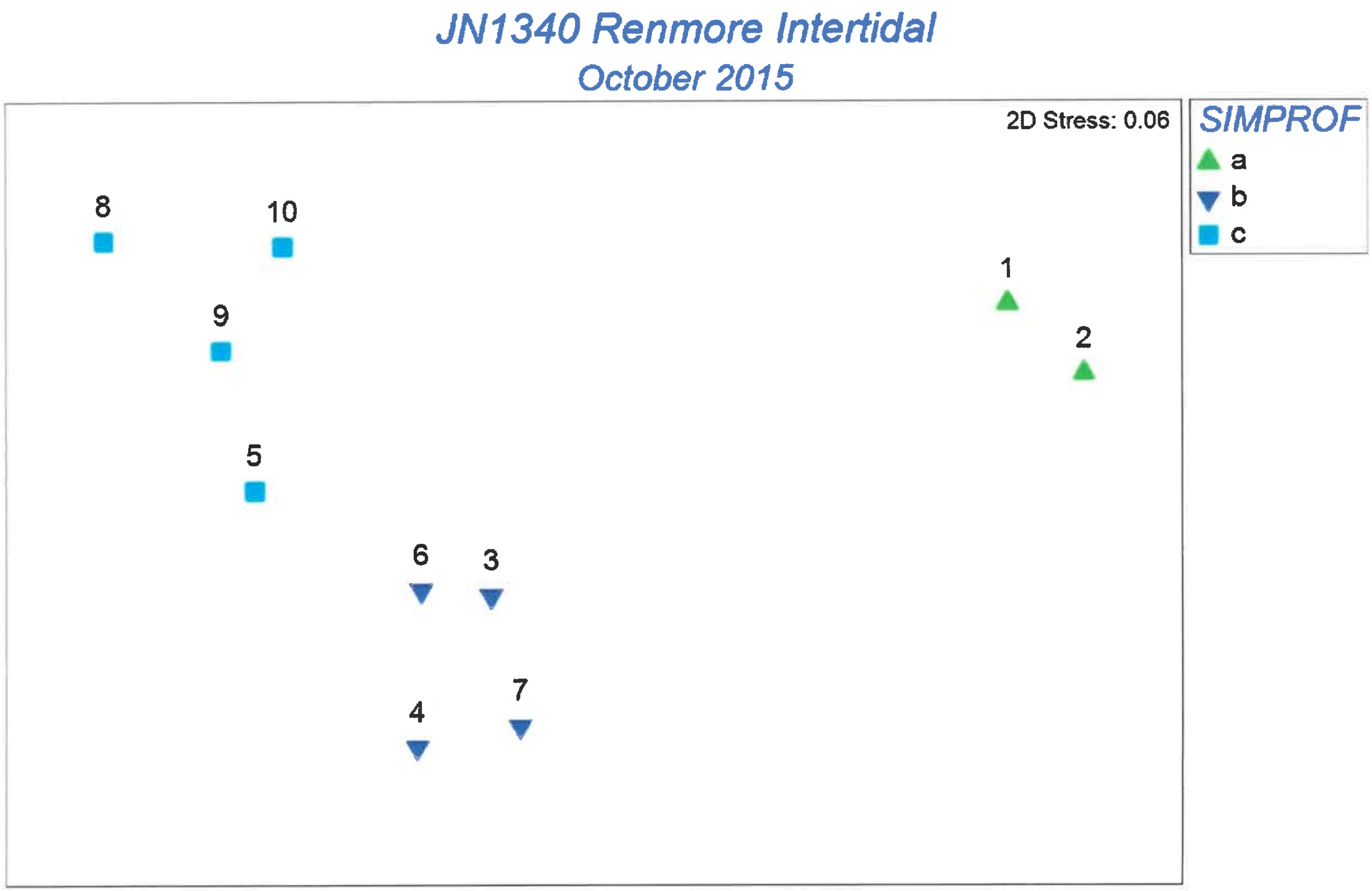

Figure 3.7: MDS of quantitative faunal data from ten intertidal stations at Renmore.

Table 3.4: SIMPER results.

Group a Average similarity: 72.64%					
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Tubificoides benedii	5.29	11.53	#######	15.87	15.87
Eteone longa agg.	2.99	6.65	#######	9.15	25.02
Nematoda	2.78	6.19	#######	8.52	33.54
Baltidrilus costata	3.23	6.01	#######	8.28	41.82
Tubificoides pseudogaster aggregate	3.04	5.82	#######	8.01	49.84
Malacoceros fuliginosus	2.65	5.72	#######	7.87	57.71
Hediste diversicolor	2.31	4.68	#######	6.45	64.15
Brachyura	1.67	3.56	#######	4.9	69.05
Macoma balthica	1.84	3.56	#######	4.9	73.95
Melita palmata	1.91	3.4	#######	4.68	78.63
Pygospio elegans	1.6	3.22	#######	4.43	83.06
Venerupis corrugata	1.41	3.22	#######	4.43	87.48
Tetrastemma melanocephalum	1.34	2.27	#######	3.13	90.61
Group b Average similarity: 57.46%					
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Pygospio elegans	2.45	6.21	6.95	10.81	10.81
Heteromastus filiformis	2.59	6.03	8.04	10.49	21.3
Eteone longa agg.	2.42	5.72	3.47	9.95	31.25
Tubificoides sp.	2.8	5.69	2.79	9.91	41.16
Cerebratulus sp.	1.64	4.11	10.24	7.15	48.31
Macoma balthica	1.56	3.78	4.43	6.58	54.89
Glycera tridactyla	1.52	3.76	6.33	6.54	61.43
Nephtys hombergii	1.65	3.55	3.07	6.18	67.61
Scoloplos armiger	1.53	3.38	4.17	5.89	73.5
Melinna palmata	1.35	2.86	8.23	4.98	78.48
Prionospio sp.	1.27	1.9	0.9	3.31	81.79
Protodorvillea kefersteini	1.03	1.61	0.9	2.81	84.6
Leptochiton asellus	1.27	1.59	0.81	2.76	87.36
Parvicardium scabrum	1.07	1.38	0.89	2.4	89.76
Parvicardium minimum	0.83	1.22	0.91	2.12	91.87
Group average similarity: 53.65%					
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Eteone longa agg.	2.21	15.85	6.5	29.55	29.55
Capitella sp. complex	1.82	12.1	3.27	22.56	52.11
Pygospio elegans	1.35	9.45	6.73	17.61	69.73
Tellina fabula	1.14	5.12	0.9	9.54	79.27
Nephtys hombergii	1.08	4.57	0.9	8.51	87.78
Tellina tenuis	0.59	1.79	0.41	3.34	91.12

Table 3.5 and Figure 3.8 shows the AMBI results from the analysis of the samples. Three stations were classified as heavily disturbed (Stations 1-3) and these were located to the west of the survey

area closest to the navigational channel. Four stations (4, 6, 8 and 9) were classified as moderately disturbed and three stations were classified as slightly disturbed (5, 7 and 10). These stations were distributed throughout the central and eastern parts of the survey area. The heavily disturbed stations were dominated by opportunistic species which thrive in reduced sediments (Group V; 77.5% on average).

The moderately disturbed stations were dominated by species tolerant to organic enrichment and opportunistic species which thrive in reduced sediments (Group III; 40.6% on average and Group V; 37.8% on average). The slightly disturbed stations were dominated by species that are tolerant to excess organic matter enrichment (Group III, 55.8%). Appendix 3-3 shows the detailed station results.

Table 3.5: AMBI Results.

Station	%I	%II	%III	%IV	%V	%n.a	AMBI	Disturbance
1	3.2	0.4	12.4	0.1	84	0.5	5.319	Heavily disturbed
2	1.4	0.2	19.6	0.1	78.7	1.3	5.315	Heavily disturbed
3	0	3.5	24.5	2.2	69.9	0	5.041	Heavily disturbed
4	4.2	3.9	39.9	24.4	27.7	2.2	3.918	Moderately disturbed
5	11.8	11.8	60	3.5	12.9	0	2.888	Slightly disturbed
6	7.7	10.8	24.2	19.2	38	4.2	4.007	Moderately disturbed
7	17.7	6.6	47.5	18.7	9.5	2.9	2.952	Slightly disturbed
8	4.4	2.2	46.7	0	46.7	0	4.395	Moderately disturbed
9	4.8	4.8	51.6	0	38.7	0	3.683	Moderately disturbed
10	24.4	8.9	60	0	6.7	0	2.288	Slightly disturbed

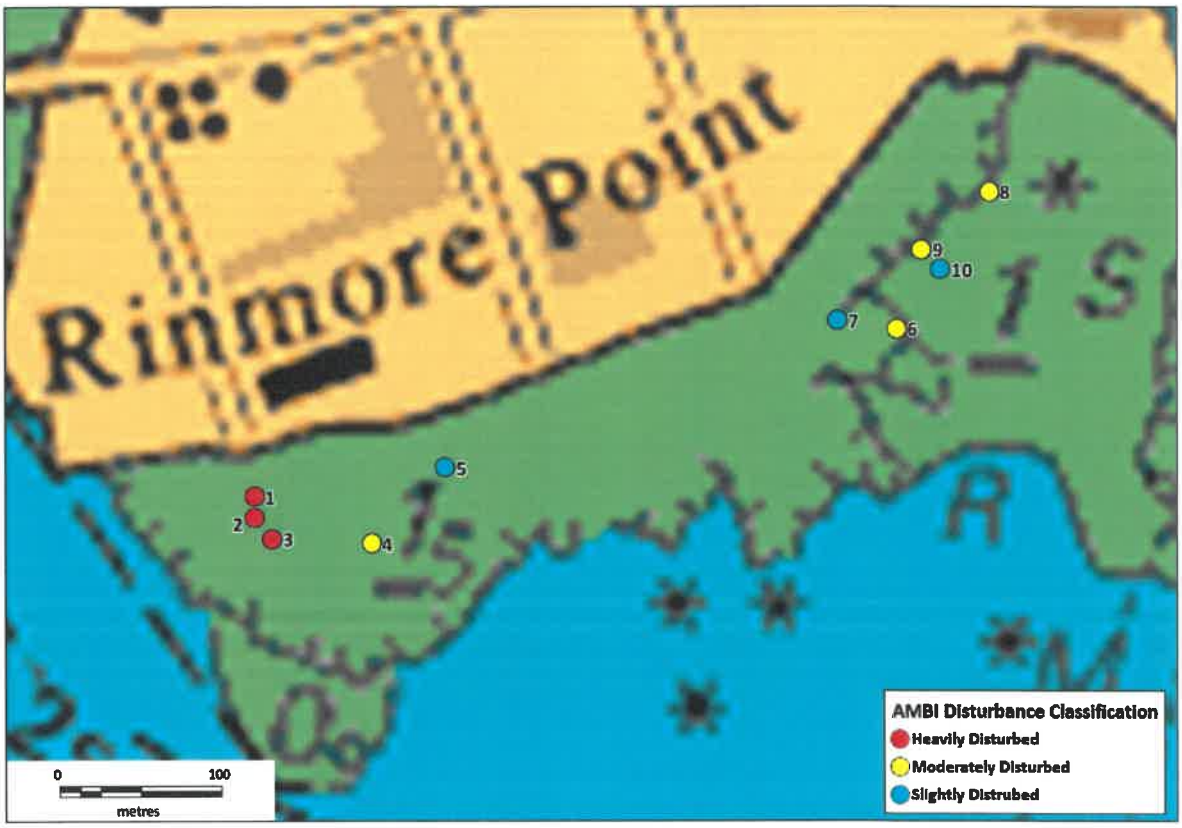

Figure 3.8: AMBI disturbance classification.

3.3.3. Sediment Characteristics

Table 3.6 shows the results of the Principal Component Analysis (PCA) on the arcsin transformed sediment gain size data and the $\log_{10}$ transformed organic carbon data; the ordination can be seen in Figure 3.9. PC1 and PC2 represent 89.3% of the variation in the data. Sediments were split based on fine sand, very fine sand and silt-clay (positive coefficients) and gravel, very coarse sand, coarse sand, medium sand and organic carbon (negative coefficients) along PC1. Sediments were split based on gravel, very coarse sand, coarse sand, medium sand and fine sand (positive coefficients) and very fine sand, silt-clay and organic carbon (negative coefficients) along PC2. Figure 3.9 also shows the SIMPROF groupings assigned to each station during the CLUSTER analysis. Faunal groups a and b were characteristed by gravel, very coarse sand, coarse sand and medium sand whereas faunal group c was characterised by fine sand, very fine sand and silt-clay with station 5 standing out due to very high organic carbon levels. Figure 3.10 shows the PCA ordination with bubble plots for each sediment parameter at each station superimposed on the plot (the larger the bubble, the higher the value of that parameter).

Table 3.6: Two dimensional PCA on the transformed sediment data.

Axes	PC1	PC 2	PC 3	PC 4	PC
Eigenvalues	5.58	1.56	0.439	0.251	0.111
Cumulative % Variation	69.8	89.3	94.8	98.0	99.4
Gravel (G)	-0.374	0.02	0.684	0.15	-0.195
Very Coarse Sand (VCS)	-0.41	0.015	-0.311	-0.191	-0.256
Coarse Sand (CS)	-0.39	0.012	-0.57	-0.083	-0.141
Medium Sand (MS)	-0.361	0.253	-0.178	0.768	0.233
Fine Sand (FS)	0.362	0.379	-0.165	-0.062	0.52
Very Fine Sand (VFS)	0.369	-0.333	-0.211	0.182	-0.476
Silt-Clay (SC)	0.006	-0.781	-0.063	0.298	0.372
Organic Carbon (OC)	-0.378	-0.266	0.054	-0.467	0.432

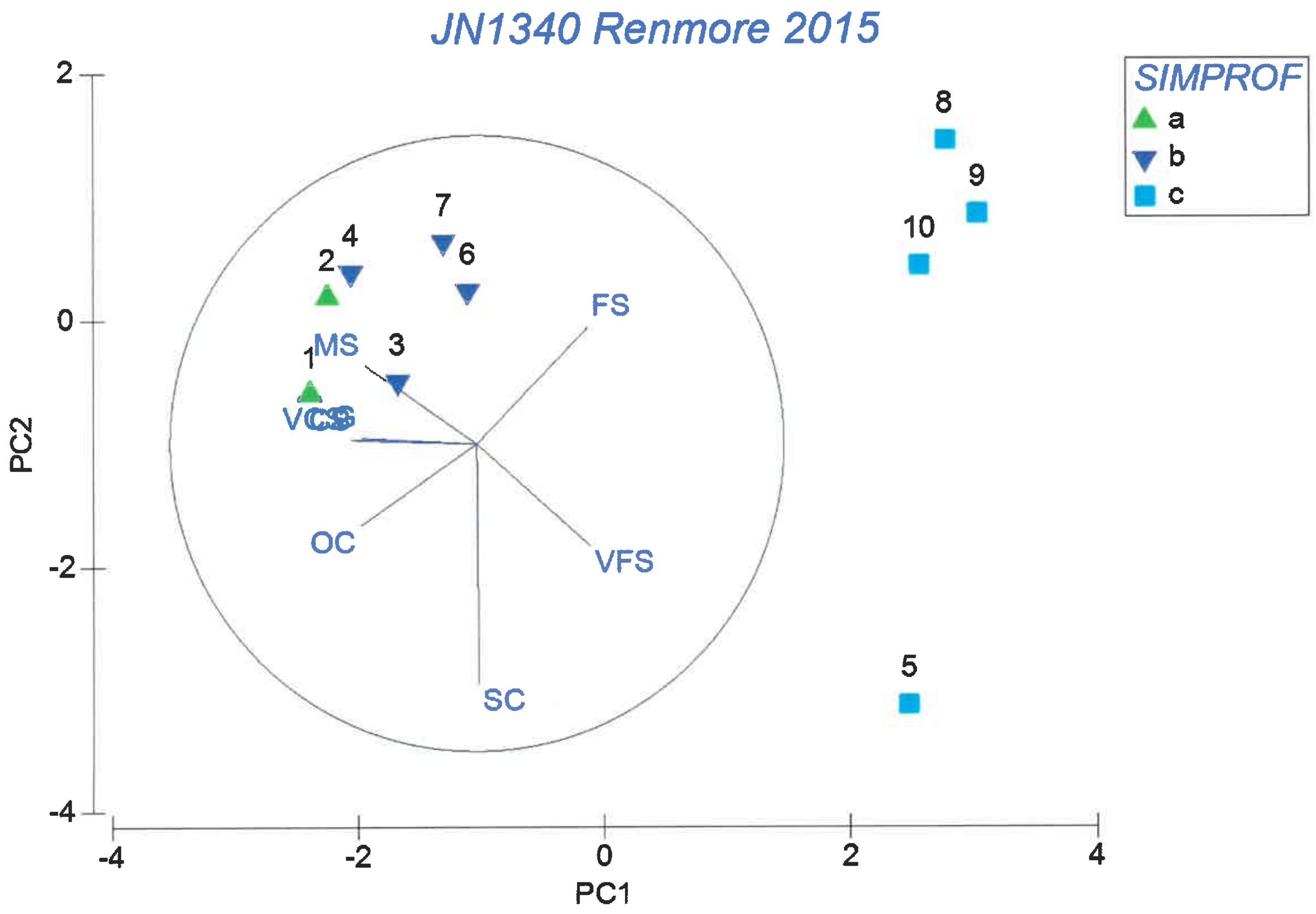

Figure 3.9: 2D PCA ordination of the transformed sediment data.

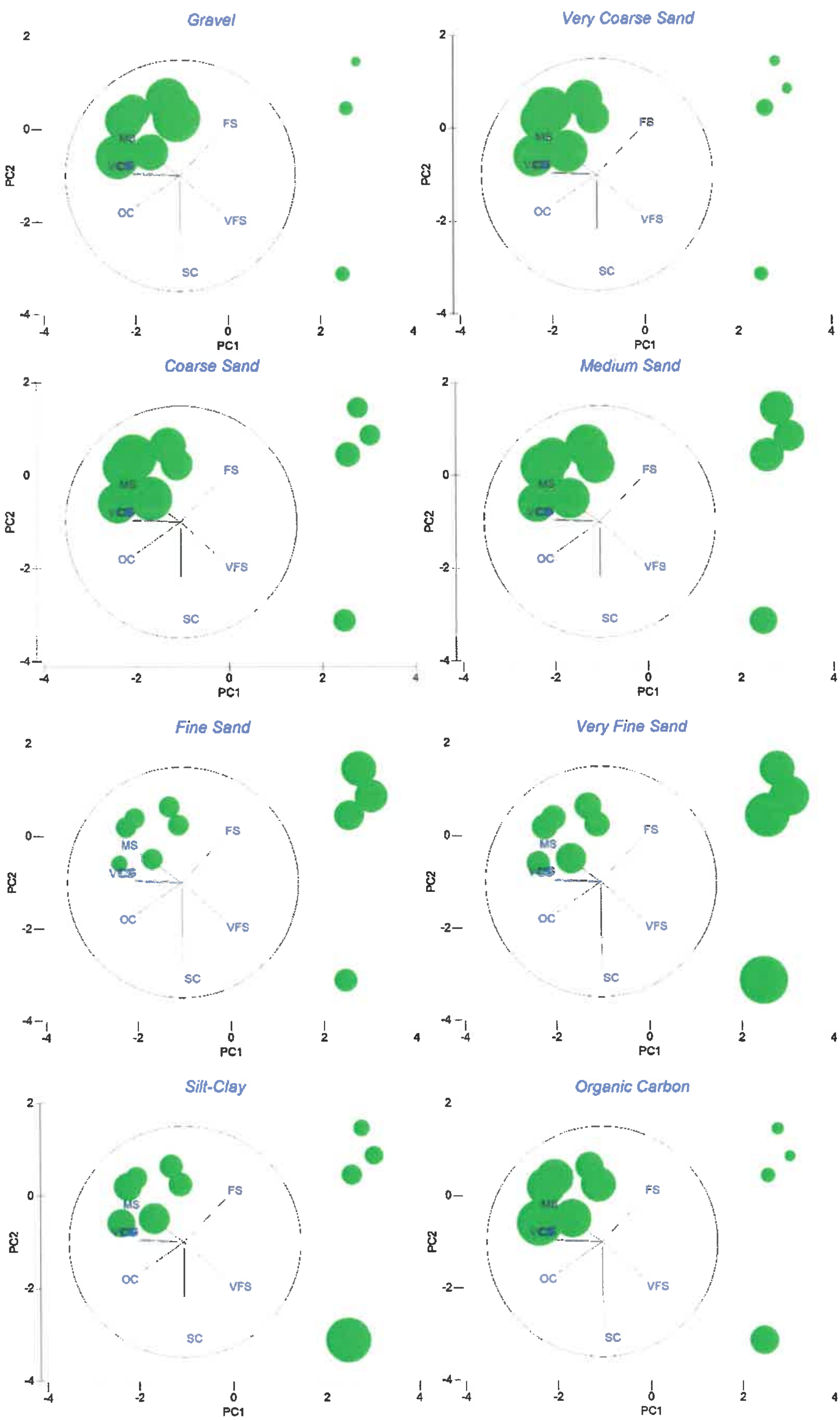

Figure 3.10: Bubble plots showing sediment parameters superimposed on the PCA ordination.

3.4. *Distribution of intertidal communities.*

The result of the walk over of the intertidal area at Renmore and the documentation of the intertidal communities recorded are shown in Figure 3.11 below.

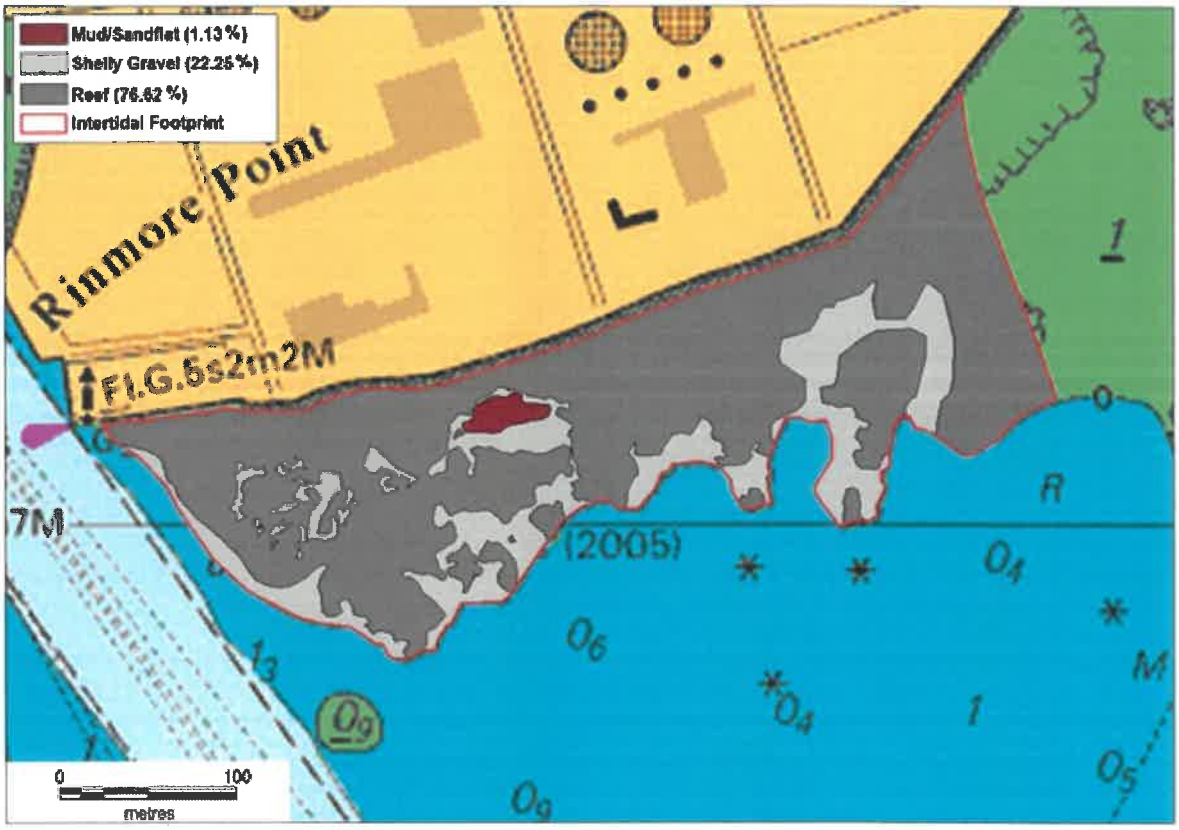

Figure 3.11: Distribution of intertidal communities recorded at Renmore.

As can be seen from this figure, the reef and shelly gravel habitats together make up *c.* 98.8% of the habitat type with mud/sand flat only comprising a little over 1%. There is a large area of mud and sand flat just to the east of the red line marked above at Ballyloughan Beach.

4. Discussion

The intertidal habitat at the Renmore area has historically been impacted by organic enrichment from loadings in the River Corrib which on an ebbing tide, flows over the western parts of the area. Before the Mutton Island treatment plant was commissioned in the early years of this century, untreated sewage effluent was disposed of to the sea either in the river itself or via a disposal pipe south of Nimmo's Pier for many, many decades giving rise to sediments with low levels of oxygen, high levels of sedimentary hydrogen sulphide and therefore reduced numbers of infaunal invertebrates. Besides the untreated effluent as a source of organic enrichment, the catchment of the Corrib particularly along the eastern area of Co. Galway and to a lesser extent, the southern section, drains lands that are intensively farmed. These areas also have a number of towns, *e.g.* Tuam, Headford, Oughterard that only have secondary treatment works, the effluent of which is disposed of to rivers that eventually flow into Lough Corrib and then on to the River Corrib and enter the sea at Galway City. The fact that the water of the Corrib River has its own organic loading contributes to the impact that the intertidal habitat at Renmore is experiencing. This effect is clearly shown when both the dendrogramme and the PCA plots are examined (see Figures 3.5 and 3.6 above) with the two further western stations (Sts. 1 and 2) that are closest to the Corrib cluster together while the most easterly stations, furthest away from the Corrib, Stations 8, 9 and 10 grooup together.

In assessing the status of the intertidal habitat and species at Renmore both are deemed inadequate due to the levels of organic enrichment that this habitat is exposed to.

The results of the AMBI analysis (see Figure 3.8 above) showed that the area to the west of the survey location at Renmore is heavily disturbed with indictors of organic enrichment such as *Capitella capitata* being recorded. Other species that are tolerant of organic enrichment that were recorded there include *Malacoceros fuliginosus* and the oligochaetes *Tubificoides benedii* and *T. pseudogaster*. Further to east of the survey area, the remainder of the site was classified by AMBI as being moderately or slightly disturbed. This suggests that the organic enrichment effect of the River Corrib reduces to the east.

5. References

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Appendix 4-1

Grain Size Methodology

Granulometry

1. Approximately 25g of dried sediment is weighed out and placed in a labelled 1L glass beaker to which 100 ml of a 6 percent hydrogen peroxide solution was then added. This was allowed to stand overnight in a fume hood.

2. The beaker is placed on a hot plate and heated gently. Small quantities of hydrogen peroxide are added to the beaker until there is no further reaction. This peroxide treatment removes any organic material from the sediment which can interfere with grain size determination.

3. The beaker is then emptied of sediment and rinsed into a. 63µm sieve. This is then washed with distilled water to remove any residual hydrogen peroxide. The sample retained on the sieve is then carefully washed back into the glass beaker up to a volume of approximately 250ml of distilled water.

4. 10ml of sodium hexametaphosphate solution is added to the beaker and this solution is stirred for ten minutes and then allowed to stand overnight. This treatment helps to dissociate the clay particles from one another.

5. The beaker with the sediment and sodium hexametaphosphate solution is washed and rinsed into a 63µm sieve. The retained sampled is carefully washed from the sieve into a labelled aluminium tray and placed in an oven for drying at 100ºC for 24 hours.

6. When dry this sediment is sieved through a series of graduated sieves ranging from 4 mm down to 63µm for 10 minutes using an automated column shaker. The fraction of sediment retained in each of the different sized sieves is weighed and recorded.

7. The silt/clay fraction is determined by subtracting all weighed fractions from the initial starting weight of sediment as the less than 63µm fraction was lost during the various washing stages.

Appendix 4-2

Renmore Intertidal Species list

Station			1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B
CNIDARIA	D	1																				
ANTHOZOA	D	583																				
ACTINIARIA	D	662																				
Actiniaria	D	662					1				1											
NEMATODA	HD	1																				
Nematoda	HD	1	37	27	36	19																
NEMERTEA	G	1																				
HETERONEMERTEA	G	37																				
Cerebratulidae	G	38																				
Cerebratulus sp.	G	39					3	2	6	7	1	2	1	4	5	3				1		
ENOPLA	G	80																				
Tetrastemmatidae	G	116																				
Tetrastemma melanocephalum	G	130	1		3	5																
ANNELIDA	P	1																				
POLYCHAETA	P	2																				
Pholoidae	P	90																				
Pholoe sp.	P	91														1						
Phyllodocidae	P	114																				
Eteone longa agg.	P	118	36	37	42	45	13	35	5	4	21	16	12	19	37	38	11	2	12	15	13	10
Phyllodoce mucosa	P	145							2	2	1				6	3						
Glyceridae	P	254																				
Glycera sp.	P	255				1							1									
Glycera tridactyla	P	265	1	1			6	4		4			1	2	5	1		1		1		
Nereididae	P	458																				
Nereididae	P	458	1			3																
Hediste diversicolor	P	462	40	3	14	4																
Eunereis longissima	P	475										1										
Nephtyidae	P	490																				
Nephtys sp.	P	494		2																		
Nephtys hombergii	P	499					2	3	1		4	5	12	16	4	7			2		3	1
EUNICIDA	P	536																				
Dorvilleidae	P	598																				
Protodorvillea	P	638					2			9						2						

Station			1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B
kefersteini																						
ORBINIIDA	P	654																				
Orbiniidae	P	655																				
Scoloplos armiger	P	672					2	2	11	4		1		1	7	2						
Scoloplos sp.	P	673									3											
SPIONIDA	P	707																				
Spionidae	P	720																				
Spionidae	P	720		8																		
Aonides oxycephala	P	722								11												
Malacoceros fuliginosus	P	737	42	19	17	23	4															
Microspio sp.	P	745								17												
Polydora sp.	P	748											1									
Prionospio sp.	P	763								5			5	8	8							
Pygospio elegans	P	776		4	1	9	7	44	10	39	1	6	5	19	8	18	2			4	1	1
Chaetopteridae	P	810																				
Spiochaetopterus sp.	P	818											1	2	2							
Cirratulidae	P	822																				
Cirratulus cirratus	P	836								2												
CAPITELLIDA	P	902																				
Capitellidae	P	903																				
Capitellidae	P	903			1																	
Capitella sp. complex	P	906		3					8	2	7		41				12	9	23		3	
Heteromastus filiformis	P	917	1			1	3	8	25	61		3	28	28	41	16						
Mediomastus fragilis	P	919												2								
Notomastus latericeus	P	921																1				
Arenicolidae	P	928																				
Arenicola marina	P	931									1						4					
TEREBELLIDA	P	1099																				
Ampharetidae	P	1118																				
Melinna palmata	P	1124						1	8	7				1	2	2		1				
SABELLIDA	P	1256																				
Sabellidae	P	1257																				
Manayunkia aestuarina	P	1294	1																			
OLIGOCHAETA	P	1402																				

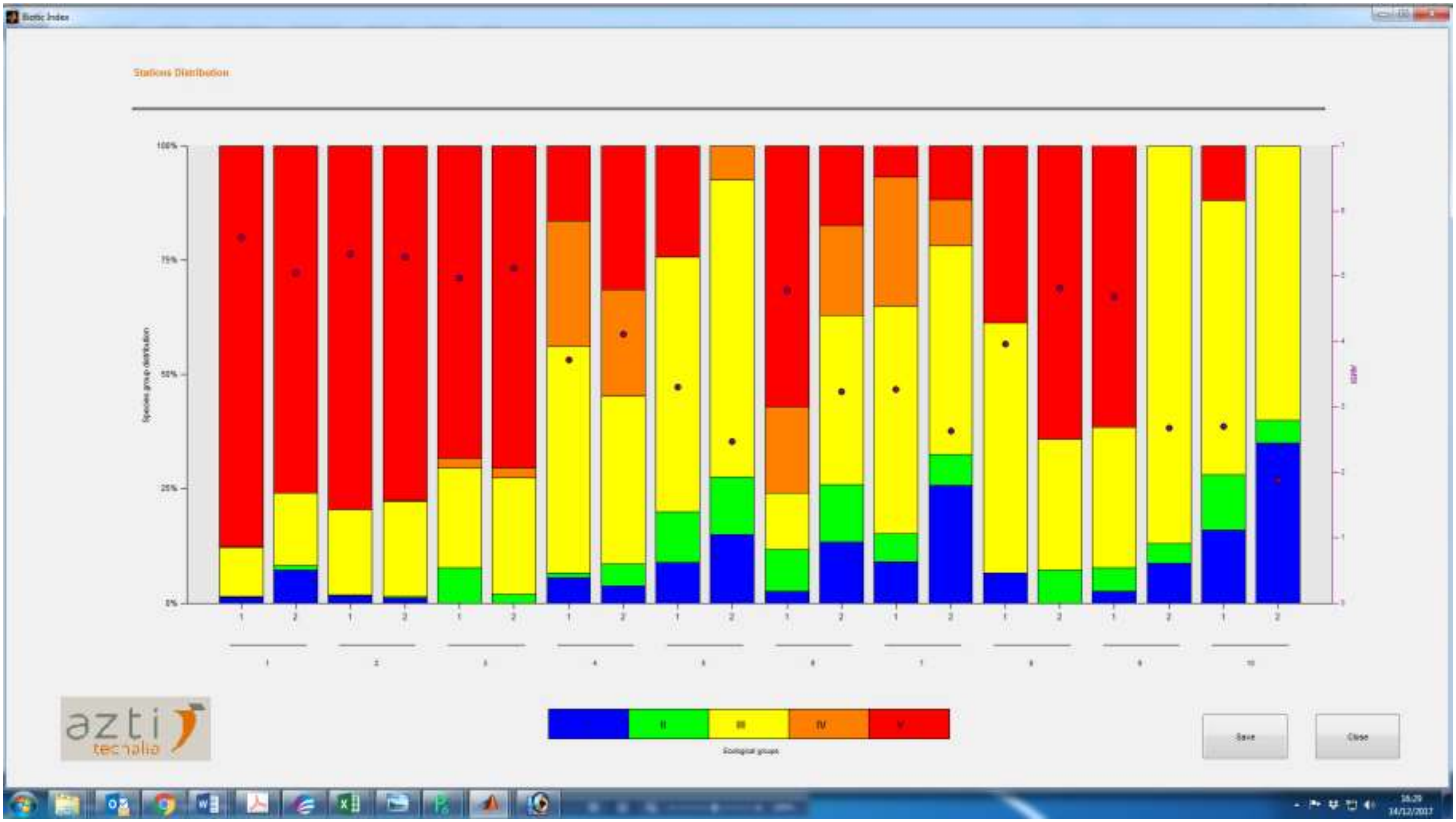
Station			1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B
TUBIFICIDA	P	1403																				
Tubificidae	P	1425																				
Baltidrilus costata	P	1479	213		40	9																
Tubificoides sp.	P	1487					93	260	7		4		47	25	10	19			1			
Tubificoides amplivastus	P	1489								83												
Tubificoides pseudogaster aggregate	P	1498	105	47	19	24																
Tubificoides benedii	P	1490	606	321	368	293																
CRUSTACEA	R	1																				
MAXILLOPODA	R	13																				
CIRRIPEDIA	R	14																				
BALANOIDEA	R	59																				
Archaeobalanidae	R	63																				
Semibalanus balanoides	R	69												1								
COPEPODA	R	142																				
Copepoda sp.	R	142								3												
EUMALACOSTRACA	S	23																				
AMPHIPODA	S	97																				
Calliopiidae	S	110																				
Calliopius laeviusculus	S	112														1						
Gammaridae	S	464																				
Gammarus salinus	S	481													1							
Melitidae	S	495																				
Melitidae	S	495	1																			
Melita palmata	S	525		29	4	1																
Aoridae	S	577																				
Microdeutopus sp.	S	592	2													9						
Microdeutopus anomalus	S	593							2				1	2								
Corophiidae	S	604																				
Corophium sp.	S	605							1													
Sphaeromatidae	S	857																				
Lekanesphaera monodi	S	870	1	2																		
Janiridae	S	883																				

Station			1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B
Jaera albifrons	S	885	8	3																		
DECAPODA	S	1276																				
Crangonidae	S	1380																				
Crangon crangon	S	1385												1		3					2	
BRACHYURA	S	1485																				
Brachyura	S	1485	3	3	5	5																
BRACHYRHYNCHA	S	1567																				
Portunidae	S	1569																				
Liocarcinus sp.	S	1577		1																		
MOLLUSCA	W	1																				
POLYPLACOPHORA	W	46																				
NEOLORICATA	W	47																				
Leptochitonidae	W	48																				
Leptochiton sp.	W	51																				
Leptochiton asellus	W	53								1			2	10	6	19						
Lepidochitona (Lepidochitona) cinerea	W	79			1																	
PELECYPODA	W	1560																				
MYTILOIDA	W	1689																				
Mytilidae	W	1691																				
Mytilus edulis spat	W	1695												2								
VENEROIDA	W	1815																				
Galeommatidae	W	1867																				
Kellia suborbicularis	W	1875													1							
Montacutidae	W	1888																				
Kurtiella bidentata	W	1906						3		5												
Cardiidae	W	1938																				
Parvicardium minimum	W	1950								1			1		2	1						
Parvicardium scabrum	W	1952	2	2	1				2	2				1	3	9						
Tellinidae	W	2008																				
Tellina tenuis	W	2012							1	2				3			2				2	
Tellina fabula	W	2019									1	6							1	2		7
Macoma balthica	W	2029	3	3	8	12	6	5		3				3	5	5					1	1
Semelidae	W	2057																				

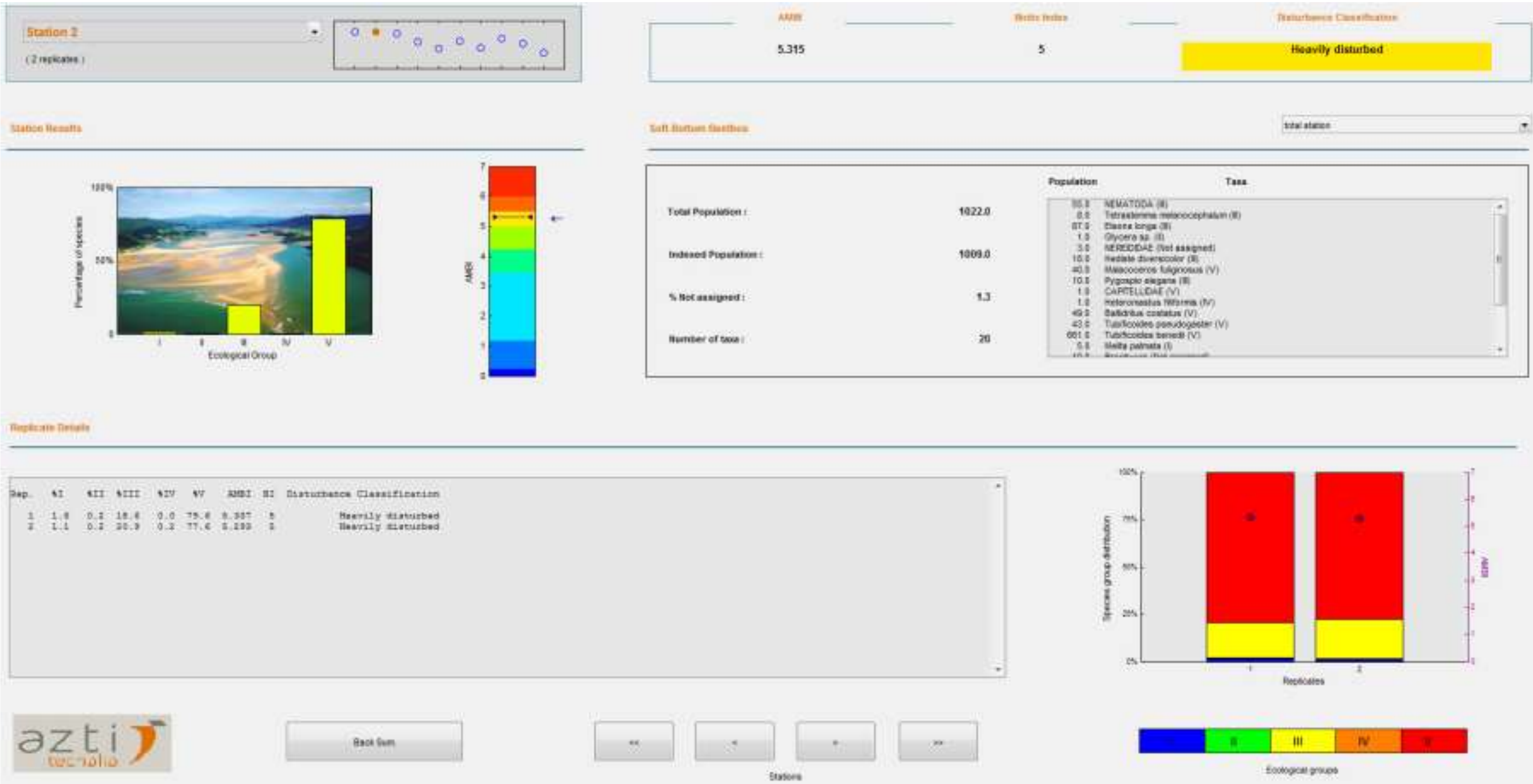
Station			**1A**	**1B**	**2A**	**2B**	**3A**	**3B**	**4A**	**4B**	**5A**	**5B**	**6A**	**6B**	**7A**	**7B**	**8A**	**8B**	**9A**	**9B**	**10A**	**10B**
Abra sp.	W	2058						2														
Abra alba	W	2059							2							2						
Veneridae	W	2086																				
Timoclea ovata	W	2104				4																
Venerupis corrugata	W		2	2	4					4				1								

Appendix 4-3

AMBI Results


Biotic Index
Stations Distribution
100%
75%
50%
25%
0%
II
III
IV
V
Save
Close

Station 1
(2 replicates)
AMBI
5.319
Biotic Index
5
Disturbance Classification
Heavily disturbed
Station Results
Soft Bottom Benthos
total station
Percentage of species
Ecological Group
AMBI
Population
Taxa
Total Population :
1623.0
Indexed Population :
1615.0
% Not assigned :
0.5
Number of taxa :
26
NEMATODA (III)
Tetrastemma melanocephalum (III)
Glycera tridactyla (II)
NEREIDIDAE (Not assigned)
Hediste diversicolor (III)
SPIONIDAE (III)
Malacoceros fuliginosus (V)
Pygospio elegans (III)
Capitella sp. (V)
Heteromastus filiformis (IV)
Baltidrilus costatus (V)
Replicate Details
Rep. %I %II %III %IV %V AMBI BI Disturbance Classification
Heavily disturbed
Heavily disturbed
Species group distribution
Replicates
Back Sum
Stations
Ecological groups

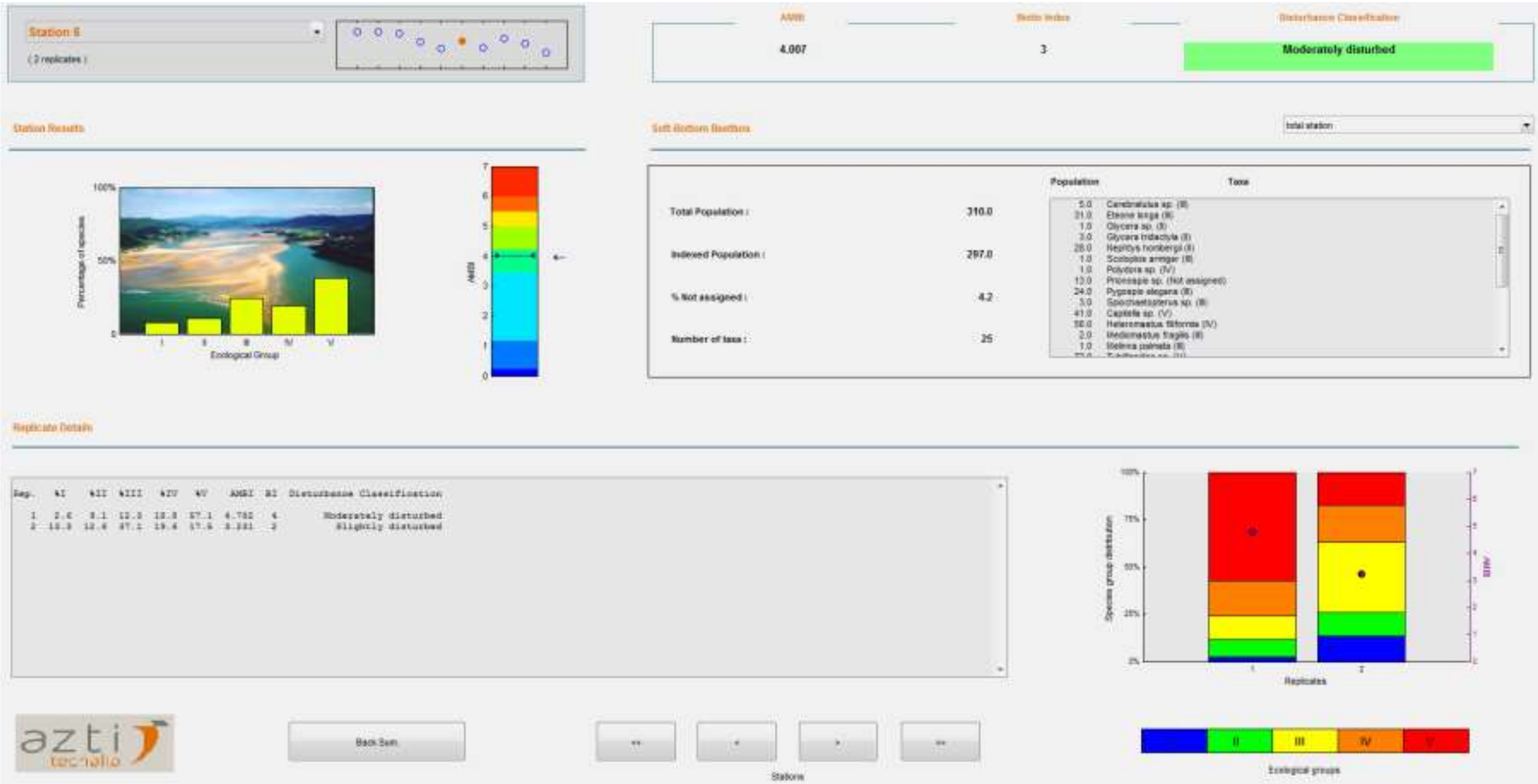


Station 2
5.315
5
Heavily disturbed
total station
Total Population :
1022.0
Indexed Population :
1009.0
% Not assigned :
1.3
Number of taxa :
20
Population
Taxa
Percentage of species
Ecological Group
AMBI
Rep.
Disturbance Classification
Heavily disturbed
Heavily disturbed
Species group distribution
Replicates
Back Sum
Stations
Ecological groups
azti tecnalia

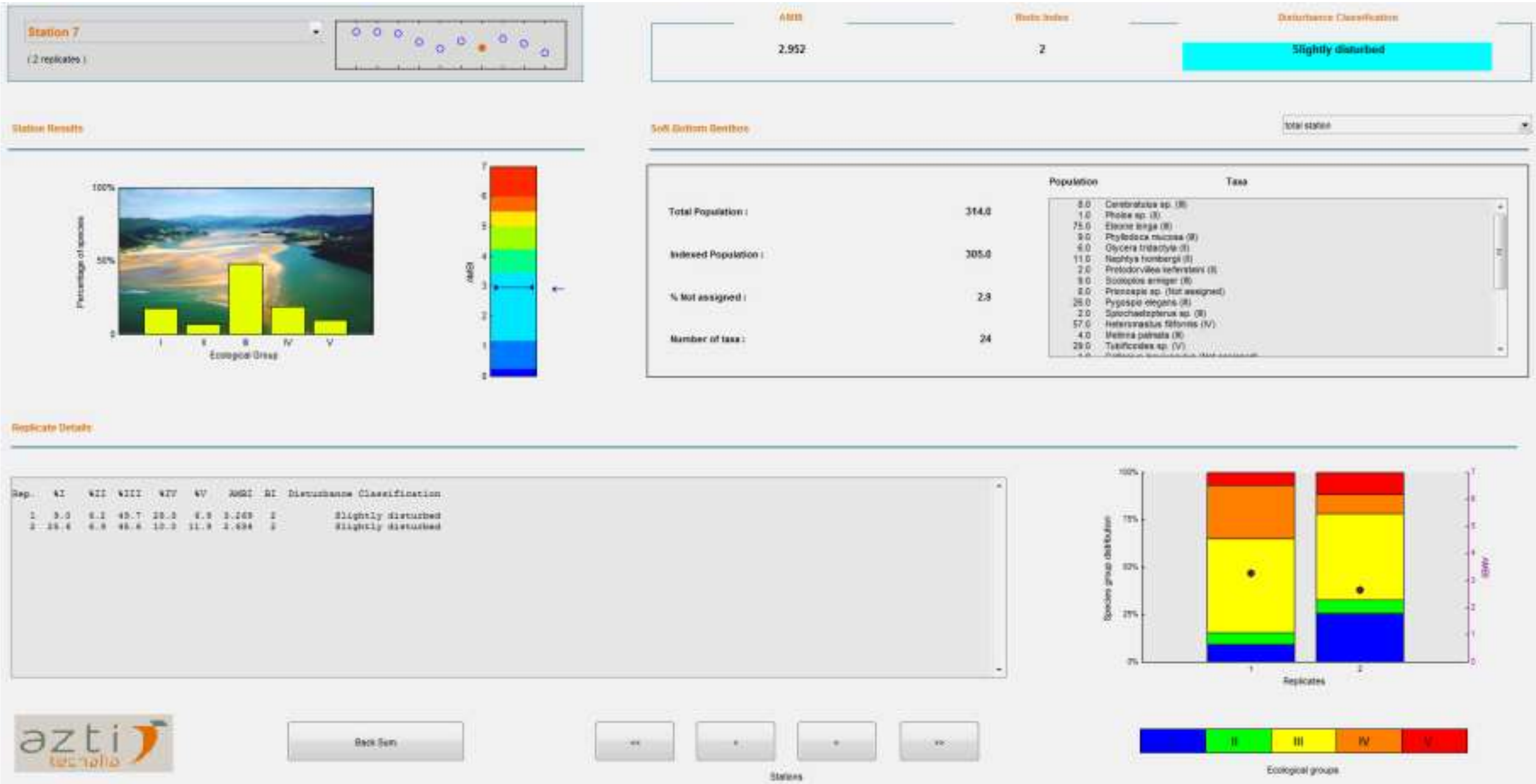
Station 3
(2 replicates)
AMBI
Biotic Index
Disturbance Classification
5.041
5
Heavily disturbed
Station Results
Soft-Bottom Benthos
total station
Percentage of species
Ecological Group
AMBI
Total Population :
511.0
Indexed Population :
511.0
% Not assigned :
0.0
Number of taxa :
15
Population
Taxa
ACTINIARIA
Cerebratulus sp.
Eteone longa
Glycera tridactyla
Nephtys hombergii
Pygospio elegans
Heteromastus filiformis
Melinna palmata
Tubificoides sp.
Kurtiella bidentata
Macoma balthica
Replicate Details
Rep. %I %II %III %IV %V AMBI BI Disturbance Classification
Moderately disturbed
Heavily disturbed
Species group distribution
Replicates
Back Sum
Stations
Ecological groups

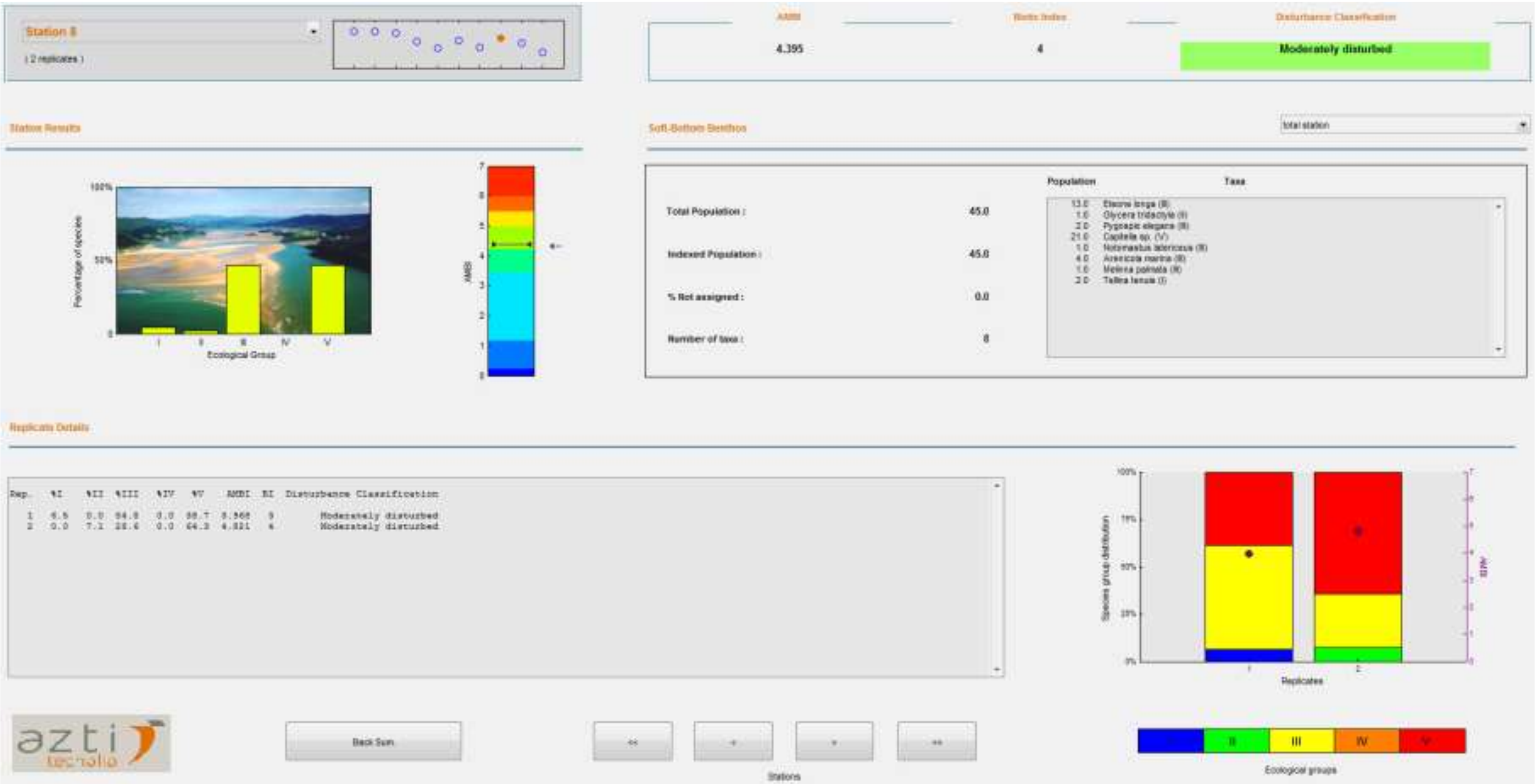

Station 4
(2 replicates)
AMBI
3.918
3
Moderately disturbed
Station Results
Soft-Bottom Benthos
total station
100%
50%
0
Percentage of species
I
II
III
IV
V
Ecological Group
AMBI
Total Population :
369.0
Indexed Population :
361.0
% Not assigned :
2.2
Number of taxa :
28
Population
Taxa
Replicate Details
Disturbance Classification
Moderately disturbed
Moderately disturbed
Replicates
Back Sum
Stations
Ecological groups

AMBI
Biotic Index
Disturbance Classification
2.888
2
Slightly disturbed
(2 replicates)
Station Results
Soft-Bottom Benthos
total station
Percentage of species
Ecological Group
Total Population :
85.0
Indexed Population :
85.0
% Not assigned :
0.0
Number of taxa :
14
Population
Taxa
ACTINIARIA
Cerebratulus sp.
Capitella sp. (V)
Tubificoides sp. (V)
Replicate Details
Rep. %I %II %III %IV %V AMBI BI Disturbance Classification
Slightly disturbed
Slightly disturbed
Species group distribution
Replicates
AMBI
azti tecnalia
Back Sum
Stations
Ecological groups

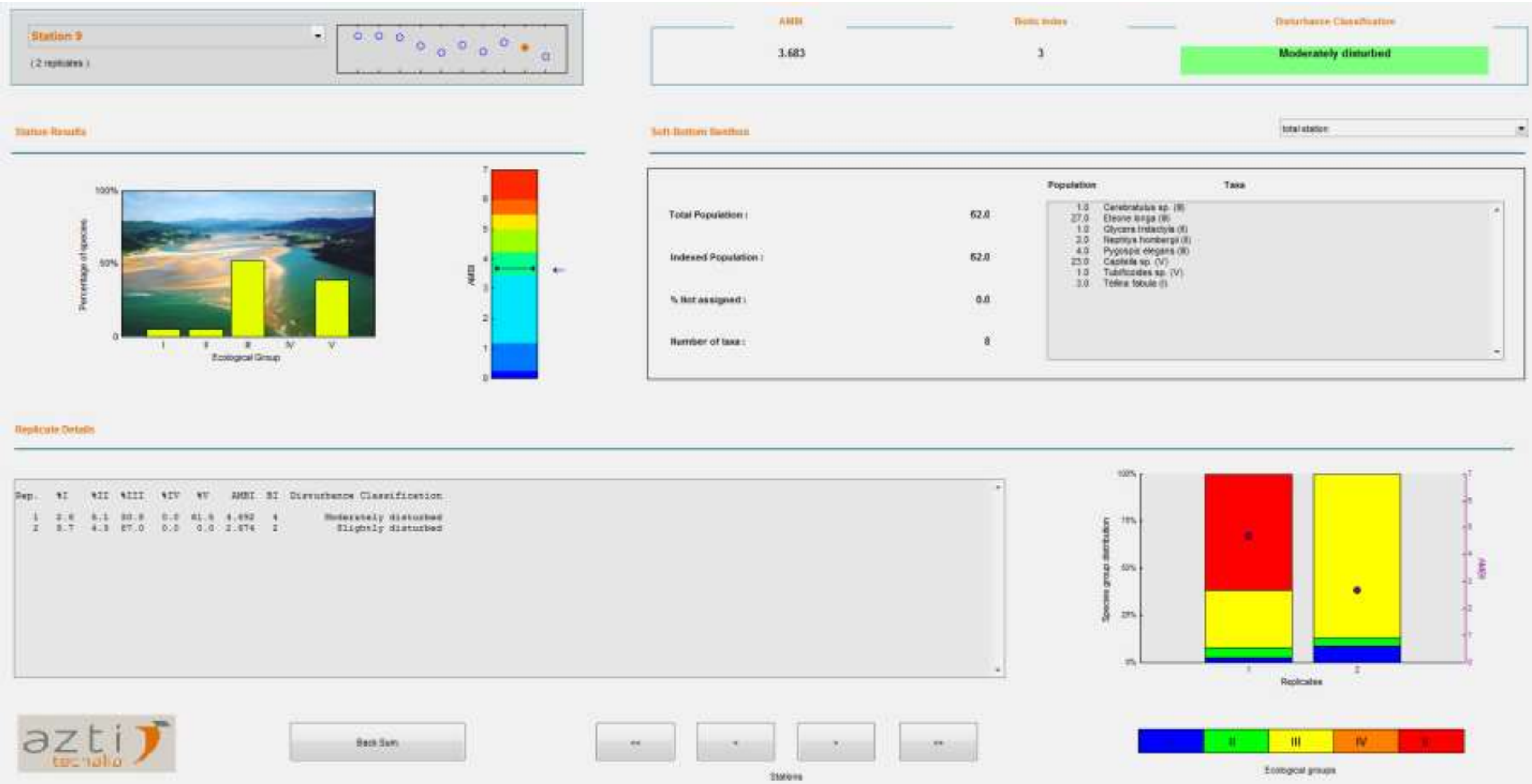


Station 6
(2 replicates)
AMBI
4.007
3
Moderately disturbed
Station Results
Soft Bottom Benthos
total station
100%
50%
0
Percentage of species
I
II
III
IV
V
Ecological Group
AMBI
Total Population :
310.0
Indexed Population :
297.0
% Not assigned :
4.2
Number of taxa :
25
Population
Taxa
Replicate Details
Moderately disturbed
Slightly disturbed
Species group distribution
Replicates
Back Sum
Stations
Ecological groups
azti tecnalia

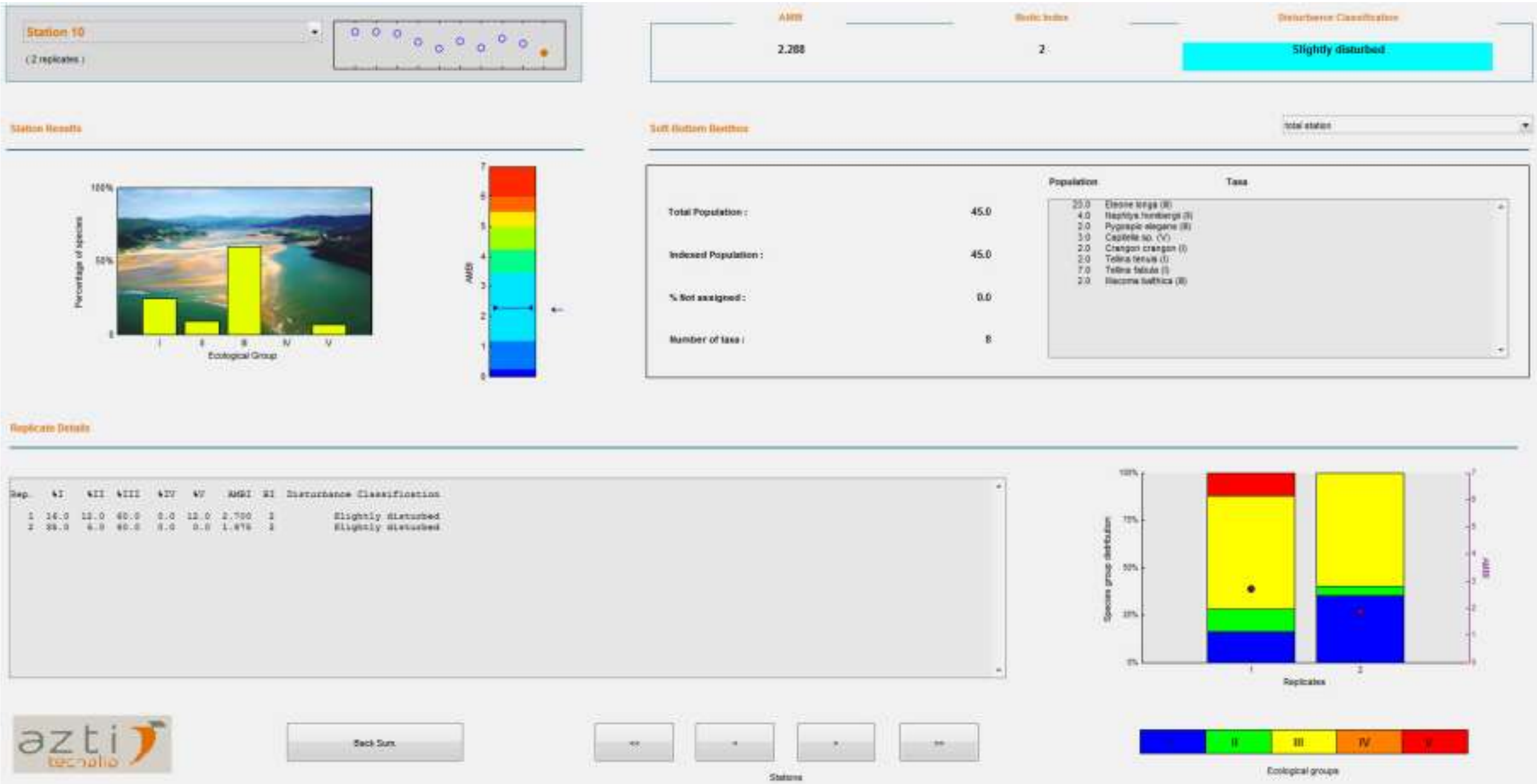

Station 7
(2 replicates)
AMBI
2.952
Biotic Index
2
Disturbance Classification
Slightly disturbed
Station Results
100%
50%
0
Percentage of species
I
II
III
IV
V
Ecological Group
AMBI
Soft Bottom Benthos
total station
Total Population :
314.0
Indexed Population :
305.0
% Not assigned :
2.9
Number of taxa :
24
Population
Taxa
Replicate Details
Rep. %I %II %III %IV %V AMBI BI Disturbance Classification
Slightly disturbed
Slightly disturbed
100%
75%
50%
25%
0%
Species group distribution
Replicates
AMBI
Back Sum
Stations
II
III
IV
V
Ecological groups



(2 replicates)
AMBI
4.395
Biotic Index
4
Disturbance Classification
Moderately disturbed
Station Results
Soft-Bottom Benthos
total station
Percentage of species
100%
50%
0
I
II
III
IV
V
Ecological Group
AMBI
Total Population :
45.0
Indexed Population :
45.0
% Not assigned :
0.0
Number of taxa :
8
Population
Taxa
13.0
1.0
2.0
21.0
1.0
4.0
1.0
2.0
Capitella sp. (V)
Arenicola marina (III)
Melinna palmata (III)
Tellina tenuis (I)
Replicate Details
Rep. %I %II %III %IV %V AMBI BI Disturbance Classification
Moderately disturbed
Moderately disturbed
Species group distribution
Replicates
Back Sum
<<
>>
Stations
III
IV
V
Ecological groups



Station 9
(2 replicates)
AMBI
Biotic Index
Disturbance Classification
3.683
3
Moderately disturbed
Station Results
Soft Bottom Benthos
total station
100%
50%
0
Percentage of species
I
II
III
IV
V
Ecological Group
AMBI
Population
Taxa
Total Population :
62.0
Indexed Population :
62.0
% Not assigned :
0.0
Number of taxa :
8
1.0 Cerebratulus sp. (III)
27.0 Eteone longa (III)
1.0 Glycera tridactyla (II)
2.0 Nephtys hombergii (II)
4.0 Pygospio elegans (III)
23.0 Capitella sp. (V)
1.0 Tubificoides sp. (V)
3.0 Tellina fabula (I)
Replicate Details
Rep. %I %II %III %IV %V AMBI BI Disturbance Classification
Moderately disturbed
Slightly disturbed
Species group distribution
Replicates
AMBI
azti tecnalia
Back Sum
Stations
Ecological groups


Station 10
(2 replicates)
AMBI
2.288
2
Slightly disturbed
Total Population :
45.0
Indexed Population :
45.0
% Not assigned :
0.0
Number of taxa :
8
Population
Taxa
Ecological Group
Percentage of species
Replicates
Species group distribution
Back Sum.
Stations
Ecological groups
azti tecnalia

Stations Distribution