FINGAL COUNTY COUNCIL

ECOLOGICAL MONITORING OF ROGERSTOWN ESTUARY

FINAL REPORT

JUNE 2003

MARENCO
Environmental Consultants

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1.0 INTRODUCTION

Rogerstown Estuary is an internationally important wintering area for birds and has been designated a National Nature Reserve, a RAMSAR site and a SPA under the EU Birds Directive. It is a proposed NHA under the Wildlife Act, 1996 and a proposed SAC under the Habitats Directive. The main habitats identified within the estuary are intertidal flats, saltmarsh, damp pasture, Balleally landfill and arable fields with hedgerows.

Identified as having a negative impact on the estuary are Balleally landfill, Lusk Sewage effluent outfall and agricultural run-off. The estuary receives the following types of pollutants from these three sources: (i) Organic matter, (ii) Nutrients, (iii) Heavy metals, (iv) Organic chemicals and bacteria.

Due to tidal flushing twice daily, the estuary is in a relatively satisfactory environmental condition (O'Brien et al., 1997; Kirk et al., 1992; IERP, 1985; Fahy et al., 1975) with sufficient life in the sediments to support wintering wild fowl (O' Brien et al., 1997). Of particular concern, is the gradual deterioration in the pollution status (since 1981) in the transition area between the inner and outer estuary and an area immediately north east of the landfill.

Balleally landfill is bounded by Rogerstown Estuary to the south. The site has been in operation since c. 1971. At present the landfill takes in domestic refuse and selected commercial and industrial wastes at a rate of approximately 450,000 Tonnes per annum. There is no leachate collection facility on the site. It has been estimated from the groundwater flow that up to 110,000 m^3 per year of leachate is discharged into the estuary. The leachate contains (i) high concentrations of organic matter and nutrients, (ii) the presence of numerous hazardous organic chemicals, and (iii), low concentrations of heavy metals. The bulk of this (80%) is infiltrated into the groundwater, where it is transported eastwards in a gravel-boulder layer and eventually ends up in the estuary. However, the landfill is not the only contributor to the pollution load to the estuary. The sewage outfall from Lusk and agricultural runoff to inflowing streams and rivers, may be much more significant contributors.

On February 16th 2000 Fingal County Council was granted a Waste Licence (Register no. 9-1) for Balleally landfill by the EPA under Section 40(1) of the Waste Management Act 1996. Under condition 9.6 of this licence there is a requirement for monitoring of Rogerstown Estuary. The monitoring programme is required to encompass ecological monitoring in addition to the monitoring of sediment and water quality with particular consideration to be

given to the monitoring of the areas to the northeast of the facility and to the transition area between the inner and the outer estuary.

MARENCO were commissioned in January 2002, to implement an ecological monitoring programme of the Estuary. The principle objectives of the monitoring programme were as follows:

- To comply with Condition 9.6 of the Ballyeally Waste Licence Register 9-1
- To ensure that existing and future landfill operational practices will not have a significant, irreversible negative impact on the environmental quality of the surrounding estuary.
- To investigate possible causes for the observed deterioration in the pollution status in the two areas already outlined and if possible to establish the biological status of the inner estuary in greater detail.
- To identify any spatial and temporal variations in the biogeochemical status, environmental quality and pollution load index of the estuary over the monitoring period.

This report presents and interprets the data for four quarterly monitoring visits (May 2002, July 2002, October 2002 and January 2003).

2.0 STUDY AREA

Rogerstown Estuary is situated approximately 19km northeast of Dublin City. It is a relatively small, narrow estuary sheltered from the open sea by a sand and shingle bar. The estuary is divided by a causeway and narrow bridge, built in the 1840s to carry the Dublin-Belfast railway line (viaduct). The estuary is shallow and drains almost completely at low tide revealing a permanent deep-water channel. Due to the constriction of tidal flow between the inner and outer portions of the estuary caused by the viaduct, drainage form the inner estuary continues for 2-3 hours after low tide. High tide coincides in both parts of the estuary with areas of saltmarsh in the upper regions of the inner estuary only covered significantly during higher spring tides. A number of small rivers/streams and drainage ditches flow into the estuary.

For the purposes of this report the inner estuary refers to the area to the west of the railway line and the outer estuary to the area to the east of the railway line. This is in keeping with the report produced by O'Brien *et al*., 1997 and also corresponds with descriptions made in site designations for Rogerstown Estuary (SAC/SPA). It should however be noted that the Environmental Protection Agency (EPA) refers to Inner Rogerstown Estuary as the area from Blakes Cross to Burrow – Whitestown which encompasses the whole of the estuary (inner and outer) as surveyed in this report. The EPA refers to Outer Rogerstown Estuary as the area seaward from Burrow – Whitestown to Rogerstown Bar.

The estuary catchment includes much of the main market gardening area for Dublin City, O'Brien *et al*., 1997. The soils are sandy and conducive to substantial nutrient run-off through field drains due to fertiliser use. As well as leachate impacts from Ballyeally landfill on the north shore of the inner estuary the main significant domestic input is from the Lusk sewage effluent outfall which enters the estuary on the east side of the railway viaduct and runs parallel to the railway line from the north shore. Beaverstown golf course has been developed on the southern shore opposite the landfill site.

3.0 METHODOLOGY

3.1 Sampling strategy

A total of 14 sampling stations were investigated (Figure 3.1, Plates 1-12). Stations 2, 3, 4, 5, 8, 9 and 10 were located in positions surveyed by O'Brien *et al*., (1997) in order to identify any temporal variations in the ecological status of each site. Some of these stations (Stations 2, 3, 5 & 10) had also previously been sampled by Kirk *et al*., (1997). An additional seven stations A-G were located within the inner estuary and adjacent to the viaduct in the outer estuary to ascertain the biological status in these areas in greater detail. Station positions were accurately determined using a Geographical Positioning System (Appendix One).

All sample stations were visited at low water and when submerged by the tide (during the period 2 hours either side of high water). The various analyses performed to satisfy the requirements of the monitoring programme specification for fauna, vegetation, sediment and water (porewater and surface water) are outlined in the following section.

3.2 Faunal Analyses

Table 3.2 details faunal analyses requirements.

Table 3.2 Specification for Faunal Analyses

Parameters measured	Procedures involved	Sites requiring sampling/surveying	Sampling frequency
a) Species Richness	Detailed qualitative visual survey	All sites	Quarterly
b) Species Abundance	Standard quantitative and semi quantitative sampling techniques for pelagic, epi-benthic and benthic fauna	All sites	Quarterly
c) Trace Element accumulation in the tissues of specific benthic infauna	Analysis of Al, As, Cd, Cr, Cu, Mn, Ni, Pb, Sn, Fe, Zn and Hg concentrations in tissues of appropriate indicator species (e.g. *Mytilus edulis*, *Cerastoderma edu*le or another species favoured by the important visiting wild fowl)	All sites that contain the chosen indicator species	Twice a year in Summer/Winter

3.2.1 Species Richness

Sampling stations for sediment macrofaunal analysis were located in areas of open mud or sand. Any species visible within a 5 m radius around each sample station were recorded

and habitat and species information also recorded along a transect from high water to the position of the sampling station. Biotopes were assigned according to Connor *et al.,*1997.

3.2.2 Species Abundance

Pelagic

Sweeps for pelagic and epi-benthic fauna were taken at each of the 14 sample stations where site conditions allowed. Excessive water depth and hazardous conditions at Station E prevented net sampling during the October 2002 and January 2003 visits. Species were sampled by pushing a hand net with a rectangular opening measuring 600 cm^2 and 1 mm mesh size over the surface of the substrate for 30 seconds.

Benthic

Sediment samples were taken for benthic analysis using a corer of $0.01m^2$ internal circular section forced into the sediment to a depth of 15cm. A $1m^2$ area was assessed for abundance of obvious mounds, casts and algal cover and the area forked through to identify larger macrofaunal species. Core samples were sieved through a 0.5mm mesh and fixed with 10% formalin solution.

Specimens were identified to species level, if possible, otherwise, to the lowest possible taxonomic level. Blotted wet biomass (to 0.0001g) was calculated on enumerated fauna, with the extraction and assignment of major fragments to the appropriate group where possible. All extracted material was stored in 70% industrial methylated spirits (IMS). To ensure consistent identification throughout the survey, multiple reference specimens of each taxa recorded in the survey were selected and retained as a reference collection.

3.2.3 Trace element accumulation in fauna

The cockle *Cerastoderma edule* was chosen as the indicator species for trace element accumulation in the tissues of infauna important for feeding wildfowl. Sediment was raked over at low water to find representative species for collection and analysis.

3.3 Vegetation Analyses

Table 3.3 details vegetation analyses requirements.

Table 3.3 Specification for Vegetation Analyses

Parameters measured	Procedures involved	Sites requiring sampling/surveying	Sampling frequency
a) General vegetation survey	Identification of plant, algae, bryophyte and lichen species and the communities comprising the major habitats within the estuary	The 5 major habitats within the estuary, as identified by Goodwillie *et al*. (1997)	Quarterly
b) Species abundance	Semi-quantitative estimations using standard cover/abundance techniques	All sites	Quarterly
c) Abundance of green algae	Visual survey	The whole inner and outer estuary	Quarterly
d) Trace element accumulation in algae	Quantitative analysis of Al, As, Cd, Cr, Cu, Mn, Ni, Pb, Sn, Fe, Zn and Hg concentrations in tissues of *Fucus* species	All sites that contain the chosen *Fucus* species	Quarterly

3.3.1 General vegetation survey

A Phase 1 Habitat Survey of Rogerstown estuary SAC (from Blake's Cross to Rogerstown Pier) using the Nature Conservancy Council UK methodology (JNCC 1990) was carried out on the 22 and 23 August 2002; 3, 10 and 11 October 2002; 29 and 30 January 2003 and 10 and 11 April 2003. This entailed a walkover survey of the whole estuary from Newhaggard Bridge to Rogerstown Pier on the north side of the estuary and from Daws Bridge to Burrow townland on the southern side of the estuary.

3.3.2 Species abundance

Species *in situ* were recorded using a 'percentage cover' or 'density of individuals' abundance scale, which uses the SACFOR (Superabundant, Abundant, Common, Frequent, Occasional, Rare) notations. Abundance was calculated for an area within a 5m radius around each sample station and also for key species identified along a transect from high water to the position of the sampling station.

3.3.3 Abundance of green algae

The % cover of the green alga *Enteromorpha* sp. was estimated for an area of 5m radius around each sample station and notes made on green algal presence in the surrounding environs to allow an assessment of total green algal abundance throughout the estuary.

3.3.4 Trace element accumulation in algae

Samples of Bladder Wrack *Fucus vesiculosus* were collected for trace element analysis from those stations where the species was identified. Where sample stations were located in areas of open mud *Fucus vesiculosus* was sampled from adjacent upper to middle shore areas where the presence of harder substratum allowed attachment.

3.4 Sediment Analyses

Table 3.4 details sediment analysis requirements.

Table 3.4 Specification for Sediment Analyses

Parameters measured	Procedures involved	Sites requiring sampling/surveying	Sampling frequency
a) Granulometric analysis	Quantitative measurement of the grain size fractions	All sites	Quarterly
b) Total organic carbon	% Loss on ignition (LOI)	All sites	Quarterly
c) Temperature	*In situ* measurement of sediment temperature	All sites	Quarterly
d) Redox	*In situ* measurement of redox potential	All sites	Quarterly
e) Trace elements	Quantitative analysis of Al, As, Cd, Cr, Cu, Mn, Ni, Pb, Sn, Fe, Zn, Hg, Total Nitrogen and Phosphorus	All sites	Quarterly

3.4.1 Granulometric analysis

Particle size analysis of May 2002 and July 2002 sample station sediments was carried out by the UK Environment Agency (UKAS accredited laboratory) by laser diffraction. This technique provided results for the <2000um particle size fraction of sampled sediments. The analysis of October 2002 and January 2003 sediments was carried out by an alternative UK accredited laboratory using wet sieve analysis to standard methodology.

3.4.2 Total organic carbon

The organic carbon content of May 2002 and July 2002 sample station sediments was calculated by the UK Environment Agency by % Loss on Ignition (LOI). However, the results produced appeared low, given the silty nature of the marine sediments. The October 2002 and January 2003 sediment samples were analysed at an alternative accredited laboratory. Interpretation of total organic carbon results for the survey has therefore been based on the results for October 2002 and January 2003.

3.4.3 Temperature

An *in situ* measurement was made of the temperature of sample station sediments using a thermometer pushed into the sediment.

3.4.4 Redox

An *in situ* measurement was made of the redox potential of sample station sediments by taking a direct reading using a Hanna Instruments ORP meter.

3.4.5 Trace elements

Sediment samples were taken using a circular corer of 7.5cm diameter pushed into the sediment to a depth of 15cm. Samples were placed into 1 l plastic containers and transported to the laboratory in cool boxes.

Laboratory methodologies for sediment, porewater and surface water are outlined in full in Appendix Two.

3.5 Water Analyses

Table 3.4 Specification for Water Analyses

Parameters measured	Procedures involved	Sites requiring sampling/surveying	Sampling frequency
(A) Porewater			
(i) Nutrient and trace element content	Quantitative analysis of concentrations of Chloride, Phosphate, Ammonia, Nitrite/Nitrate, Al, As, Cd, Cr, Cu, Mn, Ni, Pb, Sn, Fe, Zn and Hg in the interstitial soil porewater	All sites	Quarterly
(ii) Hydrocarbons	Quantitative analysis of the concentration of the total dissolved and emulsified oils in sediment porewater	All sites	Quarterly
(iii) DO, COD, BOD	Quantitative estimates of the available dissolved O_2 and the biochemical and chemical oxygen demand in the sediment porewater	All sites	Quarterly
(iv) Faecal and total coliforms	Quantitative analysis of the faecal contamination in the sediment porewater	All sites	Quarterly
(v) Salinity	*In situ* measurement of salinity of the porewater	All sites	Quarterly
(vi) Conductivity	*In situ* measurements of the specific conductance of the porewater	All sites	Quarterly
(B) Surface water			
(i) Colour	Visual estimation of turbidity of water at each site	All sites	Quarterly
(ii) Total suspended solids	Quantitative estimates of the concentration of the dissolved and suspended matter in the surface water	All sites	Quarterly
(iii) Trace element content	Quantitative analysis of concentrations of Chloride and Ammoniacal N	All sites	Quarterly
(iii) DO, COD, BOD	Quantitative estimates of the available dissolved O_2 and the biochemical and chemical oxygen demand in the sediment porewater	All sites	Quarterly
(iv) Temperature	*In situ* measurement of surface water temperature	All sites	Quarterly
(v) Salinity	*In situ* measurements of the salinity of the surface water	All sites	Quarterly
(vi) Conductivity	*In situ* measurements of the specific conductance of the salinity of the surface water	All sites	Quarterly

3.5.1 Porewater

The technique trailed for the collection of sediment porewater during the first quarterly survey visit in May 2002 involved syringe extraction of supernatant water which had diffused back into vacant areas created by removing $0.01m^2$ cores of sediment to a depth of 20cm. However, this technique proved time consuming and may have incorporated runoff from areas of standing water.

An improved technique was therefore employed for the remaining surveys in July 2002, October 2002 and January 2003 which involved collection of 20 l of sediment for centrifugal extraction of porewater in the laboratory.

The methods for porewater analysis are presented in Appendix Two.

3.5.2 Surface Water

Surface water samples were collected using 2 l plastic bottles. *In situ* measurements of salinity, dissolved oxygen, pH, temperature and conductivity were made using a YSI multi-meter probe.

The methods for surface water analysis are presented in Appendix Two.

4.0 FAUNAL ANALYSES

4.1 Benthic Fauna

Macrofauna abundance data for all 14 sample stations for each of the separate monitoring visits is presented in Appendix Three. The twenty most frequently occurring infaunal species recorded for all stations are presented in Table 4.1. Additional faunal species identified in the vicinity of macrofaunal core sample locations are described in the biotope descriptions in Section 6.0.

A total of 63 infaunal species or higher taxa were recorded for all stations throughout the monitoring survey. In general stations were represented by only a few species. Station E was the most impoverished station with a low of 3 species recorded in October 2002. Station C was also very impoverished. Station 10 was the most diverse with 19 species recorded in October 2002. The infauna was generally indicative of impacted estuarine sediments with high abundances of small opportunistic species.

Stations were represented by high numbers of pollution-tolerant opportunistic species especially the detritus feeding oligochaete *Tubificoides benedii*. This species was prevalent at all stations and is representative of stressed conditions. Also very common were the opportunistic polychaete worms *Capitella capitata* and *Manayunkia aesturina* which are both known to occur in areas of high organic enrichment and are capable of exploiting sewage contaminated conditions. The mud snail shell *Hydrobia ulvae* which grazes on muddy sand was common at most stations especially Station A. Species tolerant of reduced salinity conditions were also present at some Stations including the ragworm *Hediste diversiclor* and the snorkel shrimp *Corophium volutator*.

It is recommended that in future surveys a minimum of three replicate cores are taken at each station to account for natural 'patchiness' in species density. Sample replication will increase the chance of encountering larger biomass individuals such as *Hediste diversicolor* and bivalves which are often represented by fewer individuals and may be missed if only a single core is taken.

Table 4.1. Twenty most frequently occurring infaunal species for all stations

	Species	Description
1	*Tubificoides benedii*	Oligochaete worm; opportunistic; pollution tolerant;
2	*Hydrobia ulvae*	Laver spire shell (mud snail)
3	*Capitella*	Polychaete worm; opportunistic; pollution tolerant
4	*Enchytraeidae*	Oligochaete worm
5	*Heterochaeta costata*	Tubifex worm
6	*Manayunkia aestuarina*	Polychaete worm
7	*Streblospio shrubsolii*	P polychaete worm
8	*Corophium volutator*	Crustacean; Snorkle shrimp
9	*Fabricia sabella*	Polychaete worm
10	*Hediste diversicolor*	Polychaete worm; Ragworm
11	*Tharyx* (Type A)	Polychaete worm
12	*Pygospio elegans*	Polychaete worm
13	*Aphelochaeta marioni*	Polychaete worm
14	*Mediomastus fragilis*	Polychaete worm
15	*Abra tenuis*	Thin brittle shell
16	*Malacoceros fuliginosus*	Polychaete worm
17	*Scoloplos armiger*	Polychaete worm
18	*Chironomidae*	Midge (not marine)
19	*Eteone longa* (agg.)	Polychaete worm
20	*Ampharete grubei*	Polychaete worm

4.2 Benthic Data Analysis

The PRIMER analytical package (Clarke & Warwick 1994) was used for the analysis of station data.

4.2.1 Univariate analyses

Univariate methods reduce the full set of species counts for a sample into a single coefficient e.g. diversity index. Diversity indices for the 14 sampling stations are presented in Appendix Four.

Margalef Richness

Species richness is, in its most simple form, the total number of species present, although it is also highly dependent on the sample size used. Margalef Richness (D) takes both the total number of species present and the total number of individuals recorded in the sample into account (Clarke & Warwick 1994). Station 10 was the richest site with values of 3.20 and 3.12 calculated for the July 2002 and October 2002 data. Station C had the lowest richness value during May 2002.

Pielou's Eveness

Pielou's Evenness (J) relates to how evenly the individuals are distributed among the different taxa. With any assemblage or sample, the constituent fauna can be dominated by one or two species, or several species can be equally abundant. The former case would indicate an assemblage with low evenness and high dominance, and the latter one with high evenness and low dominance. Sites with a high evenness are often considered to be more diverse and where communities are dominated by one or two species, the evenness values are low, indicating a stressed environment. The evenness values varied between stations with a range from 0.09 at station C in May 2002 to 0.81 recorded for station 10 in July 2002 and station G in October 2002. Evenness values were low at many stations due to the predominance of high numbers of oligochaetes at these stations.

Shannon-Weiner Diversity

Shannon-Weiner Diverstiy (H) incorporates both the number of species (species richness) and evenness. Increasing levels of environmental stress have generally been considered to decrease diversity, decrease species richness and decrease dominance. Diversity was highest at station G due to a more even spread of individuals across the taxa.

4.2.2 Graphical/Distributional analysis (k-dominance plots)

The purpose of graphical/distributional representations is to extract information on patterns of relative species abundances without reducing that information to a single summary statistic, such as a diversity index. This class of techniques can be thought of as intermediate between univariate summaries and full multivariate analyses. Unlike multivariate methods, these distributions may extract universal features of community structure which are not a function of the specific taxa present, and may therefore be related to levels of biological 'stress'.

K-dominance curves were produced for each station using year averaged abundance data for the four monitoring visits (Figure 4.1). K-dominance curves are cumulative ranked abundances plotted against species rank. As pollution impact becomes more severe, communities tend to become numerically dominated by one or a few very small opportunistic species which is indicated by the plot being skewed to the top left of the graph.

Figure 4.1 K-Dominance curves for stations using averaged data. The x axis shows the species rank order on a log scale and the y axis shows the cumulative percentage abundance

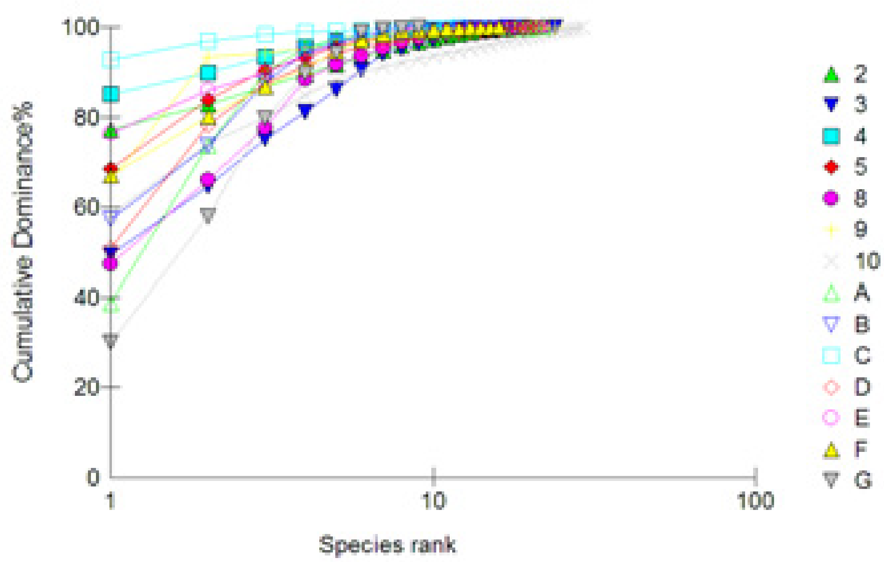


Figure 4.1 illustrates that the k-dominance plots for many of the stations tend to skew towards the top left corner of the graph which may indicate a degree of pollution impact throughout the estuary.

4.2.3 Abundance/biomass comparison (ABC) plots

ABC curves were also plotted for each station using year averaged abundance and biomass data for the four monitoring visits (Figures 4.2a-b). The method involves the plotting of separate k-dominance curves for species abundances and species biomasses on the same graph and making a comparison of the forms of these curves. In unpolluted situations the k-dominance curve for biomass lies above the curve for abundance for its entire length. Under moderate pollution, the biomass and abundance curves are closely coincident and may cross each other one or more times and in grossly polluted conditions the abundance curve lies above the biomass curve throughout its entire length.

Figure 4.2a ABC plots (Stations 2, 3, 5, 8, 9, 10) for year averaged abundance and biomass station data

Abundance = △ Biomass = ▼

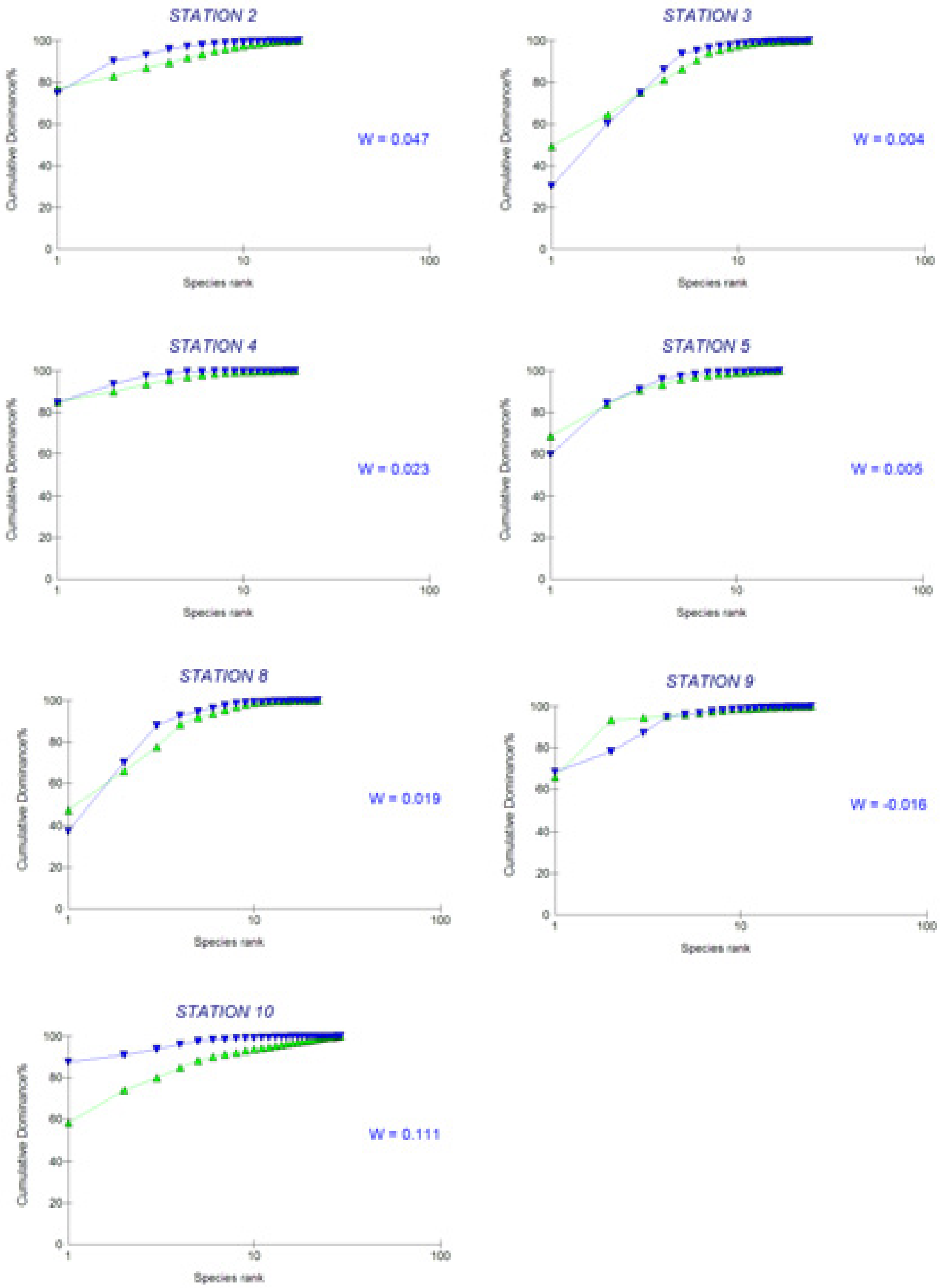
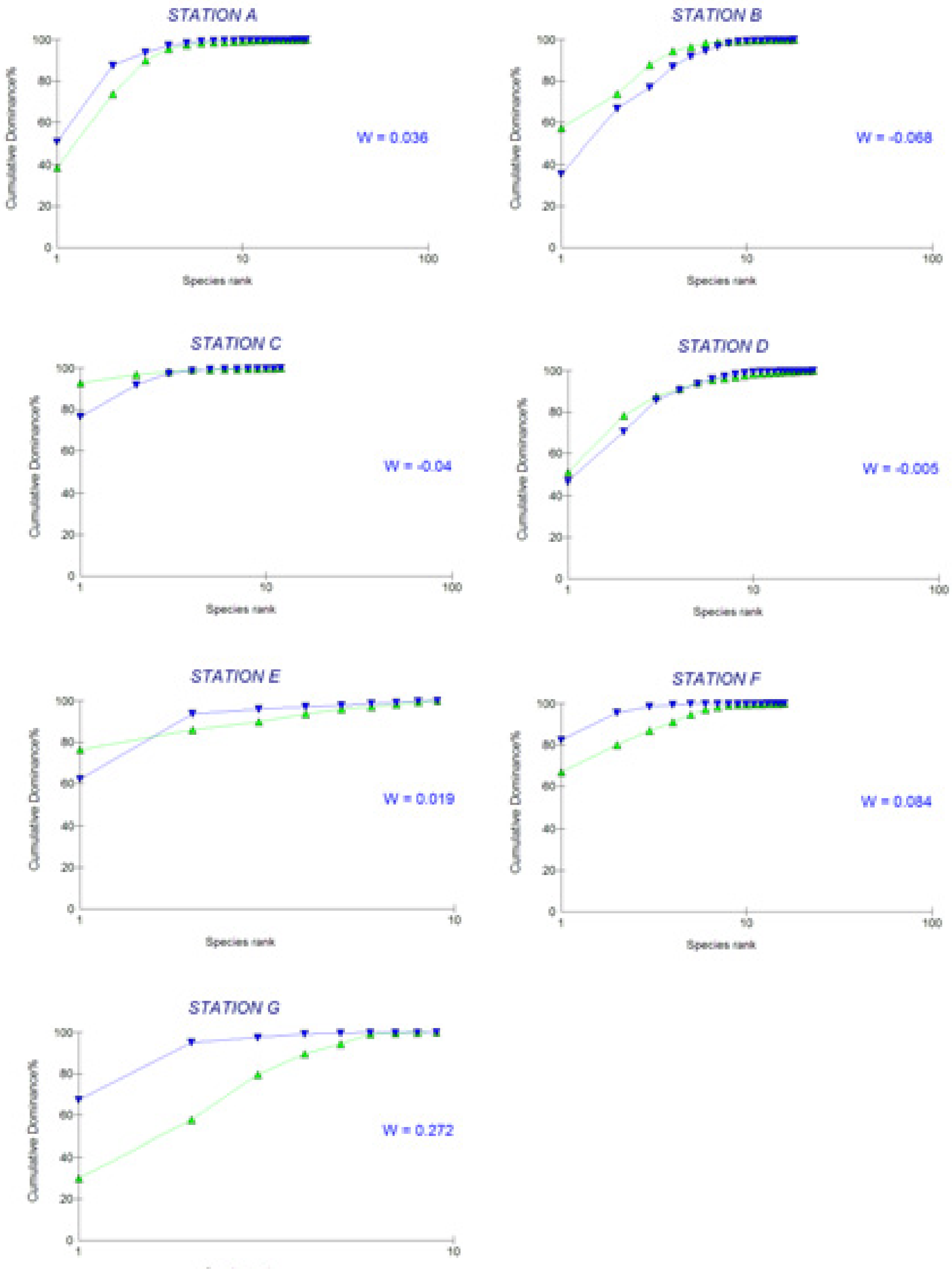


Figure 4.2b ABC plots (Stations A-G) for year averaged abundance and biomass station data

Abundance = ▲ Biomass = ▼



The ABC curves further illustrate this stress with a high number of the curves for biomass and abundance either close together or crossing over indicating a moderate pollution effect. Stations B and C appear to be the most impacted. The W statistic (Clark 1990) has been displayed for each ABC plot. W takes values in the range (-1, 1), with W→ +1 for even abundance across species but biomass dominated by a single species and W → -1 in the converse case.

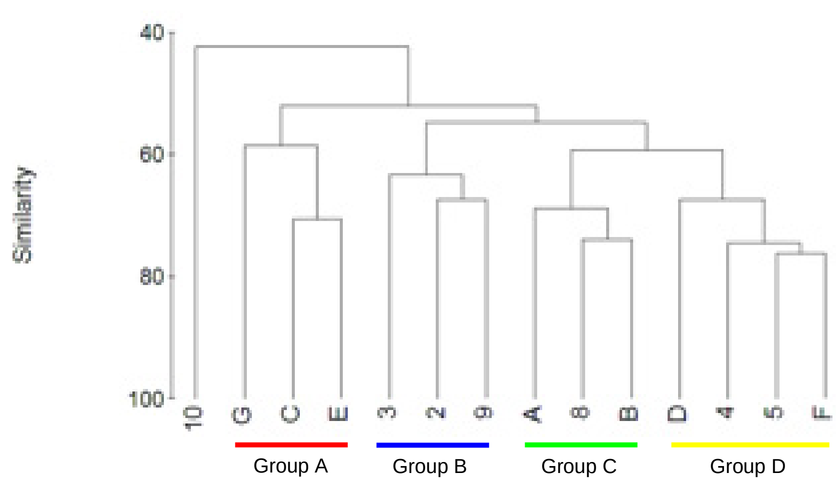
4.2.4 Multivariate analysis

Multivariate analyses are believed to be more sensitive in detecting community differences than univariate methods. Large data matrices are reduced to a pictorial representation. Analysis was performed on year averaged abundance data after it was averaged over the four monitoring visits for each station.

Cluster analysis

Cluster analysis was performed on the year averaged data for each station using the Bray-Curtis similarity index to obtain a measure of the degree of similarity between the faunal composition of each of the sampling stations. Root-root transformation of abundance data was used to reduce the influence of abundant species along with the group averaging cluster algorithm. The clustering technique compares, for each taxon, the abundance of the taxon in a sample, with the abundance in each of the other samples. The similarity matrix resulting from the cluster analysis is presented diagrammatically as a dendogram in Figure 4.3.

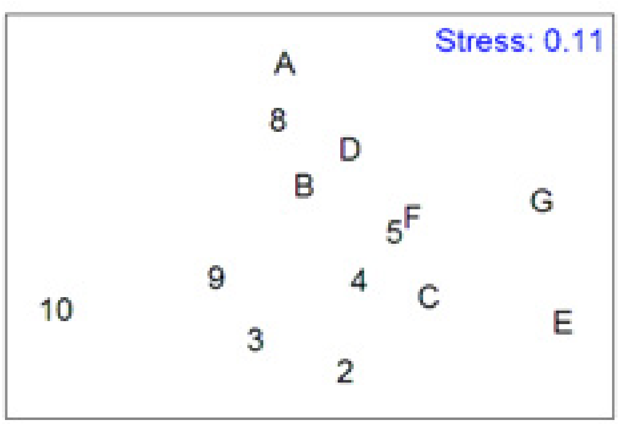
Figure 4.3 Bray-Curtis similarity dendogram (averaged abundance data)



Samples that are similar link together towards the bottom of the figure. Those, which are less similar, link towards the top of the diagram. The scale is an index from 0% to 100%, and should be viewed as a relative indicator of similarity, it does not indicate the proportion of species in common. Interpretation of the dendogram is subjective and involves the recognition of groups, or clusters, of samples, which are joined at higher levels of similarity on the basis of a similar fauna. It can be seen from the dendogram that there is a high degree of similarity between most stations. However, some distinction can be made with a number of the stations appearing to group together at higher levels of similarity. Station 10 can be immediately isolated at 42% similarity. The remaining stations can then be divided into three main groupings. They are designated Group A (Stations G, C and E), Group B (Stations 3, 2 and 9) and Group C (Stations A, 8, B) and Group D (Stations D, 4, 5 and F).

The two-dimensional Multi-Dimensional Scaling (MDS) configuration is illustrated in Figure 4.4. MDS provides a visual representation of differences between sites by constructing a 'map' or configuration of the samples in a specified number of dimensions based on a similarity matrix. The MDS plot represented has a stress value of 0.1, indicating 'a good ordination with no real prospect of a misleading interpretation'. It can however be seen that the MDS plot struggles to define the groupings clearly in a 2-dimensional picture with no real distance observed between the stations. This serves to illustrate the high level of similarity between the sample stations.

Figure 4.4 2-dimensional MDS configuration



4.2.5 SIMPER Analysis

Following on from the MDS it is important to know which species are responsible for the similarity or dissimilarity of one station against another. The data was therefore subjected to 'Similarity Percentage Analysis' (SIMPER). The results are presented in Appendix Five.

Group A stations (G, C and E) have an average similarity of 31%. The dominance of the oligochaete *Tubificoides benedii* and the laver spire shell *Hydrobia ulvae* contributes the most to the similarity between the stations in this group. Station G can be separated within this group due to a more even spread of individuals amongst the different species. The ragworm *Hediste diversicolor* also occurred in higher numbers at Station G compared to other stations.

Group B stations (3, 2 and 9) have an average similarity of 53%. The oligochaete *Tubificoides benedii* contributes highly to the similarity between stations in this group along with the inclusion of higher numbers of the polychaetes *Tharyx* and *Pygospio elegans*.

Group C stations (A, 8 and B) have an average similarity of 46%. The oligochaete *Tubificoides benedii* is common to all stations in this group along with important contributions from the polychaete *Capitella capitata* and the laver spire shell *Hydrobia ulvae.*

Group D stations (D, 4, 5 and F) have an average similarity of 67%). The oligochaete *Tubificoides benedii* remains common but the stations are distinguished by the presence of the polychaete *Manayunkia aestuarina* along with the laver spire shell *Hydrobia ulvae*.

The four groups are separated by only subtle variations in species presence and numbers of individuals. As indicated in the cluster analysis the similarity between all stations is high at between 60–70%. Increased sampling replication at each station would help define the groupings with more accuracy. The 10 dominant species recorded at each station are listed in Appendix Six.

4.3 Pelagic Fauna

Full species abundance data for the hand-net sweeps made at each station are presented in Appendix Seven. A total of 40 species were recorded for all stations. However, the majority of these species were already identified in the benthic cores and were probably collected by the net due to disturbance of the surface sediment layer. They included the mud shell

Hydrobia ulvae and small polychaete species such as *Manayunkia aesturina*. A number of crustacean species active in the water column were recorded including the Brown Shrimp *Crangon crangon* and the mysid *Praunus flexusosus*.

4.4 Trace Metal Analysis of *Cerastoderma edule*

The results of trace metals analysis of cockle tissue are presented in Appendix Eight as tables and histograms. The level of contaminants in shellfish is a good indicator of contaminant levels present in the water column and can provide valuable information on the quality of both the shellfish and the waters in which they are found. Guidance values are only available for a small number of metals in shellfish and these relate to levels which are considered to be hazardous to human health.

Aluminium

Aluminium levels in cockle tissue ranged from a low of 20.4 mg/kg at Station 9 in the summer to a high of 146.5 mg/kg at Station 3 in the winter.

Arsenic

Arsenic levels in cockle tissue ranged from a low of 0.8 mg/kg at Station 9 in the summer to a high of 3.7 mg/kg at Station 10 in the winter. The Marine Institute suggests an arsenic concentration of 0.66 mg/kg in the tissues of mussels may be representative of uncontaminated conditions (Marine Institute Report, 1999).

Cadmium

Cadmium levels in cockle tissue were all below 0.1 mg/kg. The strictest consumption guideline value for cadmium is applied by Germany and Norway (0.5 mg/kg wet weight). EU Commission Regulation 466/2001/EEC as amended by Regulation 221/2002/EC specifies a maximum level of 1 mg/kg wet weight for cadmium in bivalve molluscs. A background range of 0.07-0.11 is proposed by OSPAR (MON, 1998) for mussels.

Chromium

Chromium levels in cockle tissue ranged from a low of 0.5 mg/kg at Station 10 in the winter to a high of 1.1 mg/kg at Station A in the winter. Information on chromium levels in molluscs from around the Irish coast is not as extensive as for other metals and no human health guidelines or background ranges have been set (Marine Institute Report, 1999). The Marine Institute however suggests that a median concentration of 0.25 mg/kg wet weight determined for mussels from shellfish growing areas in 1993 may be representative of

uncontaminated conditions and a median concentration of 1.2 mg/kg for a number of urban estuaries on the south coast between 1980-1988 is probably the result of contamination.

Copper

Copper levels in cockle tissue ranged from a low of 0.7 mg/kg at Station 2 in the winter to a high of 3.7 mg/kg at Station A in the winter. These levels are well below the strictest human health guideline for all seafoods of 10 mg/kg set by Norway and a standard of 20 mg/kg more widely applied to shellfish in Europe.

Iron

Iron levels in cockle tissue ranged from a low of 81.4 mg/kg at Station 10 in the summer to a high of 437.3 mg/kg at Station 3 in the winter.

Lead

Lead levels in cockle tissue were lowest at Station 10 in the summer (0.1 mg/kg). Values of 0.2 mg/kg were recorded at Stations 2, 3 and 9 in the summer and Station 10 in the winter. Slightly higher values of 0.4 mg/kg and 0.5 mg/kg were recorded for Stations 9 and 2 in the winter with elevated values of 1.0 mg/kg and 2.2 mg/kg recorded at Stations 3 and A. These values are above the strictest guideline value for lead in shellfish of 0.8 mg/kg set by Germany. The proposed background range of lead in mussels from OSPAR Convention waters is 0.01-0.19 mg/kg.

Magnesium

Magnesium levels in cockle tissue ranged from a low of 327.8 mg/kg at Station 9 in the summer to a high of 706.6 mg/kg at Station 9 in the winter.

Manganese

Manganese levels in cockle tissue ranged from a low of 2.0 mg/kg at Station 10 in the summer to a high of 33.3 mg/kg at Station A in the winter. Values at all other sampled stations were below 11.9 mg/kg which would suggest that the value for Station A is elevated.

Mercury

Mercury levels in cockle tissue were all below 0.1 mg/kg. These levels do not exceed the EU human health consumption standard of 0.5 mg/kg wet weight or the environmental quality standard (EQS) for mercury in marine foods as recommended by OSPAR of 0.3 mg/kg wet weight.

Nickel

Nickel levels in cockle tissue ranged from a low of 1.4 mg/kg at Station 9 in the summer to a high of 13.3 mg/kg at Station 3 in the winter. The Marine Institute suggests a nickel concentration of 3.9 mg/kg in the tissues of mussels may be representative of uncontaminated conditions (Marine Institute Report, 1999).

Tin

Nickel levels in cockle tissue were below 0.1 mg/kg at all sampled station with the exception of Station 2 in the winter which had a recorded value of 0.6 mg/kg.

Zinc

Zinc levels in cockle tissue ranged from a low of 9.0 mg/kg at Station 9 in the summer to a high of 18.3 mg/kg at Station A in the winter. These concentrations are well within the OSPAR background range of 11.6 – 30 mg/kg lead in the tissue of mussels (MON, 1998) and within the UK guidance value for zinc in marine foods of 50 mg/kg.

5.0 VEGETATION ANALYSES

5.1 Algal Abundance

The percentage cover of intertidal algal species recorded at each sample station during each of the quarterly survey visits is presented in Table 5.1. Algal cover adjacent to most sample stations was generally low due to the location of the majority of stations in areas of open mud. The percentage cover recorded therefore includes a calculation of the seaweed species present in adjacent upper shore areas where the occurrence of stones and occasional boulders allowed attachment of seaweed. Algal species were recorded using the SACFOR notations as follows: -

>80%	**S**uperabundant	20-39%	**C**ommon	5-9%	**O**ccasional
40-79%	**A**bundant	10-19%	**F**requent	1-5%	**R**are

The calculation of % cover is an estimate based on visual appraisal and is subject to recorder error. It should however allow a comparison of % cover of the same species at the same locations during future monitoring surveys.

Brown sea weed species requiring hard substrate for attachment were most common in the outer estuary where the mudflat was fringed by an upper shore area of cobbles and small boulders. Bladder wrack *Fucus vesiculosus*, Spiral Wrack *Fucus spiralis,* Knotted Wrack *Ascophyllum nodosum* and Serrated Wrack *Fucus serratus* were most abundant at Stations 2 and 10 and dominated on mixed substrata towards the north-eastern part of the estuary. The presence of brown seaweed species at Station 3 was restricted to a narrow stony spit which projects into the estuary for a distance of approximately 60m. The southern part of the outer estuary has less available substratum for the attachment of a significant amount of brown seaweed. The density of brown algal species at individual stations varied over the year with the highest levels recorded in the summer season after periods of increased growth.

Green algae was rarely recorded in the inner estuary (west of the viaduct) with the majority of the total estuary algal abundance recorded in the outer estuary to the northeast of the landfill site alongside the railway line viaduct and on the north shore. The abundance of the green algae *Entermorpha* was highest in the spring (May 2002) and summer (July 2002) and was concentrated at stations 8, 9, 10 and A. The green algae sea lettuce (*Ulva lactuca*) was

super-abundant at stations 8, B and A in the autumn (October 2002) visit. As expected virtually no green algae was recorded in the estuary for the winter (Jan 2003) visit.

Table 5.1 Percentage cover of main intertidal algal species for each quarterly survey

(Key: S = Superabundant, A = Abundant, C = Common, F = Frequent, O = Occasional, R = Rare)

		May 2002		July 2002		October 2002		Jan 2003	
Station	**Species**	**% Cover**	**Abu.**	**% Cover**	**Abu.**	**% Cover**	**Abu.**	**% Cover**	**Abu.**
2	*Pelvetia cannaliculata*	10%	F	5%	O	10%	O	3%	R
	Fucus sp.	20%	C	40%	A	20%	C	25%	C
	Ascophyllum nodosum	20%	C	5%	O	10%	F	30%	C
	Ulva lactuca	50%	A	40%	A	<5%	R	<5%	R
	Fucus serratus	20%	C	15%	F	2%	R	2%	R
	Enteromorpha sp.	20%	C	5%	R	0%		0%	
3	*Fucus* sp.	25%	C	25%	C	5%	O	5%	O
	Ulva lactuca	10%	F	10%	F	<5%	R	0%	
	Enteromorpha sp.	20%	C	90%	S	15%	F	0%	
4	*Fucus* sp.	20%	C	20%	C	<5%	R	<5%	R
	Ulva lactuca	10%	F	10%	F	0%		0%	
	Enteromorpha sp.	<5%	R	<5%	R	0%		0%	
5	*Fucus sp.*	10%	F	10%	F	<5%	R	<5%	
	Ulva lactuca	<5%	R	<5%	R	0%		0%	
	Enteromorpha sp.	<2%	R	<2%	R	0%		0%	
8	*Fucus* sp.	<10%	O	<5%	R	<5%	R	<5%	R
	Ulva lactuca	10%	F	10%	F	90%	S	0%	
	Enteromorpha sp.	60%	A	60%	A	10%	F	0%	
9	*Pelvetia cannaliculata*	10%	F	10%	F	<5%	R	<5%	R
	Fucus sp.	20%	C	20%	C	15%	F	20%	C
	Ascophyllum nodosum	20%	C	20%	C	10%	F	10%	F
	Ulva lactuca	10%	F	5%	F	40%	A	0%	
	Fucus serratus	<10%	O	<10%	O	<10%	O	<10%	O
	Enteromorpha sp.	70%	A	70%	A	30%	C	0%	
10	*Pelvetia cannaliculata*	10%	F	10%	F	10%	F	<10%	F
	Fucus sp.	40%	A	40%	A	40%	A	25%	C
	Ascophyllum nodosum	20%	C	20%	C	25%	C	25%	C
	Ulva lactuca	20%	C	20%	C	40%	A	0%	
	Fucus serratus	20%	C	20%	C	20%	C	30%	C
	Enteromorpha sp.	>80%	S	40%	A	<5%	R	0%	
A	*Ulva lactuca*			5%	O	100%	S	0%	
	Enteromorpha sp.	60%	A	70%	A	40%	A	0%	
B	*Fucus* sp.	<10%	O	<10%	O	<10%	O	<10%	O
	Ulva lactuca					95%	S	0%	
	Enteromorpha sp.	<5%	R	<5%	R	5%	O	0%	
C	*Fucus* sp.	<10%	O	<10%	O	<10%	O	<10%	O
	Enteromorpha sp.	<5%	R	<5%	R	<5%	R	0%	
D	*Fucus* sp.	<10%	O	<10%	O	<10%	O	<10%	O
	Ulva	<2%	R	<2%	R	<2%	R	<2%	R
	Enteromorpha sp.	<2%	R	<2%	R	<2%	R	<3%	R
E	*Fucus* sp.	<10%	O	<10%	O	<5%	R	<5%	R
	Enteromorpha sp.	<2%	R	<2%	R	0%		0%	
F	*Enteromorpha* sp.	<2%	R	<2%	R	0%		0%	
G	*Enteromorpha* sp.	<2%	R	<2%	R	<0%		0%	

5.2 Habitat Survey

The main terrestrial habitat types within the SAC were identified and mapped onto a 1:10560 Ordnance Survey map of the area (Figures 5.1 and 5.2). Where feasible, a zone of one field/land parcel back from the SAC boundary was also mapped. Target Notes are presented in Appendix Nine. A plant species list is presented in Appendix Ten, Table 1. Scientific and common names follow Stace (1997). Birds observed utilising the estuary on the days of field survey are listed in Appendix Ten, Table 2. The habitats identified are described below.

Northern Side of Estuary – Blake's Cross to Rogerstown Viaduct

The habitats within the SAC along this side of the estuary have been identified as saltmarsh, semi-improved and poor semi-improved grassland, bare ground and intertidal flats (Figure 5.2). Ballyeally landfill site borders the SAC to the west of Rogerstown Viaduct. Surrounding land-use is predominantly arable and livestock farming with market gardening in places. The main habitats in this area are discussed below.

<u>Saltmarsh</u>

This habitat type stretches from the confluence of the two streams in the west of the survey area to the north-western tip of Ballyeally landfill. The saltmarsh in this section of the estuary varies in species composition from bare mud colonised by *Salicornia europaea* (Common Glasswort) (Plate 13, Target Note 7) to semi-improved grassland / saltmarsh mosaic (Plate 14, Target Note 6) and areas dominated by typical saltmarsh species such as:-

Atriplex prostrata	Spear-leaved Orache
Cochlearia officinalis	Common Scurvygrass
Triglochin maritimum	Sea Arrowgrass
Beta vulgaris	Beet
Plantago maritima	Sea Plantain
Festuca rubra	Red Fescue
Suaeda maritima	Annual Sea-blite
Juncus gerardii	Saltmarsh Rush
Glaux maritima	Sea-milkwort
Spergularia rupicola	Rock Sea-spurrey

Puccinellia maritima (Common Saltmarsh-grass) and *Limonium humile* (Common Sea-lavender) are localised, yet abundant, in places. Large stretches are infested by *Spartina anglica* (Common Cord-grass) (Plate 15, TN 5). Edges of the saltmarsh pools are colonised by *Atriplex portulacoides* (Sea-purslane), *Juncus maritimus* (Sea Rush), *Aster tripolium* (Sea Aster) and *Salicornia europaea* (Common Glasswort). The saltmarsh grades into beds of *Spartina anglica* (Common Cord-grass) southwest of Balleally landfill (Plate 16).

<u>Semi-improved Grassland</u>

Rank semi-improved grassland borders most of the saltmarsh in Newhaggard and Ballyeally West townlands. Much of this grassland has been reclaimed from saltmarsh by earthbanks and ditches (Department of the Environmment, Heritage and Local Government, 2000) (Plates 17 & 18). These fields have not been grazed recently and are dominated by rank grasses (Plate 19) including: -

Dactylis glomerata	Cock's-foot
Holcus lanatus	Yorkshire Fog
Arrhenatherum elatius	False Oat-grass
Elytrigia repens	Common Couch
Agrostis stolonifera	Creeping Bent
Festuca rubra	Red Fescue
Lolium perenne	Perennial Rye-grass

Also present throughout this grassland are:-

Cerastium fontanum	Common Mouse-ear
Rumex crispus	Curled Dock
Hypochoeris radicata	Cats-ear
Trifolium pratense	Red Clover
Crepis capillaris	Smooth Hawk's-beard
Ranunculus repens	Creeping Buttercup

Damper areas occur at intervals, as evident by the presence of *Juncus effusus* (Soft Rush) and *Senecio aquaticus* (Marsh Ragwort). There are some drier parts towards the road, where infilling has taken place in the past and the vegetation is now dominated by ruderal species (Plate 20) such as:-

Heracleum sphondylium	Hogweed

Rumex obtusifolius	Broad-leaved Dock
Cirsium vulgare	Spear Thistle
Chamerion angustifolium	Rose-bay Willowherb
Rubus fruticosus agg.	Bramble
Urtica dioica	Common Nettle
Daucus carota	Wild Carrot
Potentilla anserina	Silverweed
Plantago lanceolata	Ribwort Plantain
Senecio jacobaea	Ragwort
Taraxacum officinale	Dandelion

<u>Improved and poor semi-improved grassland</u>

At the head of the estuary, agricultural grassland borders the estuarine stream towards Newhaggard bridge and Blake's Cross. The fields consist of improved and poor semi-improved grassland for grazing cattle, sheep and horses. Hedgerows, fences and drainage ditches form the field boundaries. These fields have varying degrees of species diversity depending on grazing intensity, application of fertilizer or other agricultural practices. The improved grassland is characterised by lush green swards. The poor semi-improved grassland has received somewhat less intensive management and has a more diverse species composition than the improved grassland. The sward contains *Elytriga repens* (Common Couch), *Agrostis stolonifera* (Creeping Bent), *Holcus lanatus* (Yorkshire Fog) and *Festuca rubra* (Red Fescue). Other frequent species include:-

Ranunculus repens	Creeping Buttercup
Potentilla anserina	Silverweed
Cirsium arvense	Creeping Thistle
Juncus effusus	Soft Rush
Cerastium fontanum	Common Mouse-ear
Trifolium repens	White clover

One large field of poor semi-improved grassland (Plate 21), reclaimed from saltmarsh is included in the SAC. *Hordeum secalinum* (Meadow Barley) a rare plant protected under the Flora (Protection) Order 1999 was observed in this field. The presence of saltmarsh species such as *Suaeda maritima* (Annual Sea-blite), *Juncus gerardii* (Saltmarsh Rush) and *Aster tripolium* (Sea Aster) in the low-lying ground along the landward side of this embankment indicate a saline influence is still present there.

Bare Ground and Landfill

Three areas within this section of the study area have been mapped as bare ground in Figure 5.1. The ground is largely devoid of vegetation here for two reasons; (a) infilling and reclamation of land (Plate 22, Target Note 4) and (b) ground recently excavated for the extension to Ballyeally landfill (Plate 23, Target Note 9).

Ruderal growth occurs on patches of the infilled ground which have not been recently disturbed and along parts of southern boundary of Ballyeally landfill. Species recorded include:-

Cirsium vulgare	Spear Thistle
Chamerion angustifolium	Rosebay Willowherb
Sonchus asper	Prickly Sow-thistle
Arctium minus	Lesser Burdock
Tussilago farfara	Colt's-foot
Dipsacus fullonum	Wild Teasel
Fumaria sp.	Fumitory
Capsella bursa-pastoris	Shepherd's Purse
Euphorbia helioscopia	Sun Spurge
Melilotus altissimus	Tall Melilot
Sonchus arvensis	Perennial Sow-thistle
Sinapis arvensis	Charlock
Chenopodium album	Fat-hen
Rapistrum rugosum	Bastard Cabbage

In January 2003, work commenced on extending the landfill site to create new cells. Additional development on the site includes the construction of a settlement pond (Plate 24, Target Note 8) and water treatment plant for landfill leachate. The vegetation removed by the excavations was largely semi-improved wet grassland and areas of disturbed ground with weedy growth, to the north and west of the landfill. Waste ground species recorded here in October 2002 included the rare, non-native, *Picris echioides* (Bristly Oxtongue). The locations of where this plant was observed before the vegetation was removed are indicated in Figure 3 by Target Note 10.

Mixed Plantation Woodland

One small area planted with broadleaved trees and conifers borders the SAC in Ballyeally West townland. A drain, which forms part of the townland boundary, separates this from an area of semi-improved grassland. Tree species here include *Picea sitchensis* (Sitka

Spruce), *Acer pseudoplatanus* (Sycamore), *Salix* sp. (Willow) and *Eucalyptus* sp. (Eucalyptus). Vegetation below the canopy is dominated by rank grasses with *Hedera helix* (Ivy), *Rubus fruticosus* agg. (Bramble), *Urtica dioica* (Common Nettle), *Anthriscus sylvestris* (Cow parsley), *Heracleum sphondylium* (Hogweed) and *Rumex obtusifolius* (Broad-leaved Dock). Wetter areas towards the drain contain:-

Juncus effusus	Soft Rush
Phalaris arundinacea	Reed Canary-grass
Epilobium hirsutum	Great Willowherb
Angelica sylvestris	Wild Angelica
Filipendula ulmaria	Meadowsweet
Iris pseudocorus	Yellow Iris
Crocosmia x crocosmiiflora	Montbretia

Badgers appear to use this area to forage for food as a number of tracks and 'snuffle holes' were observed here.

<u>Scrub</u>

Scattered scrub consisting of *Ulex europaeus* (Gorse), *Rubus fruticosus* agg. (Bramble), *Crataegus monogyna* (Hawthorn), *Rosa canina* (Dog Rose) and *Sambucus nigra* (Elder) occurs along the estuarine embankments. No effort has been made to map these areas as they are relatively small and fragmented.

Dense stands of *Rubus fruticosus* agg. (Bramble), *Crataegus monogyna* (Hawthorn) and *Ulex europaeus* (Gorse) also exist on the banks of the stream leading to Newhaggard Bridge along with scattered mature trees such as *Salix viminalis* (Osier) and *Acer pseudoplatanus* (Sycamore). The stream corridor is somewhat disturbed and nutrient-enriched in places resulting in the growth of waste ground species such as:-

Urtica dioica	Common Nettle
Calystegia sepium	Hedge Bindweed
Petasites hybridus	Butterbur
Scrophularia auriculata	Water Figwort
Chamerion angustifolium	Rosebay Willowherb

Stands of *Phalaris arundinacea* (Reed canary-grass) and *Iris pseudacorus* (Yellow Iris) occur at the water's edge.

Arable

A number of fields in this area (and indeed in the entire study area) have been mapped as arable land. This broad classification has been used to categorise land that is under tillage for vegetables and cereal crops as well as horticulture (for example Daffodils, Target Note 3) and market garden greenhouses.

Northern Side of Estuary - Eastern Side of Railway Viaduct to Rogerstown Pier

The SAC along this section of the estuary encompasses intertidal flats, a field of wet semi-improved grassland and a strip of amenity grassland which is used by Brent Geese (Department of Environment, Heritage and Local Government, June 2000). The intertidal flats towards the railway line at the northern side of the estuary consist of soft muds colonised by *Spartina anglica* (Common Cord-grass) (Plate 25). A narrow roadway runs along this side of the estuary from the railway embankment towards Rogerstown Pier. Along much of the landward side of this roadway is a strip of strandline vegetation and rank grassland which is backed by a gappy hedgerow. The bordering land is intensively farmed for the production of silage, cereal crops, vegetables and flowers. Many of the original boundaries have been removed to create large open fields for this purpose. These fields have not been included in the habitat map (Figure 2).

Semi-improved grassland

At the north-eastern end of the roadway is a field of semi-improved grassland which is used to graze cattle. Grasses present include *Agrostis stolonifera* (Creeping bent), *Elytrigia repens* (Common Couch), *Dactylis glomerata* (Cock's-foot) and *Holcus lanatus* (Yorkshire Fog) with:-

Potentilla anserina	Silverweed
Ranunculus repens	Creeping Buttercup
Sonchus oleraceus	Smooth Sow-thistle
Rumex crispus	Curled Dock

Two drains dissect this area of grassland. The edges of these drains and other wet hollows in this field are lined by the saltmarsh species:-

Puccinellia maritima	Common Saltmarsh-grass
Aster tripolium	Sea Aster
Cochlearia officinalis	Common Scurvygrass

Triglochin maritima	Sea Arrowgrass
Glaux maritima	Sea-milkwort
Juncus gerardii	Saltmarsh Rush

These drains were mechanically cleaned out early in 2003, leaving them devoid of vegetation (Plate 26).

Amenity Grassland

A narrow strip of amenity grassland exists between the intertidal flats and the road from Rogerstown Hall and Rogerstown Pier (TN 13). This area was originally part of the shore which was infilled and grassed over. It is regularly mown, leaving a very short sward which is used by Brent Geese (Department of Environment, Heritage and Local Government).

Strandline vegetation

The roadway which runs along the upper shore of the estuary is flanked by a strip of vegetation which contains many typical saltmarsh species. For the most part, this vegetation is a narrow strip of approximately up to 3 metres wide which extends to 10 metres wide in places (Plate 27). *Beta vulgaris* (Beet), *Plantago maritima* (Sea Plantain) and *Atriplex portulacoides* (Sea-purslane) are frequent throughout this vegetation with localised mats of *Puccinellia maritima* (Common Saltmarsh-grass) and *Festuca rubra* (Red Fescue). Other species present include:-

Suaeda martima	Annual Sea-blite
Tripleurospermum maritimum	Sea Mayweed
Sonchus arvensis	Perennial Sow-thistle
Aster tripolium	Sea Aster
Glaux maritima	Sea-milkwort
Triglochin maritimum	Sea Arrowgrass
Atriplex prostrata	Spear-leaved Orache
Rumex crispus	Curled Dock
Cochlearia officinalis	Common Scurvygrass
Juncus gerardii	Saltmarsh Rush
Salicornia europaea	Common Glasswort
Agrostis stolonifera	Creeping Bent
Spergularia media	Greater Sea-spurrey

Hedgerow

The strandline vegetation is backed by a gappy hedgerow which is up to 10 metres tall and somewhat nutrient enriched in places at the base. Woody species in the hedgerow include semi-mature *Fraxinus excelsior* (Ash) and *Acer pseudoplatanus* (Sycamore), with *Crataegus monogyna* (Hawthorn) and *Prunus spinosa* (Blackthorn), the latter with profuse growth of the lichen *Xanthoria parietina.* Also present in the hedgerow are:-

Rubus fruticosus agg.	Bramble
Rosa canina	Dog Rose
Ulmus glabra	Wych Elm
Sambucus nigra	Elder
Salix viminalis	Osier

The hedgebank herbaceous flora is a mosaic of grassland and waste ground species (Plate 28) including *Arrhenatherum elatius* (False Oat-grass), *Agrostis capillaris* (Common Bent), *Holcus lanatus* (Yorkshire Fog), *Dactylis glomerata* (Cock's-foot), and *Plantago lanceolata* (Ribwort Plantain) with:-

Elytrigia repens	Common Couch
Lavatera arborea	Tree Mallow
Dipsacus fullonum	Wild Teasel
Daucus carota	Wild Carrot
Smyrium olusatrum	Alexanders
Sinapsis arvensis	Charlock
Cirsium vulgare	Spear Thistle
Melilotus altissimus	Tall Melilot
Lapsana communis	Nipplewort
Epilobium parviflorum	Hoary Willowherb
Heracleum sphondylium	Hogweed
Senecio jacobaea	Ragwort
Cirsium arvense	Creeping Thistle
Calystegia sepium	Hedge Bindweed
Urtica dioica	Common Nettle
Galium aparine	Cleavers

A large amount of debris has been washed up along this part of the shore. There is also localised dumping of construction rubble, wooden pallets and flower bulbs in places (Plate 29, TN 12). The bulb heaps are colonised with ruderals such as:-

Solanum tuberosum	Potato
Solanum nigrum	Black Nightshade
Sonchus asper	Prickly Sow-thistle
Veronica persica	Common Field-speedwell
Chenopodium album	Fat-hen

Eastern Side of Estuary (Burrow Townland)

This section covers the north and west shores of Burrow peninsula. Most of the shore here is fringed by a sandy beach, backed by an earthbank and rock armouring in places to protect the adjacent land from erosion (Plate 30). Land-use here includes a caravan park, amenity grassland, private dwellings and arable fields (Figure 5.2). Only saltmarsh and a small area of amenity grassland are included in the SAC.

<u>Saltmarsh</u>

A narrow strip of saltmarsh (varying from 5 to 30 metres wide) occurs on a sand/shingle substrate along the northern tip of this peninsula (Plate 31, Target Note 14). The main species noted here were *Atriplex portulacoides* (Sea purslane), *Plantago maritima* (Sea Plantain) and *Festuca rubra* (Red Fescue) with occasional *Cochlearia officinalis* (Common Scurvygrass) and *Spartina anglica* (Common Cord-grass). *Bolboschoenus maritimus* (Sea Club-rush) forms large stands in places.

Heading south towards Saint Mochuda's well there is a more extensive area of saltmarsh, grading into beds of *Spartina anglica* (Common Cord-grass) in the lower, sheltered mudflats (Plate 32). The saltmarsh here has a species composition of:-

Beta vulgaris	Beet
Festuca rubra	Red Fescue
Atriplex portulacoides	Sea Purslane
Puccinellia martima	Common Saltmarsh-grass
Cochlearia officinalis	Common Scurvygrass
Suaeda maritima	Annual Sea-blite
Aster tripolium	Sea Aster

Atriplex prostrata	Spear-leaved Orache
Plantago maritima	Sea Plantain
Triglochin maritimum	Sea Arrowgrass
Oenanthe lachenalii	Parsley Water-dropwort
Juncus maritimus	Sea Rush
Glaux maritima	Sea-milkwort
Limonium humile	Lax-flowered Sea-lavender

<u>Amenity grassland</u>

A small area of amenity grassland (Target Note 15), adjacent to the caravan Park in the northern part of Burrow townland, has been included in the SAC because it supports several *Orchis morio* (Green-winged Orchid), a Red Data Book species (Department of Environment and Local Government, June 2000.) An earthbank surrounds this grassland, which is planted with a row of *Picea sitchensis* (Sitka Spruce), *Pinus contorta* (Lodgepole Pine) and *Pinus nigra* Ssp. *nigra*.

<u>Strandline vegetation</u>

Fragments of strandline vegetation occur on the shingly upper shore between the sandflats and the estuarine embankments on the north-western side of Burrow Townland. Typical species found here are:-

Beta vulgaris	Beet
Atriplex portulacoides	Sea Purslane
Suaeda maritima	Annual Sea-blite
Tripleurospermum maritimum	Sea Mayweed
Sonchus arvensis	Perennial Sow-thistle
Elytrigia juncea	Sand Couch
Atriplex prostrata	Spear-leaved Orache
Plantago martima	Sea Plantain
Daucus carota	Wild Carrot
Cakile maritima	Sea Rocket
Ononis repens	Common Restharrow
Honckenya peploides	Sea Sandwort

Closer to the earthbank, the strandline vegetation grades to swards of *Festuca rubra* (Red Fescue) and *Elytrigia juncea* (Sand Couch), with occasional patches of *Ulex europaeus* (Gorse) and *Rubus fruticosus* agg. (Bramble).

<u>Semi-improved grassland</u>

There are two sizeable areas of semi-improved grassland in the north and west of Burrow townland. These appear to have been abandoned for a number of years and as such are dominated by rank grasses and ruderal growth (Plate 33) consisting of:-

Arrhenatherum elatius	False Oat-grass
Dactylis glomerata	Cock's-foot
Alopecurus pratensis	Meadow Foxtail
Phleum pratense	Timothy
Festuca rubra	Red Fescue
Elytrigia repens	Common Couch
Cirsium arvense	Creeping Thistle
Rumex obtusifolius	Broad-leaved Dock
Daucus carota	Wild carrot
Reseda lutea	Wild Mignonette
Rubus fruticosus agg.	Bramble
Heracleum sphondylium	Hogweed

<u>Scattered tall herb and fern</u>

Two fields in this section have been classified as scattered tall herb and fern. These are dominated by *Pteridium aquilinum* (Bracken) with *Rubus fruticosus* agg. (Bramble) and *Ulex europaeus* (Gorse) (Plate 34). Also growing in these areas are:-

Urtica dioica	Nettle
Senecio jacobaea	Ragwort
Cirsium vulgare	Spear thistle
Lathyrus pratensis	Meadow vetchling
Ranunculus repens	Creeping Buttercup
Ranunculus acris	Meadow Buttercup
Buddleja davidii	Butterfly-bush

<u>Arable</u>

Occasional Arable fields border the strand and saltmarsh along the western side of Burrow townland. Some of the original field boundaries shown on the 1:10560 Ordnance Survey map have been removed to create larger areas for tillage. On the days of survey, these fields had either been recently ploughed or harvested. Plate 35 shows one of these fields, with the remains of stubble from tillage and bales of straw.

Southern Side of Estuary - Rogerstown Viaduct to Saint Mochuda's Well

The habitats within the SAC here are saltmarsh, unimproved grassland, strandline vegetation and intertidal mudflats (Figure 5.2). Arable crop production is the most prevalent land-use adjacent to this stretch of the estuary. A steep bank and dense hedgerow backs the saltmarsh and provides some shelter for the crops in these large, elevated fields.

Saltmarsh

An expanse of *Spartina anglica* (Common Cord-grass) infested saltmarsh exists on the sheltered mudflats where Portraine townland meets the Burrow peninsula (Plate 36). This continues westwards, fringing Rahillion townland (Plate 37). The other main species present are:-

Atriplex portulacoides	Sea-purslane
Puccinellia maritima	Common Saltmarsh-grass
Beta vulgaris	Beet
Cochlearia officinalis	Common Scurvygrass
Aster tripolium	Sea Aster
Plantago maritima	Sea Plantain
Triglochin maritima	Sea Arrowgrass
Festuca rubra	Red Fescue
Suaeda maritima	Annual Sea-blite
Atriplex prostrata	Spear-leaved Orache
Juncus maritimus	Sea Rush
Glaux maritima	Sea-milkwort
Salicornia europaea	Common Glasswort

Between Raheen Point and Rogerstown Viaduct is an area of saltmarsh which is dominated by mats of *Puccinellia maritima* (Common Saltmarsh-grass) with dense stands of *Bolboschoenus maritimus* (Sea Clubrush) and *Juncus maritimus* (Sea-rush). *Spartina anglica* is abundant throughout this area.

Unimproved Grassland

An area of rank, unimproved grassland fringes the saltmarsh between Raheen Point and Rogerstown Viaduct. Species noted growing here include:-

Elytrigia repens	Common Couch
Festuca rubra	Red Fescue
Sonchus arvensis	Perennial Sow-thistle

Plantago maritima	Sea Plantain
Rumex crispus	Curled Dock
Iris pseudacorus	Yellow Iris
Daucus carota	Wild Carrot
Heracleum sphondylium	Hogweed
Rumex acetosa	Common Sorrel
Urtica dioica	Common Nettle

Strandline Vegetation

There is a small strip of strandline vegetation on the shingle substrate upper shore just east of Raheen Point with a species composition of:

Beta vulgaris	Beet
Sonchus arvensis	Perennial Sow-thistle
Elytrigia juncea	Sand Couch
Atriplex prostrata	Spear-leaved Orache
Achillea millefolium	Yarrow
Festuca rubra	Red Fescue
Plantago martima	Sea Plantain
Daucus carota	Wild Carrot
Cakile maritima	Sea Rocket
Ononis repens	Common Restharrow
Honckenya peploides	Sea Sandwort
Atriplex portulacoides	Sea-purslane

Semi-improved grassland

Two fields of semi-improved grassland, used for grazing cattle and horses, were identified adjacent to Raheen Point. The species composition of this grassland type included:-

Poa annua	Annual Meadow-grass
Agrostis stolonifera	Creeping Bent
Festuca rubra	Red Fescue
Holcus lanatus	Yorkshire Fog
Arrhenatherum elatius	False Oat-grass
Trifolium pratense	Red Clover
Achillea millefolium	Yarrow
Urtica dioica	Common Nettle
Rumex obtusifolius	Broad-leaved Dock

Hedgerow

A steep bank and tall hedgerow separates the saltmarsh and strandline vegetation from the arable land (Plate 38). The main hedgerow species are:-

Crataegus monogyna	Hawthorn
Prunus spinosa	Blackthorn
Ulex europaeus	Gorse
Sambucus nigra	Elder
Rosa canina	Dog Rose
Rubus fruticosus agg.	Bramble
Buddleja davidii	Butterfly Bush
Hedera helix	Ivy

Within this hedgerow are occasional standards of *Pinus nigra* ssp. *nigra* (Austrian Pine), *Fraxinus excelsior* (Ash) and *Populus* sp. (Poplar). This hedgerow is un-managed on the side facing the estuary where it has become overgrown and scrubby in places. Growing in the hedgebank are:-

Heracleum sphondylium	Hogweed
Galium aparine	Cleavers
Polystichum setiferum	Soft Shield-fern
Dryopteris filix-mas	Male-fern
Pteridium aquilinum	Bracken

Between the base of this hedgerow and the saltmarsh is a strip of rank grassland. Growing in the drier areas of this grassland are:-

Senecio jacobaea	Ragwort
Plantago lanceolata	Ribwort Plantain
Daucus carota	Wild Carrot
Smynium olusatrum	Alexanders
Lathyrus pratensis	Meadow Vetchling
Festuca rubra	Red Fescue
Elytrigia repens	Common Couch
Arrhenatherum elatius	False Oat-grass
Dactylis glomerata	Cocks-foot
Cirsium arvense	Creeping Thistle

Damper areas of this grassland contain:-

Agrostis stolonifera	Creeping Bent

Iris pseudacorus	Yellow Iris
Elytrigia repens	Common Couch
Angelica sylvestris	Wild Angelica
Juncus effusus	Soft Rush
Festuca arundinacea	Tall Fescue
Phalaris arundinacea	Reed Canary-grass
Filipendula ulmaria	Meadowsweet
Juncus acutiflorus	Sharp-flowered Rush
Epilobium parviflorum	Hoary Willowherb

Arable

Large arable fields border the estuary from Raheen Point to Saint Mochuda's Well. Like much of the arable land in the rest of the study area, many of the original field boundaries have been removed to create wide-open spaces for the production of cereal crops and vegetables.

Southern Side of Estuary - Daws Bridge to Rogerstown Viaduct

Saltmarsh fringes most of the land along this part of the inner estuary. Towards Daws Bridge, the tidal river is bordered by semi-improved fields reclaimed from saltmarsh by a series of earth embankments and ditches (Department of Environment, Heritage and Local Government 2000). Adjacent land-use includes arable crop production, broadleaf tree plantations, allotments and a golf course. The habitats within the SAC here are saltmarsh, semi-improved grassland, scrub and strandline vegetation.

Saltmarsh

West of Rogerstown Viaduct, saltmarsh extends from Beaverstown Golf Course as far as the confluence of the two streams at the western end of the survey area (Plates 39 and 40). The species composition of this saltmarsh was dominated by:-

Atriplex portulacoides	Sea Purslane
Triglochin maritimum	Sea Arrowgrass
Plantago maritima	Sea Plantain
Beta vulgaris	Beet
Juncus gerardii	Saltmarsh Rush
Festuca rubra	Red Fescue

This grades into beds of *Spartina anglica* (Common Cord-grass) on the lower shore in sheltered areas. The saltmarsh turf is only a few centimetres tall in places being colonised with:-

Armeria maritima	Thrift
Limonium humile	Lax-flowered Sea-lavender
Atriplex prostrata	Spear-leaved Orache
Cochlearia officinalis	Common Scurvygrass
Aster tripolium	Sea Aster
Glaux maritima	Sea-milkwort

Salicornia europaea (Common Glasswort) occurrs at the outermost edge of the vegetated saltmarsh zone on bare mudflat. *Juncus maritimus* (Sea Rush), *Phragmites australis* (Common Reed) and *Bolboschoenus maritimus* (Sea Club-rush) form dense stands in parts.

<u>Semi-improved Grassland</u>

Between Rogerstown hide and Daws bridge, the fields consist of a mosaic of semi-improved, albeit weedy, grassland (Plates 41 and 42) and scattered trees and shrubs such as *Salix viminalis* (Osier) and *Rosa canina* (Dog Rose). The grassland flora includes:-

Holcus lanatus	Yorkshire Fog
Phleum pratense	Timothy
Taraxacum officinale	Dandelion
Heracleum sphondylium	Hogweed
Sonchus arvensis	Perennial Sow-thistle
Vicia cracca	Tufted Vetch
Dactylis glomerata	Cock’s-foot
Plantago lanceolata	Ribwort Plantain
Arrhenatherum elatius	False Oat-grass
Potentilla anserina	Silverweed
Cirsium arvense	Creeping Thistle
Urtica dioica	Common Nettle
Epilobium parviflorum	Hoary Willowherb
Rumex crispus	Curled Dock
Elytrigia repens	Common Couch

The grassland is somewhat damp in places as evident by the presence of *Senecio aquaticus* (Marsh Ragwort), *Stellaria uliginosa* (Bog Stitchwort), *Juncus effusus* (Soft Rush) and

Agrostis stolonifera (Creeping Bent). One area of this grassland, near the confluence of the two streams, has been recently infilled (Plate 43, TN 2).

Scrub

A small area of scrub woodland lines the southernmost stream corridor near Daws Bridge. This consists of dense growth of *Prunus spinosa* (Blackthorn), *Crataegus monogyna* (Hawthorn), *Fraxinus excelsior* (Ash) and *Rubus fruticosus* agg. (Bramble) with a herbaceous flora of:-

Cirsium vulgare	Spear Thistle
Urtica dioica	Common Nettle
Calystegia sepium	Hedge Bindweed
Epilobium sp.	Willowherb
Anthriscus sylvestris	Cow Parsley
Rumex spp.	Dock

Wetter areas of this scrub include *Phalaris arundinacea* (Reed canary-grass), *Iris pseudacorus* (Yellow Iris), *Angelica sylvertris* (Wild Angelica), *Filipendula ulmaria* (Meadowsweet) and *Apium nodiflorum* (Fool's Water-cress).

Strandline Vegetation

There is a small corner of strandline vegetation on the upper shingly shore where Beaverstown Golf Course meets Rogerstown Viaduct. This is essentially a strip, approximately 4 to 5 metres wide of *Festuca rubra* (Red Fescue)-dominated grassland with:-

Beta vulgaris	Beet
Elytrigia juncea	Sand Couch
Suaeda maritima	Annual Sea-blite
Tripleurospermum maritimum	Sea Mayweed
Atriplex portulacoides	Sea Purslane

This vegetation is backed by dense *Ulex europaeus* (Gorse) and *Rubus fruticosus* agg. (Bramble) in places along the railway embankment. A line of mature *Pinus nigra* Ssp. *nigra* (Austrian Pine) and *Cupressus macrocarpa* (Monterey Cypress) trees separate the golf course from the estuary.

5.3 Trace Element Analysis of *Fucus vesiculosus*

There are currently no Irish or UK guideline standards available for the assessment of metals in the tissue of marine algae. The Swedish Environment Protection Agency has however produced reference values as part of its assessment criteria for interpretation of data on pollution of coastal and marine environments. The reference values are estimates of the metal concentrations which may be expected to occur in areas that have not been significantly affected by human activities. The reference values for metal concentrations in *Fucus vesiculosus* are presented in Table 5.2.

Table 5.2 Swedish Reference values for metal concentrations in *Fucus vesiculosus*

Metal (mg/kg)	Reference value[1]
Arsenic	20
Cadmium	0.9
Chromium	0.2
Copper	2.5
Nickel	3.5
Lead	0.3
Zinc	40

The results of the trace metal analysis of *Fucus* tissue are presented in tables and histograms in Appendix Eleven. The values are discussed below and an assessment made against the Swedish Reference Values outlined in Table 5.2 where possible.

<u>Aluminium</u>

Aluminium levels in *Fucus* tissue ranged from a low of 248 mg/kg at Station 10 in October 2002 to a high of 3131 mg/kg at Station B in July 2002.

<u>Arsenic</u>

Arsenic levels in *Fucus* tissue ranged from a low of 20 mg/kg at Station A in October 2002 to a high of 91 mg/kg at Station 2 in January 2003. Levels were all elevated above the Swedish Reference value for Arsenic of 20 mg/kg which is indicative of pristine natural conditions.

Cadmium

Cadmium levels in *Fucus* tissue ranged from a low of <0.6 mg/kg (Stations A, B, C, 2, 3, 4 and 9) in July 2002 to a high of 1.3 mg/kg at Station B in May 2002. Levels at most stations were less than the Swedish Reference Value for Cadmium of 0.9 mg/kg.

Chromium

Chromium levels in *Fucus* tissue ranged from a low of 3.3 mg/kg at Station 10 in January 2003 to a high of 13.3 mg/kg at Station C in July 2003. Chromium levels appeared to follow a seasonal pattern with values highest in the summer and lowest in the winter. Levels at all stations were significantly elevated above the Swedish Reference Value of 0.2 mg/kg.

Copper

Copper levels in *Fucus* tissue ranged from a low of 6.3 mg/kg at Station 2 in October 2002 to a high of 70 mg/kg Station A in October 2002. Levels at all other stations were below 20 mg/kg. The Swedish Reference Value for Copper in *Fucus* representative of pristine conditions is 2.5 mg/kg. Copper levels therefore appear elevated in *Fucus* tissue.

Iron

Iron levels in *Fucus* tissue ranged from a low of 508 mg/kg at Station 2 in October 2002 to a high of 5000 mg/kg at Station C in July 2002.

Lead

Lead levels in *Fucus* tissue ranged from a low of <0.6 mg/kg at Station B to a high of 12 mg/kg at Station A. The Swedish Reference Value for Copper in *Fucus* representative of pristine conditions is 0.3 mg/kg. Lead levels therefore appear elevated *Fucus* tissue.

Magnesium

Magnesium levels in *Fucus* tissue ranged from a low of 5290 mg/kg at Station D in October 2002 to a high of 11584 mg/kg at Station 5 in July 2002.

Manganese

Manganese levels in *Fucus* tissue ranged from a low of 156 mg/kg at Station 2 in July 2002 to a high of 821 mg/kg at Station C in May 2002.

Mercury

Mercury levels in *Fucus* tissue were <0.6 mg/kg at all stations.

Nickel

Nickel levels in *Fucus* tissue ranged from a low of 5.2 mg/kg at Station 2 in October 2002 to a high of 14.1 mg/kg at Station 10 in May 2002. The Swedish Reference Value for Copper in *Fucus* representative of pristine conditions is 3.5 mg/kg.

Tin

Tin levels in *Fucus* tissue were < 0.6 mg/kg at all stations.

Zinc

Zinc levels in *Fucus* tissue ranged from a low of 40 mg/kg at Station 2 in July 2002 to a high of 161 mg/kg at Station A in October 2002. The Swedish Reference Value for Zinc in *Fucus* representative of pristine conditions is 40 mg/kg.

6.0 BIOTOPE ASSIGNMENTS

Habitat descriptions for the intertidal area of the estuary were based upon the results of the benthic survey and the qualitative assessment of the areas around individual sampling stations. This technique fulfilled the requirements of accepted Phase 2 survey methods and incorporated a benthic assessment of sediments (Section 4.1) along with the recording of habitat and species details for each distinct habitat at each station, including the use of SACFOR for algal abundance (Section 5.1). Essentially, the intertidal element of the estuary can be separated into areas of upper shore mixed substrata with seaweed, mudflat and saltmarsh. Where the outer estuary narrows adjacent to the tidal channel there is also an area of mussel beds on the southern shore.

A number of intertidal biotopes were identified throughout the estuary and are described below according to Connor *et al*., 1997.

SLR.FX Fucoids, barnacles or ephemeral seaweeds (mixed substrata)

<u>Biotope Description</u>

Sheltered to very sheltered mixed substrata (pebbles and cobbles overlying muddy sand and gravel) supporting fucoid communities. The bladder wrack *Fucus vesiculosus* and the knotted wrack *Ascophyllum nodosum* both occur on the mid-shore (SLR.FvesX, SLR.AscX). The serrated wrack *Fucus serratus* occurs on the lower shore SLR.FserX. These mixed substrata communities differ from those on bedrock in having a less dense canopy of fucoids and reduced richness of epifaunal species. In summer months, dense blankets of ephemeral green seaweed can dominate these shores (SLR.EphX), while in upper estuarine conditions and by streams *Fucus ceranoides* occurs (SLR.FcerX).

This biotope is represented at Stations 10, 9, 8, 2 and 3 forms a littoral fringe above lower shore mudflat in the north and east of the outer estuary. The extent and quality of the biotope is dictated by the availability of suitable hard substrata for attachment of fucioid seaweeds. The biotope is best represented at Station 10. Sediment between patches of hard substrata often contains the lugworm *Arenicola marina*, cockles *Cerastoderma edule* or the ragworm *Hediste diversicolor*. Littorinids particulary *Littorina littorea*, commonly graze on the algae. Large mussels commonly occur in clumps, and provide further suitable substrata for the attachment of fucoids and barnacles. The spaces between cobbles and boulders provide a refuge for crustaceans, especially *Carcinus maenas*. The north shore between station 9 and A is characterised during the summer months by blankets of ephemeral green

algae. The main species present are *Enteromorpha* spp. and *Ulva lactuca*. Fucoid algae occur to a lesser extent than at Stations 10 and 2. Small numbers of other species such as barnacles *Semibalnaus balanoides* and *Elminius modestus* and keel worms *Pomatoceros* spp. are confined to larger cobbles and pebbles. In common with other areas of mixed substrata with patches of sandier sediment the cockle *Cerastordema edule* and polychaete *Arenicola marina* are present in small numbers.

The upper shore along the railway embankment (adjacent to stations B and C) is represented by an impoverished example of the SLR.FX biotope.

LMU.Smu Sandy mud shores

Biotope Description

Soft sediment shores, comprising predominantly sandy mud between 30% and 80% silt/clay fraction. The presence of at least 30% silt/clay gives rise to typically muddy communities in which the lugworm *Hediste diversicolor* and oligochaete worms are common. As the sediment has a reasonable proportion of sandy material in it the shores are relatively firm under-foot.

LMU.Mu Soft mud shores

Biotope Description

Shores of soft mud, typically with over 80% silt/clay fraction, forming very or extremely soft sediment shores. Although not very species-rich, with increasingly lower salinity conditions the mud supports even more impoverished communities, characterised by oligochaete worms.

The majority of the outer and inner estuary with the exception of areas of saltmarsh is comprised of mud shore biotopes with a high percentage silt clay fraction. The faunal assemblages identified for station sediments suggest that variations of the following mud shore biotopes are present in the outer and inner estuary.

LMU.HedStr Hediste diversicolor and Streblospio shrubsolii in sand mud or soft mud shores

Biotope Description

Sandy mud and mud shores in sheltered marine inlets and estuaries subject to variable or reduced salinity. The biotope is typically found on the mid and lower shores and is often associated with the presence of sea defences, rocky outcrops, rubble training walls or shallow layers of cobbles and pebbles in the sediment in the upper or mid estuary. In addition, the presence of nearby sewage outfalls or a high organic content probably influences the infaunal community. Tidal streams can be strong, further supporting the possibility that this biotope has a disturbed habitat. The infaunal polychaete community includes species with a limited salinity range tolerance such as *Streblospio shrubsolii*, *Tharyx* sp. and *Manayunkia aestuarina*. In addition to the mentioned polychaetes, *Hediste diversicolor*, *Pygospio elegans*, the burrowing amphipod *Corophium volutator*, the mud snail *Hydrobia ulvae* and the bivalves *Macoma balthica* and *Abra tenuis* are characterising species, the presence of the polychaetes *Polydora* spp., *Heteromastus filiformis* or *Ampharete grubei* are also indicative of this biotope. The sediment is anoxic and black close to the surface and remains water saturated throughout the tidal cycle. The frequency and abundance of oligochaetes, particulary *Tubificoides benedii* and *Tubificioides pseudogaster*, is greater than in LMU.HedMac, whilst the closely related LMU.HedMac.Pyg rarely has *Streblospio shrubsollii* or *Manayukia aestuarina* and has a greater frequency and abundance of *Cerastorderma edule* and *Eteone longa*. LMU.HedScr is similar to this biotope, but is slightly less muddy, has a higher frequency and abundance of bivalve species and a less diverse range of polychaete species, reflecting the more stable habitat of LMU.HedScr. The polychaete species richness is greater than in LMU.HedOl. The number of species that may be present in this biotope and the number of transition areas along salinity, wave-exposure and sediment particle size continua make this biotope potentially variable in species content.

LMU.HedOl Hediste diversicolor and oligochaetes in low salinity mud shores

Biotope Description

A low species-rich community found in soft mud in low salinity conditions, typically at the head of estuaries. Oligochaete worms are common or abundant together with the ragworm *Hediste diversicolor* and sometimes the mud amphipod *Corophium volutator*. The polychaete *Manayunkia aestuarina* may be common in more saline conditions, whilst at the very upper limit of the estuary only oligochaetes would be expected. *Corophium volutator* can be present in firmer mud. Filamentous algae such as *Enteromorpha* spp. may form

mats on the surface of the mud during the summer months. The mud is often very soft and fluid, with a 'wet' surface appearance.

LMU.NVC SM8 Salicornia spp.

Biotope Description

Mud, often consolidated with coarse sand or gravel, on the extreme upper shore with Salicornia spp. plants forming a pioneer saltmarsh community. This habitat typically occurs in very sheltered estuarine conditions. Usually a reduced marine fauna is present which may include the amphipod *Corophium volutator*, the ragworm *Hediste diversicolor* and often the mud snail *Hydrobia ulvae*. The fucoid alga *Pelvetia canaliculata* may be found on hard substrata, consolidated mud or lying unattached. This community is equivalent to saltmarsh community SM8 in the National Vegetation Classification (Rodwell in prep.) and was recorded at a number of locations around the estuary (see Section 5.2).

LMU.Sm Saltmarsh

Biotope Description

Angiosperm-dominated stands of vegetation, occurring on the extreme upper shore of sheltered coasts and periodically covered by high tides. The vegetation develops on a variety of sandy and muddy sediment types and may have admixtures of coarser material. The character of the saltmarsh communities is affected by height up the shore, resulting in a zonation pattern related to the degree or frequency of immersion in seawater. Areas of established and pioneer saltmarsh are found in both the inner and outer estuary (see Section 5.2).

SLR.MX Mytilus (mussel) beds (mixed substrata)

Biotope Description

On moderately exposed to sheltered shores the mussel *Mytilus edulis* can form dense aggregations on mixed substrata, creating stable biogenic reefs. This biotope is represented adjacent to the tidal streams in the narrow inlet to the outer estuary.

7.0 SEDIMENT ANALYSIS

7.1 Particle Size Analysis and Total Organic Carbon

The assessment of particle size analysis (PSA) and total organic carbon (TOC) has been based on the sediment analysis results for October 2002 and January 2003 (see Section 3.4.1 and 3.4.2 for explanation). Particle size fractions for station sediments according to the Wentworth scale are presented in Appendix Twelve. Histograms of the percentage size fractions for each station are presented in Figures 7.1 a-b. TOC values are presented below in Table 7.1.

Table 7.1 Total Organic Carbon results for October 2002 and January 2003

Station	October 2002	January 2003
A	7.4	8.4
B	8.6	7.8
C	9.9	7.3
D	5.9	7.5
E	11.8	12.8
F	8.7	9.5
G	12.4	12.3
2	4.6	6.3
3	5.5	5.2
4	6.7	4.8
5	4.4	6.7
8	7.9	8.4
9	2.3	3.5
10	3.7	6.9

Granulometry analysis indicates that the sediment at most sampling stations is moderately to well sorted with a high silt fraction. Stations 9 and 10 were poorly sorted with sediments consisting of a mixture of pebbles, sand and silt. Stations A, B, E, F and G had the highest silt fractions. Station G had a silt fraction of over 90% due to its location within an area of saltmarsh.

The organic content of inshore and estuarine sediments are generally highly correlated with the fine silt/clay fraction and this is reflected with the highest values for TOC being recorded at Stations E and G. TOC levels ranged from 2.3 at station 9 to 12.8 at station E and appear to increase in a pattern of transition from the outer estuary into the inner estuary.

Figure 7.1a Particle Size Distribution for October 2002 and January 2003 Sediments (Stations A-G and 2)

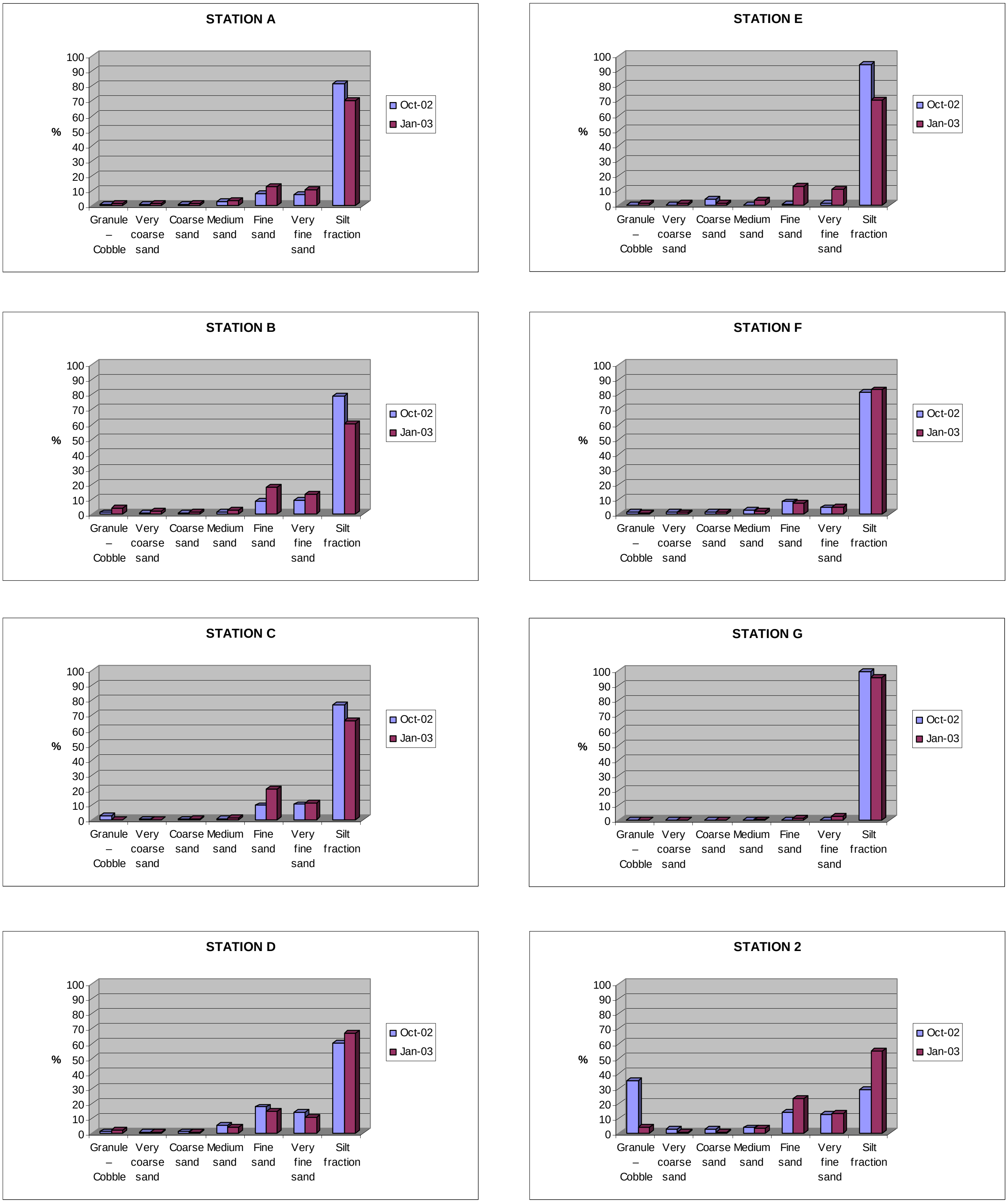
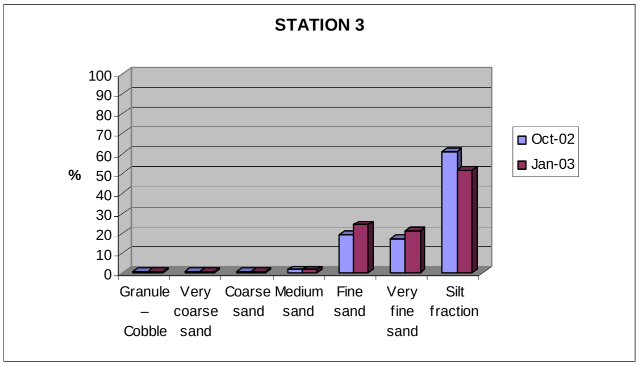
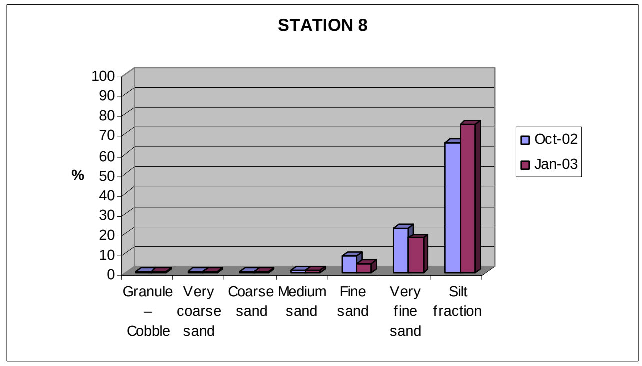
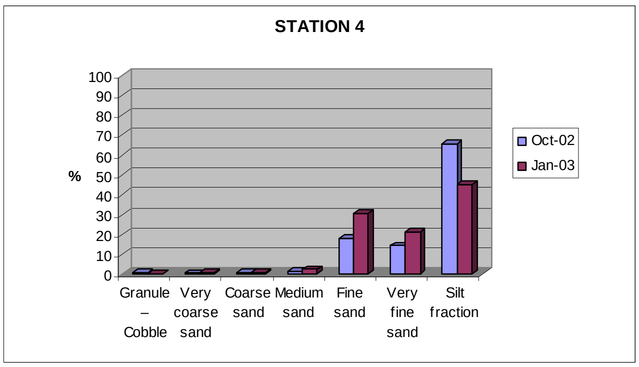
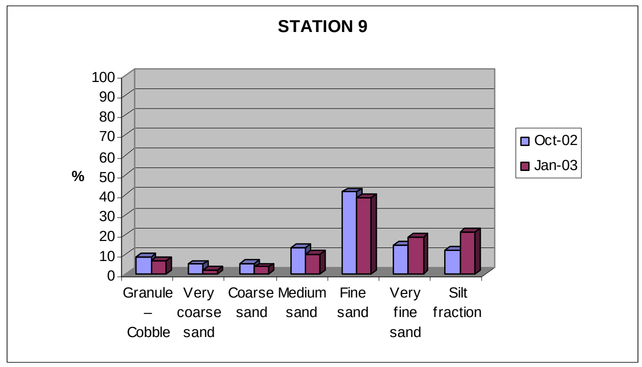


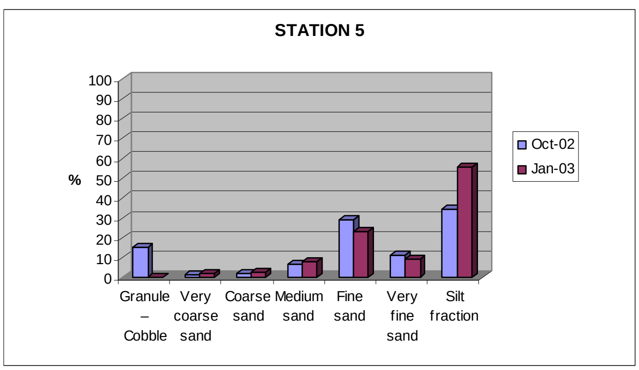
Figure 7.1b Particle Size Distribution for October 2002 and January 2003 Sediments (Stations 3, 4, 5, 8, 9, 10)

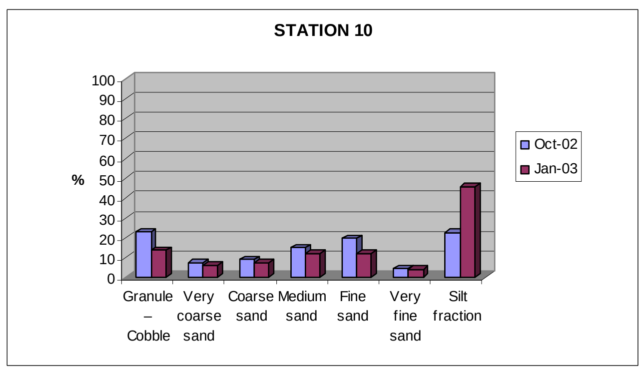












7.2 Redox Potential, Temperature and pH

An important parameter characterising marine sediments is the redox regime which is related to the concentration of oxygen dissolved in the water occupying the space between the grains (interstitial water). This regime is described by the redox potential (Eh) measured in mV. In general oxidizing conditions (high Eh values up to +400 mV) mean a high oxygen concentration while reduced conditions (low Eh down to –200 mV) reveal a lack of oxygen. Redox potential is affected by sediment grain size and organic content. Sediments with a high silt/clay fraction (< 63 um) will have lower Eh values than sandy sediments. Decomposition of organic content by bacteria may increase oxygen consumption. As a result sediments with high organic content usually have extremely low Eh values. The redox potentials of sample stations sediments are presented in Table 7.2. Redox values indicate reduced conditions at all stations as would be expected for sediments with a large silt/clay fraction and high levels of organic matter.

Table 7.2. Temperature, Redox and pH Results for Station Sediments

	Temp ° C				Redox mV				pH			
Station	**May 02**	**Jul 02**	**Oct 02**	**Jan 03**	**May 02**	**Jul 02**	**Oct 02**	**Jan 03**	**May 02**	**July 02**	**Oct 02**	**Jan 03**
2	11.9	15.0	10.0	5.0	n/v	-140	-120	-184	8.4	7.0	7.2	7.9
3	12.3	15.5	10.0	6.0	n/v	-165	-180	-112	8.8	7.5	7.1	7.6
4	12.6	15.5	9.5	6.0	n/v	-182	-124	-190	8.4	6.9	7.6	7.6
5	12.6	20.0	10.0	6.0	n/v	-216	-126	-114	8.8	7.2	7.3	7.6
8	15.8	18.0	10.0	6.0	-220	-300	-194	-207	7.5	7.1	7.2	7.4
9	16.4	18.0	10.0	6.5	-160	-230	n/v	-165	7.7	7.7	7.4	n/v
10	16.8	17.5	7.5	6.5	-131	-206	n/v	-160	7.8	7.5	7.5	n/v
A	15.7	17.5	10.0	6.0	-245	-239	-189	-211	7.7	7.3	7.3	7.8
B	15.6	17.5	10.0	6.0	-240	-245	-171	-189	6.3	7.1	7.3	7.5
C	15.7	17.5	9.5	6.0	-272	-342	-215	-192	8.2	7.2	7.6	7.5
D	12.5	20.0	10.0	6.0	n/v	-170	-207	-112	8.6	7.0	7.4	7.6
E	11.9	19.0	9.5	5.0	n/v	-164	-168	-169	7.8	7.4	7.1	8.0
F	12.6	20.0	9.0	6.0	-237	-188	-168	-181	8.1	7.3	7.1	7.6
G	12.2	18.0	9.0	5.0	n/v	-132	-145	-156	8.4	7.4	7.6	7.4

The sediment temperature values recorded during each sample period reflect natural seasonal variations. Differences between stations can be attributed to the time of day that a reading was taken. As expected sediment temperatures were lowest in January and highest in July.

The values recorded for sediment pH ranged between 6.3 and 8.8.

7.3 Sediment Trace Element Analysis

There are currently no Irish or UK guideline standards for metals levels within sediments. The current assessment of estuarine and offshore sediment quality in Ireland is based mainly on data generated from surveys of harbour areas (e.g. as part of dredging applications) conducted since 1988 as well as surveys conducted by the FRC in Ireland and by CEFAS in the UK (Marine Institute, 1999). Relevant standards are however being developed by the Marine Institute which are scheduled for publication in June 2003. The Marine Institute approach uses Provisional Action Guideline Levels developed from guidance given in International legislation and from the experience of EU countries with regard to the disposal of contaminated dredge material.

In the absence of applicable standards the UK recommends the Canadian/US approach which involves the derivation of Threshold Effects Levels (TEL) and Probable Effect Levels (PEL). Table 7.3 summarises interim sediment quality guidelines issued by Environment Canada in 1999 for a range of metals. These guidelines can be used as a first approximation in assessing whether organisms are at risk from sediment concentrations of toxic substances. The Swedish Environmental Protection Agency has also produced assessment criteria to facilitate interpretation of data on pollution of coastal and marine environments and the reference values for levels of several metals in sediments are also included in Table 7.3. The current Dutch target values for general sediment quality and Quality Criteria for the disposal of dredged material have also been presented. The guidelines are provided for comparative purposes only and are not available for all metals tested for during this survey.

Table 7.3. Sediment Quality Guidelines for Metals (values in mg/kg)

	Canadian Guidelines		Dutch		Sweden	
Metal	**TEL**	**PEL**	**Target value[1]**	**Quality criteria[2]**	**Reference value[3]**	**Class 5[4]**
Arsenic	7.24	41.6	29	29	10	> 45
Cadmium	0.7	4.2	0.8	4	0.2	> 3
Chromium	52.3	160	100	120	40	> 70
Copper	18.7	108	36	60	15	> 80
Lead	30.2	112	85	110	25	> 110
Mercury	0.13	0.70	0.3	1.2	0.04	> 1
Nickel	15.9	42.8	35	45	30	> 100
Zinc	124	271	140	365	85	> 350

Notes:

1. Dutch Target value for general sediment quality
2. Dutch Quality criteria for dredged material that may be dispersed in the sea
3. Swedish Reference Value (representative of pristine natural conditions)
4. Class 5 metal concentrations in sediments indicate pollution from a local point source.

TEL Threshold Effects Level (Level below which biological effects are unlikely
PEL Probable Effects Level (Level above which negative biological effects are probable)
nv no value

The results for sediment trace metal analysis are presented in Appendix Thirteen as tables and histograms.

<u>Aluminium</u>

Aluminium levels in sediments ranged from 6340 mg/kg at Station 9 (May 2002) to an elevated level of 181009 mg/kg at Station 8 (July 2002). Levels at the majority of stations were below 20000 mg/kg throughout the year.

<u>Arsenic</u>

Arsenic levels in sediments ranged from < 5 mg/kg to 19.4 mg/kg at Station F in January 2003. Levels were less than the Canadian PEL of 41.6 mg/kg and the Dutch Target Value of 29 mg/kg.

<u>Cadmium</u>

Cadmium levels in sediments were below 0.5 mg/kg at the majority of stations. A high of 1.0 mg/kg was recorded at Station 10 in July 2002. Levels were low and were generally below the Canadian TEL of 0.7 mg/kg and the Dutch Target Value of 0.8 mg/kg.

Chromium

Chromium levels in sediments ranged from a low of 12 mg/kg at Station 3 in July 2002 to a high of 79 mg/kg at Station C in October 2002. Levels were highest at the majority of Stations in October 2002 and January 2003. With the exception of the elevated value at Station C levels were below the Canadian TEL for Chromium of 52.3 mg/kg and were well below the Dutch Target Value for Chromium of 100 mg/kg. The stricter Swedish reference value of 40 mg/kg representative of pristine conditions was met at the majority of stations, but the Swedish Class 5 value of 70 mg/kg may indicate pollution from a point source at Station C in October 2002.

Copper

Copper levels in sediments ranged from a low of 4 mg/kg at Station 3 in July 2002 to a high of 36 mg/kg at Station A in May 2002. Levels were higher at the majority of Stations in October 2002 and January 2003. Levels were well below the Canadian PEL for Copper of 108 mg/kg but did exceed the TEL of 18.7 mg/kg at many Stations. Levels were all below the Dutch Target value of 36 mg/kg. The stricter Swedish reference value of 15 mg/kg may indicate slightly elevated copper levels above pristine natural conditions at many of the sites with the exception of Stations 3 and 4.

Iron

Iron levels in station sediments ranged widely from a low of 222 mg/kg at Station 2 to a high of 41600 mg/kg at Station B. The majority of stations had iron levels of less than 20000 mg/kg.

Lead

Lead levels in station sediments ranged from a low of 10 mg/kg at Station 3 in July 2002 to a high of 78 mg/kg at Station B in October 2002. Levels at all stations were below the Dutch Target Value of 85 mg/kg and the Canadian Probable Effects Level of 112 mg/kg. Levels were however elevated above the Canadian Threshold Effects Level of 30.2 and the Swedish Reference Value of 25 mg/kg representative of pristine natural conditions at many stations at some time during the year. Levels were highest at Stations A, B, 8, A, E and G which are closest to the landfill.

Magnesium

Magnesium levels in sediments ranged from a low of 4370 mg/kg at Station 9 in May 2002 to a high of 17100 at Station E in October 2002. No guidance levels are available for Magnesium in marine sediments.

Manganese

Manganese levels in sediments ranged from a low of 136 mg/kg at Station 3 in July 2002 to a high of 577 mg/kg at Station 10 in October 2003. No guidance levels are available for Manganese in marine sediments.

Mercury

Mercury levels in sediments were all below 0.5 mg/kg with the exception of Station B which had a level of 0.6 mg/kg in October 2002. These are below the Canadian PEL of 0.7 mg/kg but the levels do suggest elevations above natural conditions (0.04 mg/kg Swedish Reference Value).

Nickel

Nickel levels in sediments ranged from a low of 4 mg/kg at Station 3 in July 2003 to a high of 41 mg/kg at Station 10 in July 2002. Nickel levels were elevated above the Canadian TEL of 15.9 mg/kg at all stations. Levels were also higher than the Swedish Reference Value of 25 mg/kg at most stations in October 2002 and January 2003.

Zinc

Zinc levels in sediments ranged from a low of 25 mg/kg at Station 3 in July 2002 to a high of 144 mg/kg at Station G in January 2003. Levels at all stations were below the Canadian PEL of 271 mg/kg. Levels were elevated above the Canadian TEL of 124 mg/kg at Stations A, B, E, F and G. The Swedish Reference Value of 85 mg/kg for pristine natural conditions would indicate that zinc concentrations are elevated in the estuary with the exception of the south and eastern part of the outer estuary.

8.0 WATER ANALYSIS

The quality of Ireland's tidal waters is determined by the quality of the waters of the North East Atlantic and the degree to which this is altered locally by inputs of organic matter, nutrients and other materials from the land and from the atmosphere (EPA report, Water Quality in Ireland 1998-2000). The quality of estuarine and coastal waters is monitored by a number of government and regulatory agencies, including EPA, coastal local authorities, the Marine Institute's Fisheries Research Centre (FRC) and various arms of the Department of the Marine and Natural Resources. A number of EC Directives have driven monitoring requirements and the implementation of mandatory and guideline water quality standards. Prior to the mid 1990s, water quality surveys of estuarine and coastal areas in Ireland concentrated on the effects of discharges from municipal, industrial and agricultural sources particularly in relation to oxygen availability for fish populations as well as for aesthetic acceptability to the public. Recently the problem of eutrophication, first identified in inland waters has also become an important consideration for estuarine and coastal areas. Effects include the increased frequency and duration of blooms of algae, oxygen depletion and alteration of the natural faunal and floral communities both in the water column and on the seabed.

The Environmental Protection Agency has produced a discussion document which outlines proposed Environmental Quality Standards (EQS) for adoption for the Irish aquatic environment. Table 8.1 outlines the proposed EQSs for those parameters analysed in this survey. The EQSs which the UK has set have also been included for comparison. The Water Quality (Dangerous Substances) Regulations, 2001 specifies stricter standards for a number of parameters and these limits have also been outlined.

A number of water quality guidelines have also been produced as an aid to the assessment of nutrient levels and organic enrichment. They do not constitute water quality standards. The parameters used have been broadly broken down into three categories, representing (L) low (M) moderate and (H) high concentrations. The classification scheme is summarised in Table 8.2.

Table 8.1 Guidance Standards for Trace Metals in Seawater

Parameter	EPA Standard[1]	UK Standard[2]	Dangerous Substances Mean Annual Standard[3]
Aluminium	200 ug/l	nv	nv
Arsenic	nv	25	20
Cadmium	5 ug/l	5	nv
Chromium	nv	15	15
Copper	nv	5	5
Iron	1000 ug/l	1000	nv
Lead	nv	25	5
Manganese	300 ug/l	nv	nv
Mercury	0.1 ug/l	0.5	nv
Nickel	nv	30	25
Zinc	nv	40	40

Notes

1. Environmental Protection Agency Proposed National EQS Values
2. UK Water quality standards for the protection of saltwater life for List I and List II substances
3. Water Quality (Dangerous Substances) Regulations, 2001 standards for tidal waters

nv No value

Table 8.2 Water quality indices applied to Irish estuarine and coastal areas

Parameter	Units	(L)	(M)	(H)
BOD	mg/l	<3.0	3.0-5.0	>5.0
Oxidised Nitrogen 0-20 psu	mg N/l	<1.0	1.0-3.0	>3.0
Oxidised Nitrogen > 20 psu	mg N/l	<0.2	0.2-1.0	>1.0
Ortho-Phosphorus	mg P/l	<0.05	0.05-0.15	>0.15
Total Ammonia	mg N/l	<0.2	0.2-1.0	>1.0
Dissolved Oxygen	% Sat	<70	70-110	>110

8.1 Porewater Analyses

The results of the porewater analysis are presented in Appendix Fourteen as tables and histograms. The values are discussed below and an assessment made where possible against the guidance values outlined in Tables 8.1 and 8.2. It must be stressed that levels of metals and other parameters in sediment porewater would be expected to be much higher than levels in the water column due to the direct association of the interstital water with the sediment particles. The guidance values are therefore only used as a means for comparison to the levels which are available for estuarine or tidal waters and do not necessarily indicate elevation beyond acceptable levels of the parameters in the porewater.

Aluminium

The EPA proposes a guideline limit of 200 ug/l for aluminium in all waters. Aluminium levels in station sediment porewater were higher than 200 ug/l on four occasions with a highest value of 461 ug/l recorded at Station B in May 2002.

Arsenic

Arsenic levels in sediment porewater ranged from a low of 26 ug/l at Station 3 in January 2003 to a high of 145 ug/l at Station 10 in October 2003. These levels are elevated above the Dangerous Substances Standard for tidal waters of 20 ug/l.

Cadmium

Cadmium levels in sediment porewater were all below 30 ug/l. The EPA proposed standard for coastal, estuarine and marine waters is 5 ug/l.

Chromium

Chromium levels in sediment porewater were all below 50 ug/l. The Dangerous Substances Standard for tidal waters of 15 ug/l was below the analytical limit of detection.

Copper

Copper levels in sediment porewater were all below the analytical limit of detection (< 30ug/l or <50ug/l).

Iron

Iron levels in sediment porewater ranged from a low of <0.05 mg/l to a high of 13.3 mg/l at Station 4 in July 2002. Levels were generally elevated above the EPA proposed standard for all waters of 1.0 mg/l.

Lead

Lead levels in sediment porewater were all below 200 ug/l (analytical limit of detection).

Magnesium

Magnesium levels in sediment porewater ranged from a low of 252 mg/l at Station B in May 2002 to a high of 1363 mg/l at Station 3 in May 2002.

Manganese

Manganese levels in sediment porewater ranged from a low of < 0.03 mg/l to a high of 9.0 mg/l at Station 9 in October 2002. Levels were elevated at all stations above the EPA proposed standard of 0.3 mg/l for all waters.

Mercury

Mercury levels in sediment porewater were all below the EPA proposed standard for coastal, estuarine and marine waters of 0.1 ug/l in May, July and October 2002. Levels were however elevated at all stations in January 2003 with the highest value of 0.7 ug/l recorded at Station 8.

Nickel

Nickel levels in sediment porewater were all below 100 ug/l (Analytical limit of detection).

Tin

Tin levels in sediment porewater were all below <30 ug/l.

Zinc

Zinc levels in sediment porewater were generally below the 40 ug/l Dangerous Substances limit. The highest value of 80 ug/l was recorded at Station 4 in July 2002. High values (>40ug/l) were recorded at Stations D, E, 4 and 8 in July 2002 and Stations D and 8 in October.

Total Ammonia

Total ammonia levels in sediment porewater were generally high (>1 mg/l) with a peak level recorded of 228 mg/l at Station E in January 2003.

Nitrite

Nitrite levels in sediment porewater were high and ranged from <2 to <10mg/l. The majority of nitrite in saline waters is formed from the oxidation of ammonia. Nitrite is in turn relatively unstable and easily combines with oxygen to form nitrate.

Nitrate

Nitrate levels in sediment porewater ranged from <2.5 mg/l to a high value of 38 mg/l at Station F in October 2002.

Phosphate

Phosphate levels in station sediment porewater were all below 5 mg/l.

Total Petroleum Hydrocarbons

Total Petroleum Hydrocarbon levels ranged from <0.1 mg/l to a high of 3.5 mg/l at Station F in October 2002.

Biochemical Oxygen Demand

BOD varied widely in sediment porewater. Values ranged from 2 mg/l up to elevated values. The highest BOD recorded was at Station 8 (1265 mg/l) in October 2002. No guidance levels are available for the assessment of BOD in porewater.

pH

pH values for station sediment porewater were generally within the accepted marine range (7-8).

Coliforms

The levels of faecal coliforms and total coliforms in sediment porewater varied widely between stations. Faecal coliforms were found at high levels in January 2003 at Station 8, 4, D, E and F. A faecal coliform count of 8000 /100 ml was recorded at Station D. Total coliforms counts of 10000/100ml were found at Stations B, C and D in May 2002 and elevated values of 100,000/100ml were found at Stations D and E in January 2003. The levels demonstrate sewage impact to the estuary especially in the area directly north-east of the landfill and in the transition zone between the inner and outer estuary. The EPA proposed levels for coliforms in seawater are taken from the Bathing Water Regulations. The national limits for faecal coliforms are 1000/100ml and total coliforms 5000/100ml.

8.2 Surface Water Analyses

The results of the surface water analysis are presented in Appendix Fifteen as tables and histograms. The results are discussed below.

Temperature

The temperature of surface water within the estuary is a function of solar heating as well as mixing of fresh and seawater. Temperatures ranged in value according to sampling season with the lowest temperatures (4.8 – 7.2℃) recorded in January and the highest (15.8 – 18.5℃) in July.

Colour

The appearance of surface water samples ranged widely depending upon the weather conditions and the timing of sampling with respect to low water. Apparent colour was more pronounced at some stations, especially if bottom sediment had been disturbed. Apparent colour values reflected this with levels ranging from 19 - >1000 pt co units.

Salinity

Salinity ranged from 3.06 – 33.6 parts per thousand and was influenced by the state of the tide and freshwater inputs to the estuary. Freshwater influence was detected at nearly all stations. Almost fully marine conditions were detected at Stations G and F in July and January indicating the incursion of seawater deep within the inner estuary during spring tide conditions.

Oxygen

The only legislative standards pertaining to dissolved oxygen in saline waters relate to areas designated under the EC Shellfish Directive as implemented in Ireland through the Quality of Shellfish Waters Regulations (1994) and as amended (2001). These stipulate that shellfish waters must have an average dissolved oxygen saturation of not less than 70%. Surface water oxygen levels ranged from 77.3% – 151.0% indicating high levels of oxygen in the estuary.

pH

The values recorded for pH in surface water ranged from 8.0 – 8.6. The EPA proposed range for pH in coastal, estuarine and marine waters is 6 –9.

Biochemical Oxygen Demand

Biochemical Oxygen Demand values ranged from <2 mg/l to <5 mg/l at the majority of stations representing low to moderate levels. The EPA proposed guidance value for coastal, estuarine and marine waters is < 4 mg/l O_2. Elevated values were recorded at Station C (7 mg/l) in January and Station 4 (10 mg/l) in July 2002.

Suspended Solids

Suspended solids levels ranged from 4 mg/l at Station 9 in July to 595 mg/l at Station 3 in May. Suspended solid levels were generally high and may be attributed to sediment disturbance in shallow water tidal conditions.

Total Ammonia

In the un-ionised state, ammonia is toxic to fish but there are no environmental quality standards for saline waters. Ammonia concentrations ranged from < 0.08 mg/l to a one off peak of 40 mg/l. Only four values exceeded the moderate standard of <1.0 mg/l.

9.0 POLLUTION INDICES

9.1 Pollution Load Index

The Pollution Load Index was designed by the Irish Estuarine Research Programme (IERP) in 1981 as a method for the evaluation of estuarine quality. The index is based primarily on pollutant concentrations in mid-tidal estuarine sediment.

The index has a number of functions:

a) To relate pollutant values to a baseline
b) To interpret pollutant analysis in terms of biological effect
c) To combine measured values for different pollutants
d) To permit the integration of pollutant patterns for several sites in the same estuary
e) To facilitate inter-comparison between estuaries of different type and differing pollutant pattern
f) To readily permit the incorporation of additional pollutants as circumstances require.

The index is both scaled and weighted. Scaling is necessary to bring analytical values to a common numerical value in view of the differing concentration ranges over which pollutants must be evaluated. Weighting is required to interpret the observed value in terms of the unpolluted estuary and unacceptable pollutant values.

Two indexing points are used, a baseline and a threshold. The concept of baseline is that of the natural unpolluted estuary and corresponds with other authors views of the 'pre-industrial' situation for sediments. The threshold is the pollutant concentration beyond which deleterious environmental change is observable (Table 9.1).

Between these two points a logarithmic scale is constructed, defining the base-line as 10 and threshold value as unity. A PLI of 10 therefore indicates a site with natural unpolluted conditions while PLI values approaching zero indicated degraded sites (IERP, 1985).

At least 10 pollutants should be analysed and included in PLI construction. Six of these are mandatory and include:

- Organic Content (Loss on ignition)
- Total Nitrogen (N)
- Total Phosphorus (P)
- Cadmium (Cd)
- Chromium (Cr)
- Zinc (Zn)

Also included to allow comparison with O'Brien *et al*., (1997) were:

- Lead (Pb)
- Manganese (Mn)
- Iron (Fe)
- Copper (Cu)

Separate index scores, Pollution Load (PL), are made for each pollutant (P) using the following formula and Threshold Baseline data (Table 9.1).

$$PL = ALOG_{10}\ 1 - \left(\frac{\text{Conc P - BL}}{\text{T - BL}} \right)$$

Where $ALOG_{10}$ = Antilogarithim to base 10
Conc P = Concentration of pollutant
BL = Baseline (extracted from Table 9.1)
T = Threshold (extracted from Table 9.1)

The Pollution Load Index (PLI) for the site is calculated by combining the PL scores for the site by using the following calculation where n = the number of pollutants.

$$\text{PLI site} = \sqrt[n]{\text{PL1 x PL2 x PL3 x PL4 x PL5 x....PLn}}$$

Table 9.1 Threshold and Baseline values for estuarine pollutants (IERP, 1985)

Pollutant	Threshold	Baseline
Loss on Ignition	7.5	1
Total N	2500	400
Total P	500	150
Cd	1.5	0.5
Cu	50	5
Cr	50	5
Fe	2.0	0.2
Pb	100	10
Zn	100	20
Mn	500	150
Al	0.5	0.1

The pollution loads calculated for each of the ten pollutants using year-averaged data for each sample station are presented in Table 9.2

Table 9.2 Pollution Loads calculated for each pollutant at each station. (Station PLI right hand column)

STATION	Cd	Cr	Cu	Fe	Pb	Mn	LOI	N	P	Zn	PLI
A	10	2.05	3.08	0.48	4.3	2.68	0.87	4.27	0.74	1.00	1.90
B	10	1.85	3.59	0.34	3.08	2.07	0.78	1.74	0.66	0.73	1.57
C	10	2.15	5.7	1.37	6.15	3.88	0.68	5.08	0.88	1.78	2.71
D	10	2.15	5.41	1.12	6.3	3.47	1.33	4.95	0.52	2.18	2.70
E	10	2.27	3.78	0.43	5.14	1.67	0.18	2.96	0.11	1.09	1.35
F	10	2.93	4.64	0.93	5.55	3.08	0.57	3.51	0.47	1.29	2.20
G	7.94	2.05	3.24	0.34	4.52	2.87	0.18	2.61	0.18	0.74	1.30
2	10	3.59	6.99	2.15	7.17	3.61	2.03	3.47	0.95	2.90	3.49
3	10	4.41	7.74	3.33	7.94	4.91	2.1	5.95	1.75	4.47	4.61
4	10	4.19	7.74	3.20	7.55	5.83	1.83	6.69	1.28	3.65	4.38
5	10	3.41	5.99	2.61	6.99	4.34	1.96	6.83	0.68	2.90	3.66
8	10	2.78	3.59	1.17	4.64	3.61	0.78	3.09	0.88	1.19	2.34
9	10	3.59	5.99	3.37	6.99	4.54	5.1	3.78	0.69	2.51	3.88
10	7.94	2.93	3.98	1.58	6.99	1.49	2.18	8.32	0.38	2.66	2.78

The pollution loads of each pollutant were then used to calculate the pollution load index for each station (Table 9.2, right-hand column). From the indices of each station it was then possible to calculate the pollution load index for the estuary as a whole (IERP, 1985).

The lowest values (<2) were found at Stations E and G which are located adjacent to the landfill in the inner estuary and at Stations A and B which are located north-east of the landfill close to the sewage outfall. All values are however low indicating a wider pollution effect within the estuary. The estuary has a PLI value of 2.58 which is less than that

calculated by O'Brien *et al*., 1997 (3.56). which indicates a slight deterioration in estuarine quality over the last five years.

10.0 DISCUSSION

10.1 Fauna

Benthic Analysis

Recent studies of Rogerstown Estuary include those carried out by Kirk McClure Morton (1992) and O'Brien *et al* (1997). Stations 2, 3, 4, 5, 8, 9 and 10 in this monitoring survey were located in the same locations as those surveyed by O'Brien *et al* (1997). Stations 2, 3, 5 and 10 had also previously been studied by Kirk McClure Morton (1992).

O'Brien et al (1997) identified low species richness at most stations with the highest numbers recorded at Stations 2, 3, 9 and 10. Faunal density was low with the exception of those stations located in saltmarsh or those rich in oligochaete worms. A decrease in richness was noted at some stations since 1992. Recommendations were made for further study in the inner estuary and in the area north-east of the landfill, due to unusually low species numbers and elevated metals levels at Station 8.

The results of this study continue to indicate stressed sediment communities at the majority of stations. Species richness and diversity was generally low throughout the estuary with benthic communities typical of those influenced by variable or reduced salinity conditions. Sediments were dominated by one or two small opportunistic pollution tolerant species which is usually indicative of organically or nutrient enriched sediments.

Stations E and C were the most impoverished with very low numbers of species and individuals. Abundance/biomass comparison also suggests that pollution impact is high at Station B located adjacent to the sewage outfall which runs parallel to the railway line. There was visual evidence of sewage contamination in the water between Stations B and C (Plate 12) which would suggest that the sewage outfall is a major contributor to organic enrichment in the area east of the landfill. The identification of large numbers of faecal coliforms in sediment porewater in the inner estuary at Stations D and E would also suggest that sewage effluent is a source of organic enrichment in the transition zone between the inner and the outer estuary.

Station G has a low number of species and may be influenced by low salinity conditions. However, high numbers of ragworm and a more even distribution of individuals amongst species would indicate that it may be less impacted in terms of pollution effect.

Station 2,3, 9 and 10 located in the eastern part of the outer estuary had the highest number of species. Stations in this part of the outer estuary had firmer, sandier sediments.

Stations 8, A and B were dominated by oligochaetes and the pollution tolerant opportunistic polychaete *Capitella* sp. indicating impacted sediments north-east of the landfill in the outer estuary. Station B had particularly soft *Thixotrophic* (fluid) sediments.

Stations D, 4, 5 and F were dominated by oligochaetes and the polychaete *Manayunkia aesturina* which has a limited salinity range tolerance.

There is probably a transition between the identified benthic communities in the estuary depending upon the influence of natural environmental variables such as salinity regime and percentage silt/clay fraction as well as the level of organic enrichment.

Organic enrichment of sediments can initially stimulate the production of benthic invertebrate communities, which while different in composition from pre-enrichment conditions, can provide significant food supplies for fish and birds. It has even been suggested that some of the bird populations of European marine sites in estuaries are actually sustained by benthic invertebrate production resulting from anthropogenic sources of organic carbon, such as sewage (e.g. Pearce 1998).

However, whilst moderate enrichment provides food for benthic species and increases abundance and diversity there is a risk that with greater enrichment diversity will decline and communities will become increasingly dominated by only a few small opportunistic species as highlighted at many of the stations in this survey. This will result in a decrease in the variety of fish and bird predators.

It is even possible that continued inputs of high levels organic matter and nutritents to the estuary could eventually impair the functioning of the benthic ecosystem to the point that it could become abiotic in more stressed areas.

The relocation of the outfall within the outer estuary as part of the implementation of the Lusk/Rush Sewerage Scheme should significantly reduce nutrient and organic loadings to the estuary. Although, it is probable that a significant source of nutrient enrichment within Rogerstown Estuary will continue to be from agricultural run-off. Nutrient enrichment and increasing levels of nitrogen in the water will result in increased coverage and density of green macroalgal species.

The benthic survey indicates low diversity in sediments probably as a result of enrichment. However, the numbers of opportunistic species was high and there would still appear to be a continuing food source for feeding birds.

It is also important to note that many of the stations were located in mud in the periphery of the estuary which may be more susceptible to the effects of organic enrichment and nutrient run-off from adjacent agricultural land and therefore may be more impacted than harder to sample sediments further out into the estuary where most of the feeding birds were concentrated.

Trace Element Analysis of Cockle Tissue

Analysis of cockle tissue indicates elevated levels above guidance for a number of metals including arsenic, lead and nickel at Stations 3 and A and manganese at Station A. More investigation is necessary to confirm whether the levels of these metals in cockle tissue are significant. It is recommended that the blue mussel *Mytilus edulis* is also sampled as shellfish species accumulate metals in different amounts. More information is also available for metal contamination levels in the mussel and it may therefore be a better indicator organism for the assessment of pollution in the estuary.

10.2 Vegetation

Green algae

Any nutrient stimulation of marine areas may be regarded as hypernutrification which, if not controlled, produces symptoms of eutrophication, defined as the adverse effects of organic enrichment (Scott et al, 1997). Such a symptom on intertidal sand and mudflats is an increased coverage by opportunistic green macroalgae, such as *Enteromorpha* sp. which will create anoxic conditions in the sediment below the mats, reduce the diversity of infauna and interfere with bird feeding (Simpson, 1997). The abundance of green algae was highest in the outer estuary, in the area northeast of the landfill adjacent to the railway embankment and along the north shore (Plates 5 & 7). Extensive algal mats of *Ulva* sp. were identified at Stations 8, A and B during the October 2002 visit and indicate that there is evidence of eutrophication in this part of the estuary.

Trace Element Analysis of *Fucus vesiculosus*

The results of the trace element analysis of *Fucus vesiculosus* may indicate possible metal contamination in the estuary. Levels of arsenic, chromium, copper, lead, nickel and zinc were all elevated above strict Swedish Reference Values for pristine natural conditions.

However, further investigation and research on levels in *Fucus vesiculosus* in other areas on the east coast of Ireland is necessary to determine whether the identified levels for this survey are an accurate indicator of contamination in the wider estuarine environment.

Habitat Survey

The habitats identified within the area of Rogerstown Estuary SAC covered by this Phase 1 vegetation survey are (in order of percentage cover): -

Intertidal flats
Saltmarsh
Semi-improved grassland
Strandline vegetation
Amenity grassland
Bare ground
Scrub
Unimproved grassland.

Surrounding land-use includes a landfill site, a golf course, arable crop production and livestock farming.

From this survey, there does not appear to be any significant changes in the distribution of these habitats within the area of the SAC studied, since it was mapped by the Department of Environment, Heritage and Local Government in 1998. It must be stressed, however, that variations in species composition of these habitats cannot be detected without undertaking quantitative vegetation studies.

10.3 Metal Analysis of Sediments

Analysis of metal concentrations in sediment indicated elevated values above guideline levels at a number of stations. Chromium was elevated at Station C in October 2002. Copper may be slightly elevated throughout the estuary but only when compared to the stricter guideline levels for pristine conditions applied by Sweden. Values for copper were highest at Stations A, B, E and G. Lead was slightly elevated at Stations A, B, E, F, G and 8 but again only against Swedish values. Nickel was elevated throughout the estuary with the highest values at Stations A, B, E and G. Lower nickel values were recorded in the south and eastern part of the outer estuary. Zinc was elevated at Stations A, B, E, F and G again with the possible exception of the south and eastern part of the outer estuary. The highest

levels for iron and magnesium were recorded at Stations B, E and G. Isolated elevated values were recorded for mercury at Station B and tin at Station E.

The results of the present survey appear to indicate a trend for higher concentrations of metals in sediments to the northeast of the landfill (Stations A, B and 8) and in parts of the inner estuary (E, F and G). However levels do fluctuate over the year and do not necessarily remain persistently high at individual stations. Metal contamination of sediment is generally lower in the south and eastern part of the outer estuary (Stations 2, 3 and 4).

Comparison with the O'Brien *et al.,* 1997 data for six metals at Stations 2, 3, 4, 5, 8, 9 and 10 (Table 10.1) indicates a significant decrease in the elevated concentrations of copper, lead and zinc found at Station 8 in 1997 (the reason for these elevated values could not be explained). Copper levels have increased at Stations 5 and 10. Lead levels have increased at all Stations except Station 8. Zinc Levels have increased at Stations 5, 9 and 10. Chromium levels have decreased at all Stations except Station 10. Manganese levels have increased at Stations 2, 5, 8 and 10. Iron levels have increased at Stations 2 and 10.

Table 10.1 Metal concentrations at comparable stations surveyed by O'Brien *et al*., (1997) and for present survey as year averaged data

Station	Cu		Pb		Zn		Cr		Mn		Fe	
	2003	1997	2003	1997	2003	1997	2003	1997	2003	1992	2003	1997
2	12	17	23	15	63	64	25	36	305	234	1.40	0.89
3	10	16	19	12	48	55	21	33	258	262	1.06	1.83
4	10	16	21	17	55	65	22	37	232	272	1.09	1.70
5	15	13	24	15	63	49	26	30	277	190	1.25	1.30
8	25	78	40	60	94	160	30	42	305	293	1.88	1.90
9	15	17	24	19	68	63	25	31	270	279	1.05	1.35
10	23	12	24	14	66	47	29	22	439	215	1.64	1.10

When calculated as an average for the whole estuary (including additional stations A-G) metal concentrations in sediments appear to have increased since 1997 (Table 10.2).

Table 10.2 Average metal concentrations for the estuary for present survey and O'Brien *et al* survey (1997)

	2003	1997
Chromium	36	32
Copper	28	22
Iron	2.58	1.44
Lead	43	20
Manganese	350	248
Zinc	100	70

This increase in sediment metal concentrations is also reflected by the low Pollution Load Index for the estuary of 2.58 which is slightly less than that calculated by O'Brien *et al*., 1997 and would indicate a deterioration in estuarine sediment quality. The identification of higher metal concentrations in sediments adjacent to the landfill in the inner estuary and northeast of the landfill in the outer estuary may indicate that leachate from the landfill continues to be a source of metal contamination in the estuary.

10.4 Water

<u>Porewater</u>

The results of the porewater analysis were interpreted against guideline standards for tidal waters. However, it is probable that the levels of analysed parameters in sediment porewater would naturally be much higher than those in the surrounding water column.

Analysis of metal concentrations indicated possible elevated values at some stations. Arsenic levels were higher than the Dangerous Substances Standard for tidal waters at all stations. Aluminium levels were elevated on four occasions with the highest values recorded at Station B. Iron levels may have been elevated at some stations. Magnesium levels varied widely with no obvious trend.

Total ammonia, nitrite, nitrate and phosphate levels in porewater were generally high when compared to water quality indices applied to Irish estuarine and coastal areas. However, concentrations in the porewater might be naturally higher than in the surrounding water column. It is therefore difficult to ascertain if the levels would lead to eutrophication in the estuary. Biochemical Oxygen Demand was high at many stations with the highest value recorded at Station 8. However, no guidance can be found on natural BOD levels in the porewater.

High faecal and total coliform counts at Stations D and E indicate sewage impact in the estuary probably from Lusk/Rush sewage outfall.

<u>Surface Water</u>

Surface water results for oxygen and pH are representative of clean estuarine waters. Freshwater influence was detected throughout the estuary and was less pronounced at high water with the incursion of high salinity water noted deep within the inner estuary. Suspended solids levels were high however this is not unusual in a shallow estuary with silty sediments. Ammonia concentrations were generally below the moderate standard for

coastal waters. There is however not enough information to identify eutrophication effect and it is recommended that future surveys monitor nutrients in surface water.

11.0 CONCLUSIONS

Rogerstown Estuary is shallow with a strong tidal flow and variable salinity regime. The main intertidal habitats in the estuary are soft mud shores, upper shore mixed substrata and saltmarsh.

Species richness and diversity in intertidal sediments is generally low throughout the estuary with benthic communities dominated by small opportunistic pollution-tolerant species indicative of organically enriched sediments.

It would appear that benthic species richness has not improved in the estuary in recent years. Sediments at Stations B, C and E were amongst the most impoverished indicating that the area in the transition zone between the inner and the outer estuary and the area northeast of the landfill is still impacted the most.

High faecal and total coliform counts at Stations D and E and visual observations of sewage contamination at Stations B and C indicate that the Lusk/Rush Sewage outfall is a primary source of organic enrichment especially in the transition zone between the inner and the outer estuary and in sediments adjacent to the railway line in the outer estuary.

The presence of high numbers of opportunistic species such as oligochaetes and small polychaete worms indicates that the sediments are still a valuable food source for feeding birds. However, benthic diversity in sediments was very low and continued enrichment may cause some areas of the estuary, especially those subject to green algal growth to become abiotic.

Green algal growth on mudflat was significant in the area to the northeast of the landfill in the outer estuary and may indicate eutrophication in this part of the estuary.

Levels of arsenic, lead, nickel and manganese are elevated in cockle tissue at Station A.

Analysis of *Fucus vesiculosus* indicates possible metal contamination in the estuary but more research on background levels is necessary to confirm this.

The habitat survey indicates that there does not appear to be any significant changes in the distribution of habitats within the estuary since it was mapped by Dúchas in 1998.

Metal concentrations in sediments are generally higher than those recorded for the estuary by O'Brien *et al*., 1997. Concentrations appear highest in the area to the northeast of the landfill (Stations A, B and 8) and in parts of the inner estuary (Stations E, F and G). Pollution Load Indices for the estuary appear to confirm this.

Metal and nutrient concentrations in porewater are elevated at some stations, however the absence of appropriate guidance values specifically for porewater makes assessment difficult. The data from this survey will provide however provide baseline data for comparison in future surveys.

Results for parameters measured in surface water are indicative of 'clean estuarine water'. However, further nutrients and chlorophyll monitoring is required to assess eutrophication.

12.0 RECOMMENDATIONS

It is recommended that quantitative sampling of intertidal sediment species using cores is employed as the technique for the future analysis of benthic communities. In order to account for variability in density and aggregation of species at a site it is essential that replicate samples are taken. Five replicate samples should be taken to a depth of 15 cm using a $0.01m^2$ corer. A 1 m area should also be marked out using a quadrat within an undisturbed section of the site and a record taken of any obvious mounds and casts and algal cover. Samples should continue to be taken for particle size analysis and total organic carbon.

Consideration should be given to the reduction in the number of sampling stations surveyed in the estuary. Stations 4, 5 10 and A could be removed from the monitoring programme with no significant loss of information.

It is recommended that monitoring of the estuary continues at a twice yearly (Summer and Winter).

Consideration should be given to the discontinuation of handnet sweeps as this technique appears to yield little useful information on the pelagic element in the estuary.

The requirement for a repeat vegetation survey of the major habitats in the estuary should be amended following discussions with the EPA. It is recommended that the boundaries of the survey area are clearly defined and that targeted, quantitative vegetation studies are undertaken over a timeframe to be agreed with the EPA.

It is recommended that *Mytilus edulis* is chosen as the indicator species for contamination in faunal tissue as more information is available for metal contamination in this species.

In relation to surface water monitoring the following additional parameters should be included for comparison with monitoring techniques employed by EPA to identify the trophic status of estuaries:

Salinity; Temperature; pH; Dissolved Oxyen % Saturation; 5-day Biochemical Oxygen Demand; Total Oxidised Nitrogen, TON (mg/l N); Total Ammonia Nitrogen, NH3/NH4 (mg/l N); Un-ionised NH3 mg/l N; Dissolved Inorganic Nitrogen, DIN (mg/l N); Molybdate Reactive Phosphate, MRP (µg/l P); DIN:DIP Ratio; Chorophyll in summer (µg/l).

REFERENCES

Connor, D.W., Brazier, D.P., Hill, T.O., and Northern, K.O. 1997. Marine Nature Conservation Review: marine biotope classification for Britain and Ireland. Volume 1. Littoral biotopes. Version 97.06

Curtis, T.G.F. and McGough, H.N. (1988). *The Irish Red Data Book, 1 Vascular Plants*. The Stationery Office, Dublin.

Department of Environment, Heritage and Local Government (2000). *Draft Conservation Plan for Rogerstown Estuary cSAC and SPA.*

EPA Report, Water Quality in Ireland 1998-2000.

Flora (Protection) Order, SI No. 94 (1999). The Office of Public Works, Dublin.

Joint Nature Conservation Committee (1990). *Handbook for Phase 1 habitat survey. A technique for environmental audit*. England Field Unit, Nature Conservancy Council.

Fahy, E., Goodwillie, R., Rochford, J., and Kelly D., 1975. Eutrophication of a Partially Enclosed Estuarine Mudflat. Marine Pollution Bulletin. Vol 6, No. 2: 29-31.

Kirk McClure Morton, 1992. Environmental Survey of Rogerstown Estuary. Vol 2: Baseline Survey and Environmental Statement. Report issued to Dublin County Council.

Irish Estuarine Research Programme, 1985. A manual for the Evaluation of Estuarine Quality. Environmental Sciences Unit, TCD.

Marine Institute, 1999.

O'Brien, J., and O'Neill, M., 1997. A Biological Survey of Rogerstown Estuary. Vol 4: Environmental Impact Statement for Balleally Landfill and Rush/Lusk Wastewater Treatment Plant

Ordnance Survey of Ireland (2002). Record Place Map, Plot Ref. No. 204312_1.

OSPAR (MON, 1998)

Pearce 1998.

Rodwell in prep., National Vegetation Classification.

Stace, C., (1997). *New Flora of the British Isles*. Second edition. Cambridge University Press.

APPENDIX ONE

Station Positions

APPENDIX TWO

Laboratory Methodologies for Sediment, Porewater & Surface Water Analysis

APPENDIX THREE

Macrofauna Abundance Data

APPENDIX FOUR

Diversity Indices

APPENDIX FIVE

Similarity Percentage Analysis (SIMPER) Results

APPENDIX SIX

Ten Dominant Macrofaunal Species at each Station

APPENDIX SEVEN

Species Abundance Data for Hand-Net Sweeps

APPENDIX EIGHT

Trace Metals Analysis Results in *Cerastoderma edule*

APPENDIX NINE

Vegetation Survey Target Notes

APPENDIX TEN

Vegetation Survey Species Lists

APPENDIX ELEVEN

Trace Metal Analysis Results in *Fucus vesiculosus*

APPENDIX TWELVE

Particle Size Analysis Results

APPENDIX THIRTEEN

Sediment Trace Metal Analysis Results

APPENDIX FOURTEEN

Porewater Analysis Results

APPENDIX FIFTEEN

Surface Water Analysis Results