Project 324

Development of Biological Components for Estuary and Coastal Waters Classification Schemes

Project Definition Study

WRc plc

R&D Note 61

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In 1990 a Sub-group of the NRA Water Quality Survey Group proposed new classification schemes based on objective water quality, aesthetic and biological criteria to provide an absolute comparison of estuarine and coastal water quality.

The report summarises the options and research needs for the development of the biological components of the schemes. The report should be read in conjunction with other R & D outputs dealing with the feasibility of other components of the scheme.

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Development of Biological Components for Estuary and Coastal Waters Classification Schemes - Project Definition Study

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EXECUTIVE SUMMARY

The Water Act 1989 requires that all controlled waters may be subject to a system of classification. In 1990 a Subgroup of the NRA Water Quality Survey Group proposed new classification schemes based on objective water quality, aesthetic and biological criteria to provide an absolute comparison of estuarine and coastal water quality. These proposals have now been incorporated in a consultation paper published by the NRA concerning Statutory Water Quality Objectives. This R&D Note defines the options and research needs for the development of the biological components of the classification schemes. It is a requirement that classification schemes should be developed by winter 1993 and implemented by winter 1994. A phased approach is, therefore, recommended for the development of classification schemes, the immediate aim being the development of an interim scheme to meet the implementation target date.

The biological component of the classification schemes is to be based on the subtidal macrobenthos associated with consolidated sediment. A range of methods exist for assessing the pollution status of marine and estuarine benthic communities but it is unclear which would be most suitable and robust, a priori, for use in a saline waters classification scheme. However, two options have been short-listed for further assessment of their suitability for development of a preliminary classification scheme.

A number of existing estuarine and coastal waters data sets were identified which potentially could be used in the development of an interim scheme. There would also be a need for additional data collection which would include supportive physico-chemical measurements as well as sampling for the macrobenthos. Appropriate Analytical Quality Control and Quality Assurance procedures for both chemical and biological determinands would have to be adopted and established before any data collection was undertaken.

The estimated cost to the NRA of collecting the additional data would be in the order of £108K a year for the coastal scheme and £111K a year for the estuarine, depending on the sampling regime adopted. There would be additional costs involved with the management of the project and with the development of the model, amounting to approximately £300K over three years. Over the longer term it might be desirable (or necessary) to develop a RIVPACS equivalent model for use in saline waters. In which case the required database would be much more extensive and the model would take many years to develop.

KEYWORDS:

Estuaries, coastal waters, classification, statutory water quality objectives, macrobenthos, predictive model

1. INTRODUCTION

The Water Act 1989 requires, in Sections 104 and 105, that all controlled waters may be subject to a system of classification and that Water Quality Objectives may be set in relation to such waters by the Secretary of State.

To ensure that achievement of a Water Quality Objective gives an unequivocal indication of satisfactory water quality the NRA Water Quality Survey Group has proposed that each of the following criteria are satisfied:

- achievement of relevant use-related EQO (by compliance with relevant EQSs);
- achievement of target class of relevant classification scheme;
- compliance with relevant EC Directives.

These proposals were independently assessed and endorsed (Owens 1991), and have now been incorporated in a consultation paper published by the NRA (1991b) in which the issues concerning Statutory Water Quality Objectives are fully discussed.

The present NWC classification scheme for estuaries is insensitive, essentially subjective and considered by the NRA Water Quality Survey Group to be of little value for water quality management or for statutory purposes. The NWC scheme was not applied to coastal waters.

In 1990 a Subgroup of the NRA Water Quality Survey Group proposed new classification schemes based on objective water quality, aesthetic and biological criteria to provide an absolute comparison of estuarine and coastal water quality. More recently (NRA 1991b) it has been proposed that a new General Classification Scheme should include a biological component based on the extent to which a macroinvertebrate community of the watercourse falls short of what would be expected in a 'clean', or unpolluted system. At present, workable systems for applying ecological classification schemes and standards are only available for invertebrate communities in rivers. There is a need for research into developing suitable schemes for other categories of controlled waters.

The potential R&D investment required to develop the schemes is very significant and preliminary costings provided for the development of the biological component were very variable. A project definition study was subsequently awarded to WRc in June 1991 with the aim of defining the requirements and options for the development of the biological components of the classification schemes for estuaries and coastal waters, and to produce a specification that ensured any future competitive tendering would be on a strictly comparative basis.

The objective of this R&D Note is to define the research required to develop the biological components of the classification schemes with particular consideration of the implementation constraints on the NRA. In this respect, the research would lead to a classification (possibly interim) based on alternative (to a fully predictive, RIVPACS type) measures or models.

This Note has been produced in conjunction with a Project Record which had the objective of defining the detailed specification for a project to develop predictive invertebrate community models for estuarine and coastal waters, with particular reference to water quality classification schemes (Nixon *et al* 1992).

2. TIMESCALE FOR THE INTRODUCTION OF CLASSIFICATION SCHEMES FOR TIDAL WATERS

The NRA has indicated that there are two options if all of the proposed components are to be included in the final scheme: either to wait until methods are available for all components - this is unlikely to be before the end of 1995 - or to introduce the scheme in a phased manner (NRA 1991b). The second option is preferred by the NRA because it will allow the introduction of a workable scheme based on most of the components at an earlier date. It is likely that the most effective approach may be to introduce a fairly simple system rapidly and then to develop it over time. Such a scheme could be ready for introduction by the end of 1993. The system could then be progressively extended. To this end a phased approach, starting with rivers, and priority catchments was recommended (NRA 1991b). In addition, for the purposes of the introduction of the first phase of the classification, the biological criteria in the existing estuarine classification scheme could continue to be applied as an interim measure.

It is a requirement, therefore, that the schemes for estuaries and coastal waters should be developed by winter 1993 and implemented by winter 1994.

3. BASIS OF THE BIOLOGICAL COMPONENT OF THE CLASSIFICATION SCHEMES

It has been proposed by the NRA that the biological classification would be based upon the macrobenthos and furthermore would be restricted to the subtidal macrobenthic communities of consolidated sediments. The macrobenthos has been used extensively and there is a large body of knowledge and operational experience supporting the use of this biological component in environmental monitoring programmes. In recent years the use of the macrobenthos in pollution related monitoring has also been an active area of research.

The selection of consolidated sediments has the dual advantage of facilitating remote sampling by grab and, to a lesser extent, reducing the variety of macrobenthic communities under consideration to those inhabiting sediments ranging from coarse sand to mud.

An operational disadvantage of using the macrobenthos is the degree of variability associated with the estimation of macrobenthic community parameters.

The composition and distribution of macrobenthic communities in estuaries and coastal waters is determined by an interacting array of biotic and abiotic factors. In statistical parlance the composition and distribution of macrobenthic communities may be considered as the response variable(s) and the abiotic and biotic factors as the explanatory variables.

The abiotic factors can be further sub-divided into 'natural' components, such as sediment type, salinity and degree of physical disturbance, and 'anthropogenic' factors, i.e. pollution. Both of these sub-sets of explanatory variables determine the values of the response variable.

For the purposes of the classification scheme the signal that we need to detect is the values of the response variable resulting from the 'anthropogenic' factors, namely changes in water quality. The effect of the 'natural' factors in this context is to contribute unwelcome variation or noise that can mask the strength of the signal. For the purposes of classification it is clearly important that the signal to noise ratio is maximised.

It is to this end that the macrobenthic communities of subtidal sediments have been selected in preference to those of intertidal sediments. The potentially confounding influence of the degree of emersion in intertidal habitats has, therefore, been excluded from our considerations.

The level of noise can further be reduced by both the choice of the measure of stress that will form the basis of the Ecological Quality Index (EQI) and the modelling approach adopted.

4. THE DERIVATION OF THE CLASSIFICATION SCHEME

The classification scheme for estuaries and coastal waters will apply for all such waters within the control of the NRA (with respect to water quality), that is all estuaries and coastal waters up to the three nautical mile limit in England and Wales. The development of an EQI to differentiate between classes of saline water in classification schemes relies on the following cardinal points:

1. The choice of a suitable measure of water-quality-induced stress in macrobenthic communities for use as the basis of an EQI;

2. The choice of a suitable modelling approach to derive the EQI;

3. The generation or collation of a suitable database of reference information from which the EQI and/or model could be developed.

The process of development is illustrated in Figure 4.1 in which the main steps from the choice and form of an EQI, to the modelling options for generation of the EQI and the data requirements for the alternative approaches are indicated in the left hand column. The main options or choices associated with each step are also illustrated in Figure 4.1.

Section 4 deals with the selection of an EQI and the modelling approaches which could be used to generate an EQI. Section 5 discusses the data requirements for developing the classification schemes.

4.1 Choice and form of the EQI

The choice of the measure of stress to form the basis of the EQI is fundamental to the classification scheme. An ideal measure would have the following characteristics:

1. Sensitive to stress at low levels and demonstrate increasing degrees of stress in a predictable manner.

2. Specific to pollution disturbance and in particular to deteriorating water quality.

3. Applicable widely in estuaries and coastal waters.

4. Easily understood by non-specialists.

It is unlikely that a single measure would exhibit all of these characteristics, particularly because sensitivity and range of applicability tend to be mutually exclusive. However, a range of measures of stress have been generated, tested, applied and reported in the literature. These measures exhibit a range of complexity from single statistic summaries of community characteristics, such as number of taxa, diversity and biotic indices, through graphical representations of diversity, such as rarefaction curves, to multivariate measures of community structure. In order to obtain the best assessment of the usefulness of individual measures each would need to be tested on a range of data sets from estuaries and coastal waters that exhibit stress from a low to a high degree. It would also be

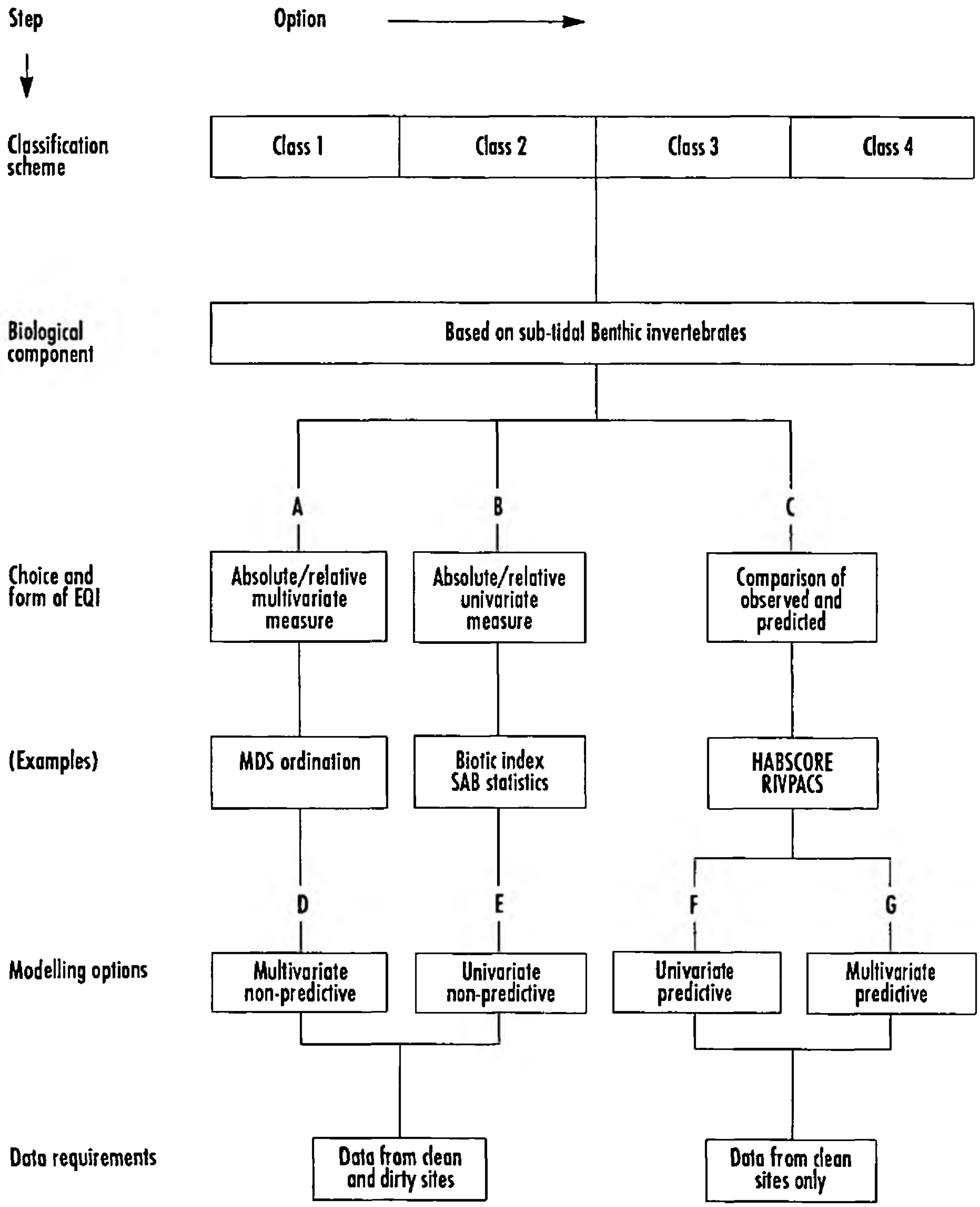

Figure 4.1 **Diagram illustrating the progressive steps and options involved with the development of the biological component of a saline waters classification scheme.**

desirable to test the effects of identifying the animals to different taxonomic levels on the sensitivity of the range of methods.

Such an intercomparison of measures was not an objective of the project definition study. Instead a detailed review of the measures from studies in the literature was undertaken with the aim of arriving at a short-list that show most potential for classification purposes within the time, and possibly financial constraints, on the NRA.

A similar suite of measures is under inspection for the purposes of deriving an 'EQS' using the benthos for the objective assessment of the effects of sewage sludge disposal in UK coastal waters (Rees personal communication). This work is being carried out by the members of the Benthos task team who report to the Group Co-ordinating Sea Disposal and Monitoring (GCSDM), a sub-group of the Marine Pollution Monitoring Management Group (MPMMG).

A report including this work was submitted to GCSDM in February 1992. The recommended measures for the purposes of deriving the 'EQS' were the primary variables T (taxa) (a more generalised term for S, the number of species), A (abundance) and B (biomass-measured as ash-free dry weight), and the ratios of these variables A/T and B/A. The use of the Shannon-Weiner diversity index (H'$\log_2$) and non-metric multidimensional scaling (MDS) was recommended for use in this context subject to further statistical evaluation of their mode of application. The application of the 'EQS' is intended solely for use on sewage sludge disposal grounds in UK coastal waters at the present time.

The main choices for the form of the EQI appear, therefore, to be either absolute or relative univariate or multivariate measures (Options B and A, respectively in Figure 4.1), or a comparison of an observed attribute of the community against that predicted (Option C in Figure 4.1).

Univariate measures have the advantage of being easily understood and are amenable to statistical testing using conventional methods but those related to diversity appear to lack sensitivity and specificity to pollution related changes. SAB (species richness: total abundance: biomass) statistics have been found to provide relative robust measures in some studies (e.g. Pearson *et al* 1982), and a predictive model based on S has been reported to be relatively reliable (Elliot and O'Reilly 1991). It is recommended that the use of SAB statistics is tested in the initial development phase of the classification schemes. Biotic indices, where available, also offer promise for use for classification purposes. Biotic indices differ fundamentally from indices of diversity in that they do not attempt to measure diversity but rather the pollution-specific response of selected taxa. The response of a particular taxon to pollution of different types can be determined by both laboratory studies and field observations. Once the response of a number of taxa to a particular type of pollution has been determined the taxa can be combined in a number of ways to produce a biotic index. These type of indices have been widely used for the assessment of pollution status in benthic communities in freshwaters, for example the BMWP and ASPT score are routinely used by the NRA for biological monitoring and for classification purposes. It is also recommended, therefore, that further work is undertaken on the development of a suitable biotic index for use in classification schemes.

Multivariate statistical techniques are so called because more than one variable is considered at the same time. In the context of marine benthic data this means that all elements of the species-by-samples matrix are used instead of being reduced to a single summary statistic. Multivariate measures are less well understood but appear to be more sensitive to pollution related change. The statistical methods for determining pollution related change are somewhat new, untested and specialised but nevertheless offer some promise. The methods for comparison among sites are less new but have still not been extensively tested and are still rather specialised. The necessary software for the above methods would be available to the NRA.

The majority of the testing and development of both univariate and multivariate measures has been carried out on marine data sets. The classification scheme is to encompass estuaries and, therefore, the performance of both sets of measures would need to be evaluated on estuarine data sets as well if they were to form the basis of the EQI.

4.2 Modelling options

There are a variety of statistical methodologies available to generate a model that could predict aspects of marine benthic community structure which could form the basis of, or generate an EQI for, classification schemes. These predictions represent a gradient of complexity. At the simplest end of the scale a single response variable is to be predicted, such as the total number of taxa, and at the other extreme the complete community composition, in terms of a list of taxa and their relative abundance, is to be predicted. Essentially, therefore, modelling approaches can be divided into univariate and multivariate with respect to the response variable (Figure 4.1), which can be used in a predictive or non-predictive way.

4.2.1 Univariate non-predictive (Option E : Figure 4.1)

An example of a possible univariate non-predictive 'model' is illustrated in Figure 4.2 where the observed measure of stress (e.g. species richness or a biotic index) is plotted against an environmental variable, in this case median particle size. Specific models might also have to relate to other important environmental variables. For example, plots similar to Figure 4.2 might have to be produced for different salinity zones or water depth. This type of empirical model could be derived from existing or new data by comparing observed community attributes or measures from a range of clean and dirty estuaries and coastal water sites. Classification bands could then be related to defined environmental variables and based, for example, on the occurrence of a percentile of the total estuary and coastal site population within each band. Alternatively, band thresholds could be based on percentages of the observed attribute or measure at clean locations (assuming that this would be different from comparable 'dirty' locations) for a particular environmental variable.

A practical example of how community characteristics (in this case species richness (S), abundance (A) and biomass (B)) have been found to vary with environmental variables (in this case organic enrichment) is given in Figure 4.3. Such differences in response to environmental and anthropogenic variables could perhaps form the basis of the classification model.

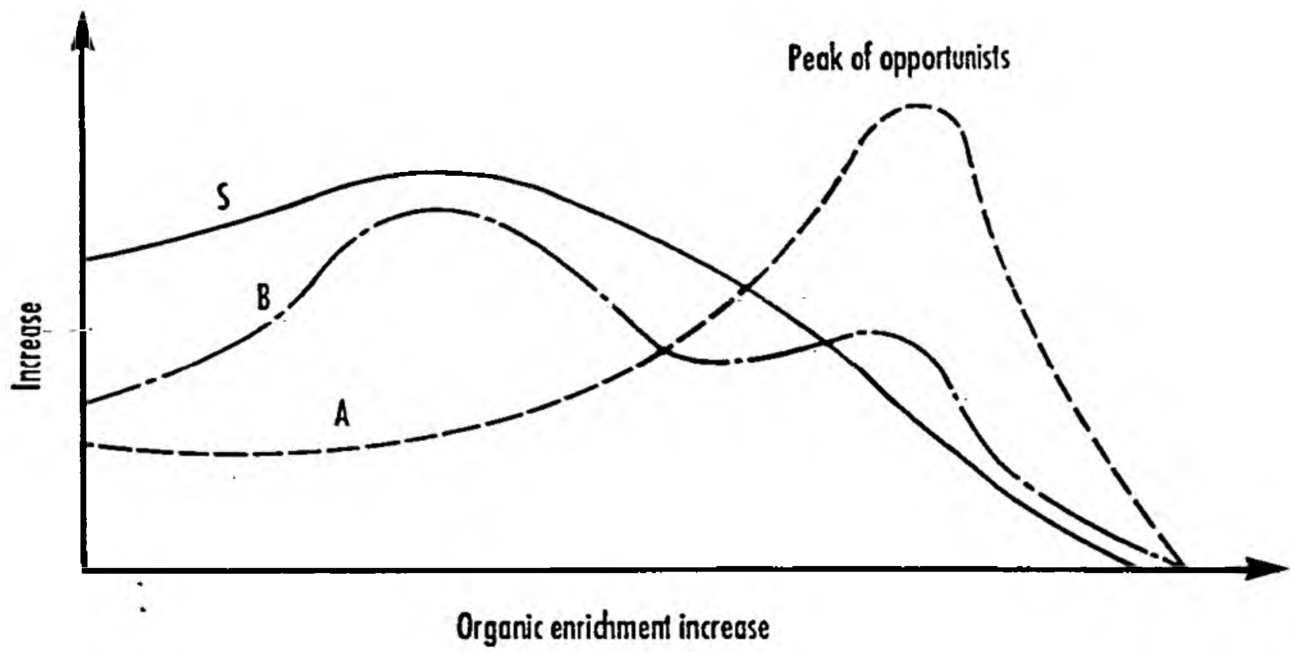

Figure 4.3 A practical example of the univariate non-predictive option: the behaviour of S, A and B in response to organic enrichment (after Pearson and Rosenburg 1978)

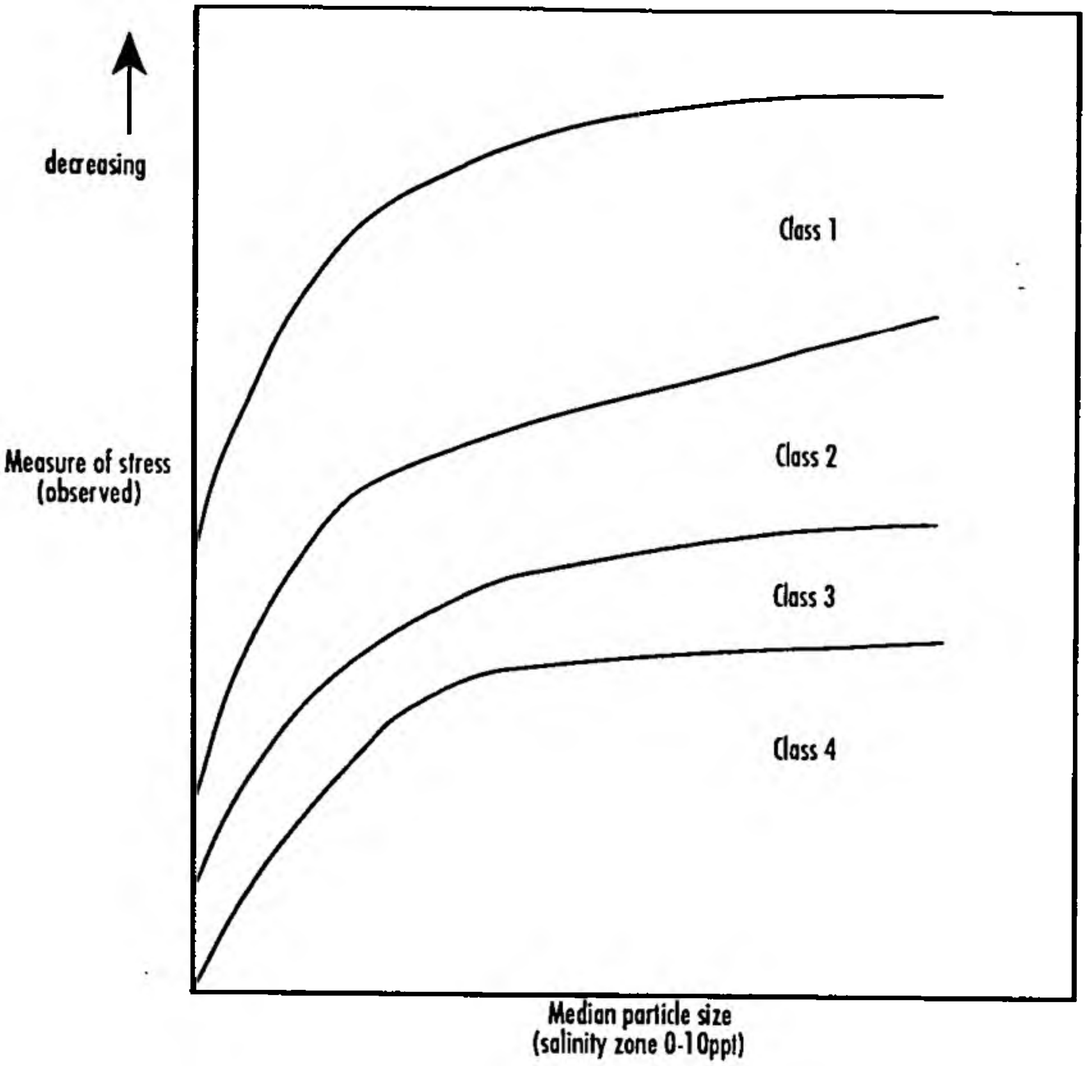

Figure 4.2 Diagram illustrating how a univariate non-predictive approach might be used for classification

A practical example of how community characteristics (in this case species richness (S), abundance (A) and biomass (B)) have been found to vary with environmental variables (in this case organic enrichment) is given in Figure 4.3. Such differences in response to environmental and anthropogenic variables could perhaps form the basis of the classification model.

4.2.2 Univariate predictive (Option F : Figure 4.1)

Univariate approaches could be used to predict a single response variable, such as the presence of a single species or community summary statistic, from a linear or non-linear combination of explanatory variables through various regression techniques. An illustration of how a univariate predictive approach might be used for classification is given in Figure 4.4 where the observed community attribute or measure of stress is plotted against that predicted. The predicted line (solid line in Figure 4.4) would be derived through a regression analysis of the observed attribute or measure from clean sites, with a single, or combination of, environmental variables, such as salinity, particle size and depth. Indeed this approach could be a natural progression from the univariate non-predictive type model (Figure 4.2) using Class 1 data. The amount by which the observed attribute or measure differed from that predicted for the measured environmental variable would then be used as the basis of the classification.

A practical example of how this option might be developed is given in Figure 4.5 where an observed community parameter (species richness) is plotted against that predicted. The predicted valves are derived from the regression equation (the regression line is also shown) relating defined environmental variables to species richness, in this example for 'clean' non-impacted sites only.

There are a number of examples of the univariate approach. For example, a multiple regression model forms the basis of HABSCORE used by the NRA to predict the density of specific age classes of salmonid species from a range of environmental variables (Milner 1985). Also a multiple regression approach applied to the Firth of Forth has been recently reported to potentially provide a predictive capability in benthic monitoring (Elliot and O'Reilly 1991). A similar approach was used by Codling *et al* (1991) in developing a generalised linear model to predict the number of intertidal macrobenthic taxa at sites in the Mersey estuary from the nature of the substratum, level on the shore and salinity zone in the estuary.

4.2.3 Multivariate non-predictive (Option D : Figure 4.1)

The basis of non-predictive approaches could be a multivariate representation, probably in the form of an ordination plot, of a range of sites from polluted to unpolluted conditions. An illustration of such an multivariate ordination is given in Figure 4.6, where the 'x' axis relates to levels of pollution and the 'y' axis to other defining factors such as salinity. Class boundaries could then be derived and superimposed on the diagram according to chosen criteria. Samples from sites to be classified are then added to the reference data set and the ordination procedure repeated. The relative position of the sites to be classified relative to

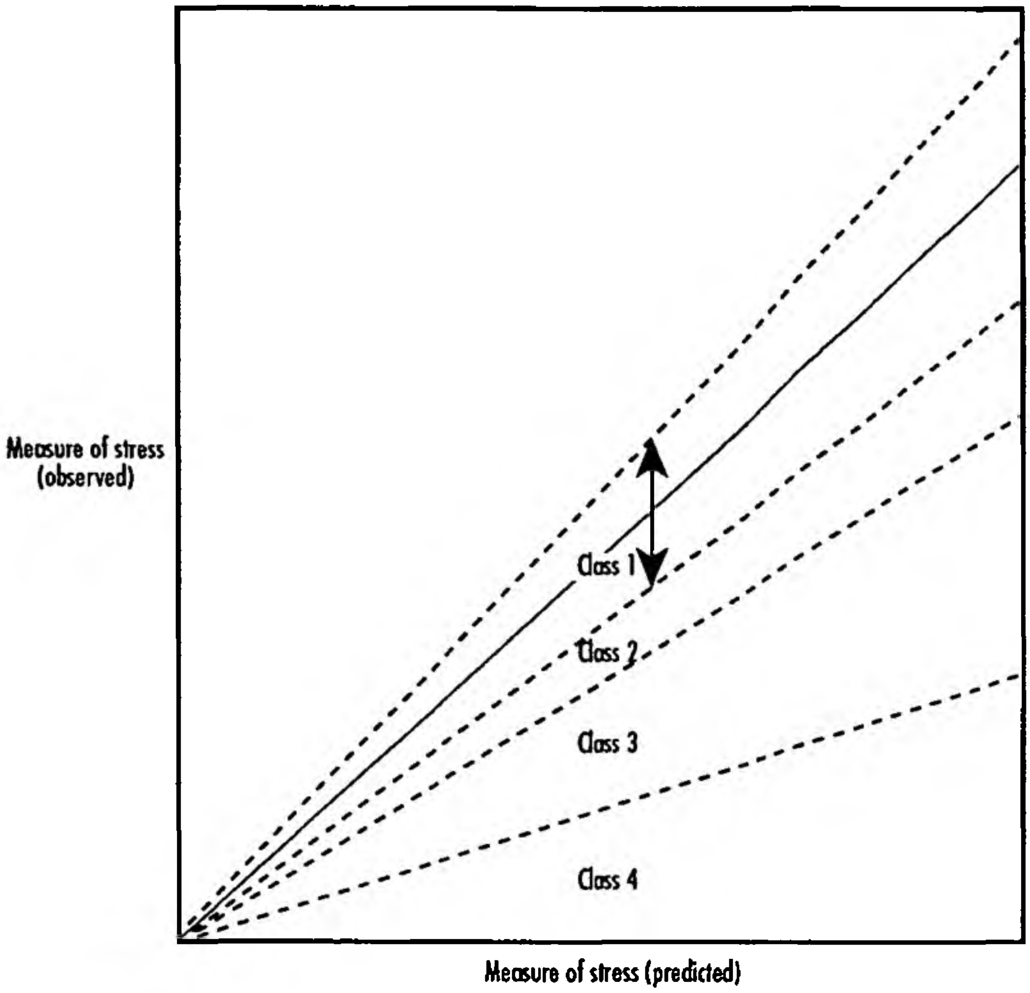

Figure 4.4 Diagram illustrating how a univariate predictive approach might be used for classification

the class boundaries then determines the class into which the site falls.

A practical example of multivariate ordination (in this case non-metric multidimensional scaling (MDS)) is given in Figure 4.7 where an ordination has been produced for macrobenthos species biomasses found at sites across a well defined pollution gradient (Warwick and Clarke 1991). In this example a correlation-based Principal Componant Analysis (PCA) was also performed on the measured environmental variables (carbon, nitrogen and metals) in the sediment : the PCA was found to closely resemble the structure of the macrobenthic MDS. This example illustrates the way in which the most influential environmental variables could be identified and their relative importance deduced from the loadings on the principal components.

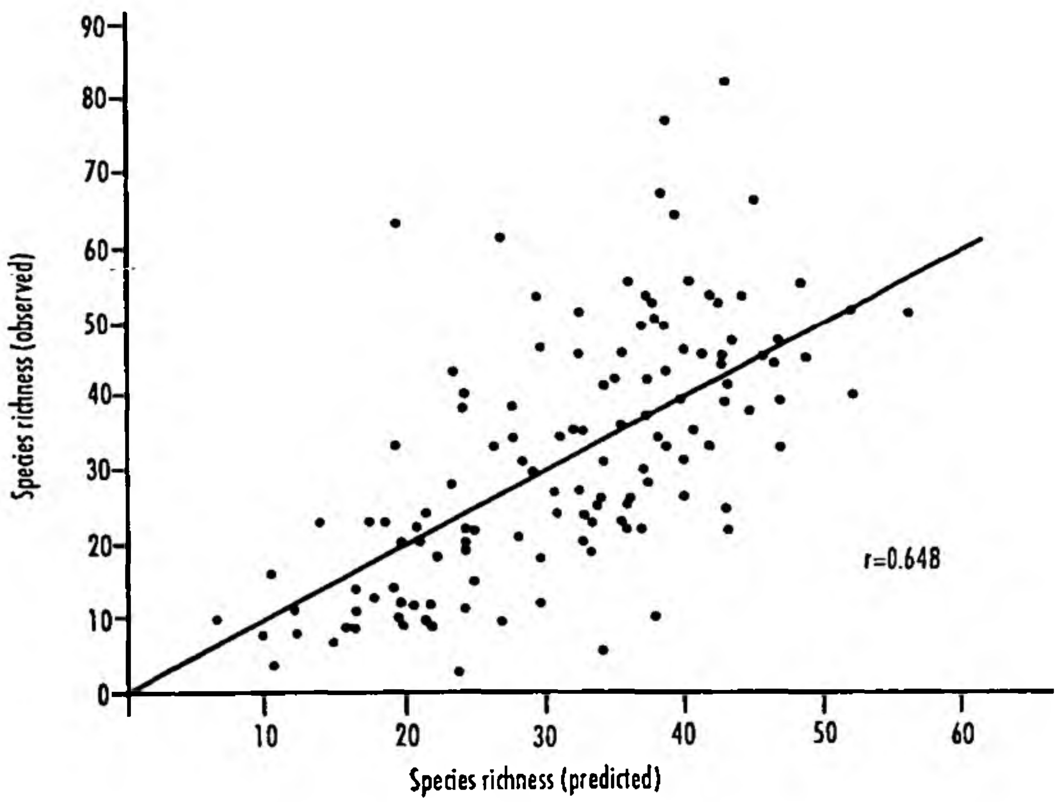

Figure 4.5 A practical example of the univariate predictive option: plot of observed against predicted species richness at sites in the Forth estuary (after Elliot and O'Reilly 1991)

4.2.4 Multivariate predictive (Option G : Figure 4.1)

Multivariate predictive approaches are those that generate a list of predicted taxa and their relative abundances and/or biomasses from a set of explanatory environmental variables. From this list a whole range of community attributes and/or measures of stress can be calculated and used as the predicted EQI against which the observed can be compared. The most relevant example of this type of model is RIVPACS which is currently used for classification purposes in rivers by the NRA. In this case the ratio of the observed to predicted BMWP and ASPT scores is used as the basis of the EQI. Banded values of the EQI are then related to the different classes of the classification scheme (NRA 1991b).

Though the ultimate aim of the the NRA might be to develop a marine equivalent to RIVPACS, it is unlikely to be achievable within the time constraints for the implementation of the classification scheme. In the short term, therefore, a non-predictive modelling approach might be more appropriate.

4.2.5 Other factors for consideration

The choice of modelling approach would also be determined to some extent by the following factors:

- the choice of the measure(s) of stress;
- the available resource for development;
- the available time to implementation of a classification scheme.

The influence of the first factor is particularly large for the univariate approaches because the measure of stress has to be defined before it can be modelled. The only way this can be avoided using the univariate approach is to develop a model for each taxon that predicts its abundance and/or biomass. The predictive multivariate approach avoids this problem by generating a predicted list of taxa from which any of the measures of stress can be calculated. The non-predictive multivariate approach selects a multivariate ordination (or classification) as the measure of stress by default.

Development costs for the three approaches can be split into generation/collation of a suitable database and actual development costs. The likely costs can be placed in decreasing rank order: multivariate predictive >univariate predictive >multivariate/univariate non-predictive. As the time to implementation is limiting (NRA 1991b) then the approach that can be developed most rapidly may receive greater favour. The rank order in development time is probably the same as for development costs, that is multivariate predictive would take the longest time to develop.

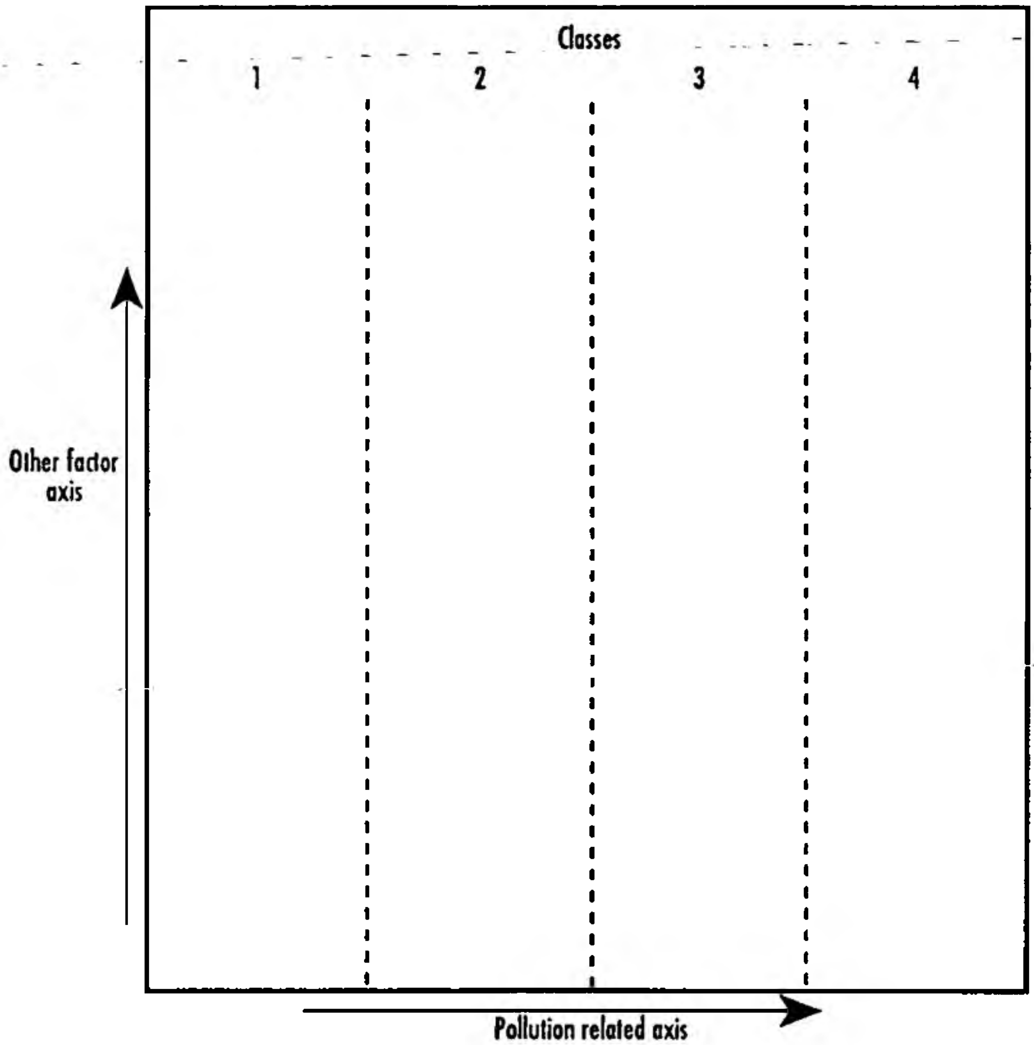

Figure 4.6 Diagram illustrating how a multivariate non-predictive approach might be used for classification

4.3 Taxonomic sophistication

In recent years the need for species level identification for the assessment of pollution effects has been questioned by several authors. For example, Warwick (1988) examined the macrobenthos of Frierfjord/Langesundfjord in terms of biomass and abundance with the data aggregated to family and phylum level using both univariate (ABC plots) and multivariate (non-metric multidimensional scaling ordination - MDS) methods. It was concluded that no information whatsoever would have been lost if the animals had been identified to family level for both techniques. The issue of taxonomic aggregation is, therefore, clearly important. There are definite operational advantages, with respect to the costs of implementation of the classification, if the identification of the taxa encountered can be restricted to either family level. The evaluation of the performance of each of the recommended measures and methods should, therefore, be assessed at species and family level.

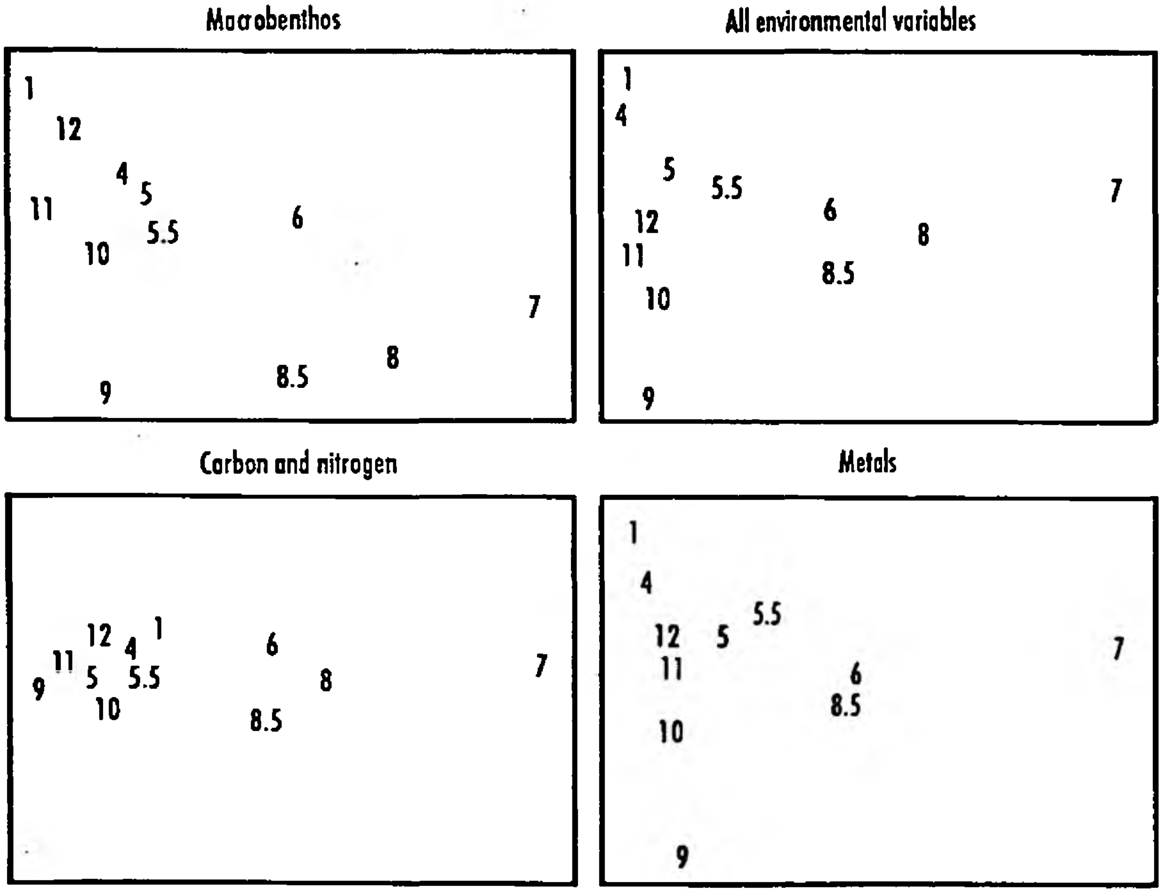

Figure 4.7 A practical example of the multivariate non-predictive option: MDS ordination diagram for macrobenthic double-square-root transformed biomass data with PCA ordinations for various environmental variables (after Warwick and Clarke 1991)

4.4 Recommendations

It is not possible to recommend any one of the above techniques in terms of their technical merit. In theory each should provide the necessary information but some may be over-complicated for the purposes of classification. Each of the approaches requires the generation or collation of a suitable database. This, along with the choice of both the measure of stress and the modelling approach, is a fundamental feature of the classification scheme.

Based on the limited existing data and bearing in mind the time-constraints on the introduction of a scheme it is recommended that the following options for an EQI and/or modelling are further tested and developed:

- univariate non-predictive model based on SAB statistics and/or a biotic index;
- multivariate non-predictive model based on non-metric multidimensional scaling (MDS) ordinations.

These techniques could be tested on existing suitable datasets and on any new data obtained as it becomes available. Within the time constraints on development of the scheme there could be two or three years data collected, depending upon the sampling regime adopted (e.g. winter and/or spring sampling). As the scheme is implemented to all estuaries for classification purposes the chosen option could be further calibrated and validated. Any new data should also be extensive enough and amenable for use in other potential measures which might be achievable within the longer term and possibly be better for classification. For example, the development of a marine equivalent to RIVPACS might still be required. In particular, it would require relatively little extra effort to develop a univariate predictive model as this could be a natural progression or development from the univariate non-predictive approach.

5. DATA REQUIREMENTS FOR THE DEVELOPMENT OF THE CLASSIFICATION SCHEME

5.1 General considerations

The establishment of a suitable database is the third cardinal element required for the successful development of the biological component of the classification schemes. The suitability of datasets is dependent to some extent on the type of index and the type of model that is to be developed and can be defined in terms of both data quantity and data quality. The amount of data can be expressed in terms of the number of:

- estuaries or stretches of coastal water to be sampled;
- sampling sites within each estuary and stretch of coastal water;
- replicate samples within each site;
- determinands to be measured in each sample.

In order to decide how many estuaries/stretches of coastal waters are required, two extreme cases might be considered. At one end of the spectrum it could be said that if the classification scheme is to apply to all estuaries/stretches of coastal waters then the database from which the index or model is to be developed should contain data from each of those estuaries/stretches of coastal water. At the opposite end of the spectrum it could be said that all estuaries and stretches of coastal water are sufficiently similar that data from a single representative estuary/stretch of coastal water would suffice. Clearly the former is impracticable and the latter ridiculous. The compromise situation, by definition, lies somewhere between these extremes.

The extent of the initial database required for the development of a predictive RIVPACS type model for the biological component of the saline waters classification schemes is fully discussed in the Project Record. The extent of the initial database required to develop an alternative, possibly interim, scheme (within the defined time constraints) might be less. A key point in developing a sensitive yet robust classification scheme would be to obtain suitable data from a sufficient number of estuaries and coastal waters to account for the major differences and variability in macrobenthic communities which result from differences in environmental factors, including water quality. These factors are fully discussed in the Project Record.

For example by sampling in three salinity zones in each estuary three basic community types might be encountered. Following the NCC subtidal community classification (Davidson *et al* 1991) these might be described as; the reduced salinity mud community, variable/reduced salinity mud community and the normal/variable salinity muddy sand community. However, there is still likely to be a large amount of variability in species composition, diversity and abundance within and between these broad community descriptions. In addition, in many estuaries these most common communities might be supplemented by 'rarer' communities, for example a clean sand community and sand/muddy sand community, and these different communities might also be a source of variability between estuaries. On the other hand, if a detailed species list was not to be predicted (as in a RIVPACS type model) then perhaps not so many estuaries or sites within estuaries would need to be included in different biogeographic regions. Considering the same physico-chemical conditions but different biogeographic location then it might be expected that animals at the same trophic level or of the same feeding types e.g. filter feeders and detritus feeders, could occupy the same ecological niche though they may be of a different taxon. In this case it might be expected, therefore, that species diversity, and possibly abundance, would be similar. However, it should be recognised that some estuaries and coastal waters when subsequently sampled might appear outside the limits of the classification.

The following factors or sources of variability were considered in assessing how many estuaries and stretches of coastal water would ideally be included in the database for the first phase of developing the classification.

Temporal factors/variability	Possible sampling unit/frequency	
Season	Seasonal sampling	1
Year	Number of years	2 or 3
Spatial factors/variability		
Small scale	Replication of samples per site	4
Large scale	Number of sites per estuary/coastal location	3
Biogeography	Number of regions	6
	Number of locations per region	3
Physico-chemical	Synoptic sampling	e.g. Sediment characteristics Salinity Water depth
Anthropogenic	Select 'clean' and 'polluted' estuaries and coastal waters	3 per biogeographic region

How these factors are accounted for in the currently available datasets and in any current or new sampling programme, for example by the number of replicates taken or the number of sampling seasons per year, would have a fundamental impact on the resources and time required to develop the scheme.

Adopting the above strategy and sampling frequency would require 18 estuary and coastal water sites. This could represent a starting point for development of the scheme but it

Table 5.1 Existing datasets of potential use in the initial phase of development of the classification scheme

Location	Grab type	Grab Area m^2	Mesh Size mm	Season	Reps.	Physico-chemical determinands PSA	CHN	RPD	Met.	PO	Others
Estuary											
Humber	Day	0.1	0.5	Sept	3	*	*	-	*	*	Ba
Exe 1990	Van Veen	0.05	0.5	Sept	4	*	*	*	-	-	
Camel 1991	" "	"	"	?	4	*	*	*	-	-	
Dart 1991	" "	"	"	Ju/Jul	4	*	*	*	-	-	
Fal 1990	" "	"	"	Sept	4	*	*	*	-	-	
Fowey 1991	" "	"	"	Aug	4	*	*	*	-	-	
Helford 1990	" "	"	"	Sept	4	*	*	*	-	-	
Kingsbridge '91	" "	"	"	July	4	*	*	*	-	-	
Taw/Torridge'90	" "	"	"	?	3	*	*	*	-	-	
Teign 1990	" "	"	"	May	4	*	*	*	-	-	
Yealm 1991	" "	"	"	July	4	*	*	*	-	-	
Severn 1990/91	Day	0.1	0.5	Nov?Dec	10	*	*	*	*	*	Wq
Thames 1989/90	Day	0.1	1.0	4	4	*	-	-	*	*	
Southampton Water 1977/85	Hunter	0.1	1.0	May/Aug	2	*	*	-	*	-	Hy
Lymington	"	"	1.0	"	2	*	*	-	*	-	
Beaulieu	"	"	1.0	"	2	*	*	-	*	-	
Test	"	"	1.0	"	2	*	*	-	*	-	
Itchen	"	"	1.0	"	2	*	*	-	*	-	
Hamble	"	"	1.0	"	2	*	*	-	*	-	
Medina	"	"	1.0	"	2	*	*	-	*	-	
Portsmouth	"	"	1.0	"	2	*	*	-	*	-	
Langstone Harbour	"	"	1.0	"	2	*	*	-	*	-	Ba
East Solent	"	"	1.0	"	2	*	*	-	*	-	
Tyne 1990/91	Day	0.1	1.0	Oct	3	*	*	-	*	-	
Wear	Day	0.1	1.0	Oct	3	*	*	-	*	-	
Tees	Day	0.1	1.0	Oct	3	*	*	-	*	-	
Coastal											
Thames	Day	0.1	0.5	July	4	*	*	-	*	-	
Margate 1988-	Hunter	0.1	1.0	Jul/Aug	2	*	*	*	*	-	Ba

cannot yet be ascertained as to how much of the inherent spatial and temporal variability they would adequately account for. To some extent it would also be dependent on the nature of the index eventually selected. The scheme could then be developed through subsequent annual sampling surveys and extended to include other estuaries when they are sampled for classification purposes. At the same time other techniques and measures could be tested to assess whether the scheme could be improved. If further measures were to be considered it would be important to ensure that any new data was as comprehensive as possible and collected by standardised methods so that it would be amenable to this approach.

5.2 Extent of available data

A search of the published and unpublished literature, and a survey (by questionnaire) of the NRA regions, was undertaken to assess how suitable existing data were for the initial stages of developing classification schemes. The results of this search indicated that there were relatively few datasets potentially of use for development of the classification. The criteria used in deciding whether a dataset was suitable or not included:

- the size of mesh used to sample the macrobenthos (0.5 mm as opposed to 1 mm);
- the type and size of grab or sampling device;
- the extent of associated supporting physico-chemical measurements;
- season of sampling; and,
- degree of sample replication.

The 27 datasets considered to be worthy of further consideration and possible use are given in Table 5.1. For some datasets the required supportive data appear to be lacking but some of these might, however, be obtainable retrospectively. Other datasets might be useful in assessing the importance of factors such as mesh size and season to the overall variability within estuarine and coastal waters macrobenthic communities. For, example the NRA Thames estuary dataset extends over four seasons and between season variability could be tested, albeit on only one estuary. Other datasets would enable a comparison to be made between 0.5 mm and 1.0 mm mesh sizes, for example on the data from the Barrow Deep sludge disposal ground (outer Thames estuary). Information obtained from these exploratory investigations would enable a decision to be made on the suitability of other existing datasets. A number of surveys are ongoing and only a small alteration to the existing sampling programmes, to standardised and agreed methods, would be sufficient to create quickly a database for development of the classification.

Coastal information that may potentially be of use for classification purposes is a scarcer commodity. The NRA questionnaire revealed very few quantitative coastal monitoring programmes, most of the information being found in the open literature or in industrial reports. Each of the eight coastal datasets included within Table 5.1 are recent, quantitative and have some supporting, physico-chemical analysis.

The questionnaire also revealed that very few of the data sets are formally recorded on computer databases and several man days may be needed to collate each of them.

Table 5.1 Continued.../2

Location	Grab type	Grab Area m^2	Mesh Size mm	Season	Reps.	Physico-chemical determinands PSA	CHN	RPD	Met.	PO	Others
Hythe 1982-	Hunter	0.1	1.0	" "	2	*	*	*	*	-	Ba
Broadstairs '88	Hunter	0.1	1.0	" "	2	*	*	*	*	-	Ba
Poole Bay	Divers	0.006	0.5	Jun/Jul	7	*	-	-	*	-	Hy
Exeter 1989	Van Veen	0.1	1.0	Dec	3-5	*	*	-	*	*	Ba
Swansea 1984 Bay	Day	0.1	1.0	Aug	2	*	*	*	*	?	
Tenby	Day	0.1	0.5	Jul/Aug	4	*	*	-	*	*	Ba

Key:

*	= analysed
-	= not analysed
?	= not known
Rep	= number of replicate samples taken per site
PSA	= particle size analysis
CHN	= carbon, hydrogen and nitrogen determination
RPD	= redox potential depth
Met	= metal analysis
PO	= persistent organic compound analysis
Wq	= water quality
Hy	= hydrocarbons
Ba	= bacteria

5.3 Selection of estuaries

The survey of the NRA regions also indicated that there are a number of monitoring programmes underway the results of which could be used, perhaps after some modification of procedures, for the database. In addition the NRA has recently proposed a baseline estuary and coastal waters monitoring programme. This programme was set up partially in response to the recommendations made by the Marine Pollution Monitoring Management Group (MPMMG) following a review of the current UK marine monitoring programmes (MPMMG 1991). One recommendation was that there should be a minimum monitoring programme in all major estuaries. The NRA programme also forms part of the Monitoring Master Plan of the North Sea Task Force (NRA 1991a) and was planned to go some way towards establishing a baseline programme for the major estuaries which fall within the responsibilities of the NRA. The estuarine sites included in the programme are:

Tyne	Humber	Southampton Water	Dee
Tees	Wash	Tamar	Mersey
Wear	Thames	Severn	

These estuaries are those also identified by the MPMMG (1991) as 'priority areas' with the addition of the Solway which the MPMMG also included and for which North West NRA may have some responsibility. The NRA programme is not intended to be a substitute for the more intensive sampling programmes presently underway in some estuaries (e.g. the Humber). Three sites per estuary are suggested, representing salinity regimes of 0-10 ppt, 10-20 ppt and 20-30 ppt. Once a sampling site has been chosen, all future sampling should be at the same sampling location under the same tidal conditions (NRA 1991a). It was also recommended that the benthic sampling associated with the NRA estuary and coastal waters programme should occur once a year between February and May inclusive (NRA 1991a). If this sampling season is to be adopted throughout the NRA then the need for additional sampling in other seasons for use in the database could be removed and the required sampling costs reduced. However, sampling only once a year would reduce the number of potential datasets available before the deadline for implementation of the scheme (winter 1994).

It can be seen that the estuaries selected for the NRA baseline survey are major estuaries which are likely to have relatively high levels of contaminant inputs and contaminant concentrations. Within a classification scheme they might, therefore, appear within the same or adjacent class. It would, therefore, be necessary to sample representative examples of less polluted, 'clean' estuaries. In selecting these consideration should be given to the number of locations required to account for a large part of the variability in subtidal macrobenthic communities between sites within the same estuary, between estuaries with different physical characteristics and biogeographical locations, and any differences which might be due to differences in sediment and water quality. Sites should, therefore, be included within each of the major biogeographic regions around the coast. It is difficult to determine the optimum number of sites required within each biogeographic region without some prior knowledge about the inherent natural variability within and between benthic estuarine communities from relatively polluted and relatively clean estuaries. It might be expected, therefore, that some estuaries and sites sampled after the initial development of the scheme might appear outside its limits. In this case the class thresholds might have to be revised as the scheme is progressively implemented and developed.

It is suggested that a number of additional estuaries are added to the NRA baseline survey list to establish the database for development of the initial classification (Table 5.2). There are three estuaries in each of the six broad basic biogeographic regions around England and Wales. An attempt has been made to include a relatively 'polluted', 'good quality' and 'average quality' estuary within each region. The selection of an estuary into each of these categories is somewhat arbitrary (based on a subjective assessment of human populations and activities associated with individual estuaries (Davidson *et al* 1991) and not on data of anthropogenic inputs) and is intended to be indicative rather than definitive. It has also included estuaries where there may be current quantitative surveys are underway. This would potentially reduce the total number of 'new' surveys required.

Table 5.2 Suggested list of estuaries that should be included in the database for development of the initial classification

Biogeo-graphical region	Estuary	Quality	Included in current programmes	Existing datasets
NE	Tyne	P	Yes	Possible
	Tees	P	Yes	Possible
	Wear	P	Yes	Possible
	Humber	P	Yes	Possible
	Tweed	A	No	No
	Wansbeck	G	No	No
S	Southampton Water	P	Yes	Possible
	Langstone Harbour	A	No	Possible
	Beaulieu	G	No	Possible
SW	Tamar	P	Yes	No
	Exe	A	No	Possible
	Camel	G	No	Possible
E	Wash	P	No	No
	Thames	P	Yes	Possible
	Stour	A	No	No
	Deben	G	No	No
NW	Mersey	P	No	No
	Duddon	A	No	No
	Esk	G	No	No
W	Severn	P	Yes	Yes
	Dee	P	No	No
	Milford Haven	A	No	No
	Mawdadach	G	No	No

Key:

P = 'polluted'
A = 'average quality'
G = 'good quality'

Possible = may be applicable after further investigation

Biogeographic region (winter-summer mean surface temperatures °C - Wood 1987)

NE	=	from the Wash to the Tweed (5 - 14)
E	=	from the Rother to the Wash (6-17)
S	=	from the Axe to the Rother (8-16)
SW	=	from the Axe to the Severn (10-16)
W	=	from the Dee to the Severn (8 -16)
NW	=	from the Solway Firth to the Dee (5 -16)

It is recommended that three salinity zones (0-10 ppt, 10-20 ppt and 20-30 ppt) are sampled within each estuary. The aim should be to sample consolidated soft sediment. To some degree the location of consolidated soft sediment within an estuary would be based on local knowledge, reported work or in some cases from admiralty charts. It would also be important to avoid areas of unconsolidated sediment e.g. fluid mud, as these would likely contain a very impoverished fauna. Sample sites should also be located away from the zone of immediate impact (mixing zone) of any discharges, and at points where they reflect more general levels of water quality.

5.4 Selection of coastal water sites

It is intended that the coastal waters classification scheme will have two zones: an inshore zone extending 200 m offshore from the spring tide low water mark; an offshore zone from 200 m below the spring tide low water mark to three nautical miles offshore. Potentially these two zones could have very different physical characteristics. For example, the inshore sites may be more physically disturbed by wave action than offshore sites, as the latter may be in much deeper water. Alternatively inshore sites will, in some locations, be more sheltered than those further offshore.

Many of the physico-chemical factors influencing benthic community structure in estuaries may also be relevant to coastal waters. Salinity would not generally be expected to be as variable as in estuaries. Particle size distribution of the sediments will be a key factor. When water quality is considered there may be marked differences between the turbid waters of the southern North Sea compared to those off the South West peninsula. As dispersion is generally greater in coastal waters than in estuaries there might be less pollution related differences in coastal benthic communities than in estuarine. It is still, however, necessary to consider how much of the coastline is required to be sampled to account for a sufficient portion of the total inherent variability in macrobenthic communities around the coast of England and Wales.

It is suggested that three sample sites are established along a seaward transect extending from the inshore zone to the outer limit of the offshore zones at each location. There would, therefore, be a site within 200 m of the shore, a second at around three nautical miles offshore and an intermediate site. Sample locations would also ideally be established on a regional basis to cover any biogeographic differences in the British marine benthic fauna, though, as for estuaries, this factor may not be so important until a predictive type model is developed.

As the aim of the classification scheme is to reflect water quality on a broad scale in coastal waters, sites should be located away from mixing zones and disposal sites, and located at points that reflect more general levels of water quality. Any differences in relation to water quality might also be more apparent in the inshore zone where dispersion is generally less and where there may be many discharges from sea outfalls, storm overflows, industrial discharges and riverine inputs. Sites directly in the estuary plume may also be subject to more variable salinity than other sites included in the coastal scheme and this may add another confounding environmental factor. However, it is likely that some coastal sites will be by necessity included in estuarine deltas (e.g. outer Thames estuary) and on some occasions may be influenced by reduced salinity.

Any new sampling programme associated with producing the database could, as for estuaries, incorporate current or proposed NRA monitoring/sampling programmes. The MPMMG (1991) has also made recommendations regarding the monitoring requirements for coastal waters stating that there should be at least 20-30 reference sites around the UK coast, with at least one in each Water Authority (now NRA Region) and River Purification Board areas. Responsibility for monitoring at these stations, biological, physical and chemical, would fall to the NRA region or Purification Board concerned, assisted as appropriate by MAFF, SOAFD or DANI/DOE Northern Ireland.

The NRA baseline survey proposes 11 coastal water sites located at the edge of the estuary plume (i.e. limit of estuarine influence) with one exception in Cardigan Bay. Exact locations would be agreed in discussion with MAFF. Also where possible these sites should be identical to existing Joint Monitoring Programme of the Oslo and Paris Commission sites. The general areas in which the sites would be located are:

Tyne	Tees	Humber	Wash
Thames	Solent	Plymouth	Bristol Channel
Cardigan Bay	Liverpool Bay	Dee	

These locations could form the basis of the initial database and potentially would cover a range of different levels of general water quality, particularly in the inshore zone, for example from the relatively 'unpolluted' Cardigan Bay to the relatively 'polluted' Liverpool Bay. These eleven coastal locations should be supplemented by other sites in the same geographic area but further away from the direct influence of the estuary plume (with the exception of Cardigan Bay). At these locations water quality might be generally better than at the edge of the plume. An extra sampling location should also be found in Cardigan Bay.

There would, therefore, be a total of 22 locations, which with three sampling sites at each location, is equivalent to 66 sites. These initial 66 sites should be considered as a starting point as there is the possibility of not sampling a representative number of the different community types (in the broad sense) present to account for all the natural inherent variability in coastal benthic communities.

5.5 Data collection

It is recommended that the following are determined during sampling for the macrobenthos or on sub-samples taken from each macrobenthic sample:

- particle size analysis*;
- organic carbon content of the <63 μm sediment fraction *;
- persistent sediment contaminants (List I and II metals) in the <63 μm fraction*;
- salinity (water column) *;
- water depth;
- water temperature *;
- turbidity (*Secchi disc);
- dissolved oxygen (water column) *;
- ammonia (water column) *.

The following should be assessed or calculated retrospectively for each sample site and/or sample occasion:

- temperature, range and annual average;
- latitude and longitudinal position of site location;
- degree of exposure;
- tidal range;
- salinity range (extremes of salinity important) and median value;
- tidal prism (mainly estuaries and perhaps enclosed bays);
- flushing time (mainly estuaries and perhaps enclosed bays);
- tidal currents.

It is recommended that the following is not included in the model physico-chemical database:

- redox potential *.

Most of the above determinands (indicated by * above) are included in the NRA baseline survey for which the measurement of redox potential is also included. Some of these physico-chemical determinands, such as particle size distribution and organic carbon and nitrogen, would have to be taken at the same time as the macrobenthos. For others, such as general indicators of sediment and water quality at each location, there might be some scope for their retrospective determination.

It is recommended that standard procedures for the measurement of the above determinands are established before any field sampling is undertaken. The suggested methods for further consideration and discussion are given in the Project Report. Many of the methods are those recommended by the Group Co-ordinating Sea Disposal and Monitoring (GCSDM) (MAFF 1991). For others there are apparently no established standard methods. The number of samples or replicates required at each site will be influenced by (Rees *et al* 1990):

- the need for statistical accuracy in assessing sample heterogeneity;
- operational constraints;
- site characteristics - local complexities and heterogeneities will influence the number of samples necessary to establish community variability.

The GCSDM group reported that the minimum acceptable number of samples to provide statistical analysis of the most common species at any site was three (Rees *et al* 1990). They quote that in soft silt, three samples might be expected to collect 60% of the species present in an area, and five samples would usually yield over 70%. For the purposes of developing the database it is recommended that four samples are taken at each site as this is the minimum required for use in hypothesis testing methods associated with multiple dimensional scaling, one of the shortlisted methods for deriving the classification. The samples should be taken, where possible randomly, within the defined area of consolidated sediment to be sampled. The same type of sediment should then be sampled on subsequent sampling occasions at a particular location, either for database generation or for classification. At each site the following sampling regime should be adopted:

- Grab 1: Macrobenthos and subsample for PS;
- Grab 2: Sub-samples for persistent contaminants and organic carbon;
- Grabs 3, 5 and 7 as for grab 1 above;
- Grabs 4, 6 and 8 as for grab 2 above;
- Move to different sample point within area of consolidated sediment between grabs 2, 4 and 6.

5.6 Quality control and quality assurance

As indicated in an earlier part of this Note further sampling would be required to establish a suitable database. The issue of quality of any new or existing data presents some problems with respect to biological data where quality control and assurance are less well developed than for chemical and physical data. This issue is fully discussed in the Project Record (Nixon *et al* 1992) and it is recommended that Analytical Quality Control (AQC) and Quality Assurance (QA) procedures should be adopted in any new or current sampling programmes.

6. APPROACH TO THE DEVELOPMENT OF THE CLASSIFICATION SCHEME

It is recommended that a phased approach is adopted in the development of the classification scheme such that the initial time constraints on implementation can be met and so that the scheme can be progressively developed and modified in the light of operational experience and as more data become available. The suggested tasks and timetable for development of the index and scheme are outlined below.

Year	1992			1993				1994				1995
Quarter	2	3	4	1	2	3	4	1	2	3	4	1
Assessment of existing datasets	|—	—	—|									
Collection of new data				|—	—|			|—	—|			
Testing of measures			|—	—	—	—	—|				
Establishment of preliminary EQI							*					
Derivation of preliminary classification scheme							*					
Further development of the EQI and classification									|—	—	—|	
Implementation											*	
Estuary and coastal water classification surveys												|—
Revise/modify preliminary scheme												|—
Continued evolution of EQI and scheme												|—

6.1 Phase I

6.1.1 Assessment of existing datasets

This would involve the collation and digitising of existing datasets identified as being of potential use, including those which might be available from NRA estuary and coastal waters baseline surveys. The recommended methods and measures would then be tested on the digitised datasets, in particular to assess the effect of various factors on the robustness of the measures and on the amount of variability within subtidal estuarine and coastal water macrobenthic communities. The factors for assessment would include:

- season of sampling;
- sampling effects e.g. size of grab, sieve mesh size, type of grab;
- spatial (e.g. salinity) differences in estuaries and coastal waters;
- temporal differences in estuaries and coastal waters;
- number of samples required at each site to achieve the desired precision in classifying tidal waters.

This initial assessment will lead to recommended standard sampling procedures (e.g. seasonal sampling or not, grab size, mesh size) for use in subsequent data collection surveys.

6.1.2 Collection of new data

The suggested sampling programme would be implemented to agreed procedures and with the appropriate AQC and QA established. There would potentially be two seasons over which new data could be collected before the implementation of the scheme by winter 1994.

6.1.3 Testing of measures

This would involve analysing and testing the data from the surveys as it became available. Effects of factors such as level of taxonomic precision could be assessed during this stage. This would lead to the establishment of a preliminary EQI, based on the suitable existing datasets and on the first seasons new data. The EQI would be further tested and developed once the second season's data became available and this would lead to derivation of the preliminary classification scheme.

6.2 Phase II

It has been assumed that the preliminary classification would be implemented in time for the 1995 national water quality survey. Data arising from this survey could not only be used for classifying the estuary or coastal water but also to further calibrate/validate the EQI and classification scheme. At this stage it might be appropriate to re-assess the need for a RIVPACS type model for saline waters, and if this remained a long-term objective, make further plans for its development.

7. PROJECT MANAGEMENT

Three main groups of activities have been identified as the constituent parts of the development of biological components of the classification scheme for estuaries and coastal waters, namely:

1. Database establishment.

2. Development of EQI.

3. Derivation of the classification scheme.

These groups of activities can proceed independently for a certain time before results from one group are required for the development of another. One of the most important roles in a large scale multidisciplinary project such as this would be the management of the project. A central co-ordinating and management group would be needed to act as a focus for collection and manipulation of data, and for development of the index. This could be achieved either totally through NRA personnel or by the appointment of a specialist subcontractor for appropriate aspects of the project. Ideally the resource for sampling and sample analysis would be available within the NRA, indeed a large part of the required resource would be already allocated to current NRA monitoring programmes.

8. RESOURCE REQUIREMENTS

The establishment of the required database for model development would represent a major investment of resources by the NRA. How much of this cost would represent 'new' resource as opposed to using present resources on additional or new duties would depend upon the availability of the required expertise within the NRA (e.g. marine biologists) and its availability in relation to present duties. An estimate of these costs, with the assumptions made, are presented in Table 8.1.

These are only estimated costs. They could be reduced by decreasing the number of sampling days required, which would be possible if more than one coastal location or estuary could be sampled a day.

This amount of sampling is likely to have only relatively minor resource implications for the NRA as only 45 boat days and around 135 man days would be required. Also the required resource would be spread around the regions and perhaps could be readily incorporated with current duties. Some of the expenditure is already incurred by regions in meeting the requirements of the national marine baseline programme.

There would also be costs associated with the management of the study and for the development of the EQI and the classification scheme.

1. Project management: Co-ordination of project and contributing regions, establishing and supervising subcontracts (if required), reporting etc. 0.5 man years a year for three years.

2. Assessment of existing datasets: Collection and digitising of existing datasets, testing of recommended measures. 1.5 man years over one year.

3. Establishing QA procedures and audit trail. Visit all sampling teams and NRA Regions, discuss requirements, on-site supervision in initial phases. 0.5 man years, first year, 0.25 man years a year subsequent two years.

4. Collation of data. Collection of data from new surveys, development of database. 0.25 man years a year for two years.

5. Development of EQI and preliminary classification scheme. Manipulation of data, testing data in different model formats, consulting with other experts in the field. 1.0 man years a year for three years.

A more extensive database would be required to develop a multivariate predictive, RIVPACS type, model for estuaries and coastal waters. This type of model would not be achievable within the immediate time constraints on the NRA but might remain a longer term aim. If so the cost of establishing the initial database was estimated to be £207K for estuaries and £411K for coastal waters for the first year of data collection. The model database would then have to be progressively developed and extended over subsequent years. As an example of the possible time scales involved the Phase I development of the RIVPACS model took place between 1977 and 1981 when 268 sites on 41 river systems were sampled. During Phase II (1981-1984) this was expanded to 370 sites on 61 rivers.

The development of the biological components of the classification will not only contribute to the overall assessment of water quality for comparison against the SWQO but potentially will have additional 'spin-off' benefits for the NRA. For example, a structured sampling programme associated with the development and implementation of the scheme will enable the NRA's marine biologists to have a role as clearly defined as it is for freshwater and fishery biologists. An extensive and quantitative database will also be established which potentially will have additional uses, for example in setting biologically based EQSs for General and Special Ecosystem Use in coastal and estuarine waters, or assisting in the implementation of the proposed EC Directive on Ecological Quality of Surface Waters. There might also be a spin-off in developing management plans for estuaries and coastal waters which could include conservation criteria such as the identification of locally and nationally important biological communities. The classification database could be of great value in establishing such conservation criteria.

Table 8.1 - Estimated annual resource and costs required for collecting data in the initial phases of development of the classification scheme

		Coastal	Estuary
Number of locations		22	23
Number of sites		66	69
Replicates		4	4
Seasons		1	1
ANALYSIS			
Number of samples		264	276
Cost of sample analysis			
i)	macrobenthos (species level)1	£ 40K	£ 41K
ii)	particle size distribution 2	£ 12K	£ 12K
iii)	organic carbon*3	£ 15K	£ 15K
iv)	heavy metals*4	£ 18K	£ 19K
SAMPLING			
Boat days+		22	23
Boat cost~		£ 17K	£ 17K
Sampling staff days#		44	46
Staff cost &		£ 4K	£ 5K
Site assessment^		£ 2K	£ 2K
Total		£ 108K	£ 111K

Key:

1	NRA cost per sample of £150
2	NRA cost of £45 a sample (£5 for laser analysis and £40 for initial separation of gross fractions)
3	NRA cost of £55 a sample, £40 for initial fraction separation and £15 for CHN analysis
4	NRA cost of £30 a sample (including Hg)
*	Includes cost of separation of <63 μm fraction (£40 a sample)
~	NRA cost of £750 a day for Vigilance class boat
+	Based on a day sampling for each estuary and coastal waters location
#	Based on two people sampling per boat day
&	Based on NRA grade 6 cost of £101 per day (£24K a year)
^	Based on one grade 6 day per location

Note: Some of the above costs would already be incurred in meeting the requirements of the national marine baseline programmes

9. CONCLUSIONS AND RECOMMENDATIONS

1. A range of methods exist for assessing the pollution status of marine and estuarine benthic communities. Each method has both conceptual advantages and disadvantages. There is no general consensus on which method to use for particular applications and it is unclear which would be most suitable and robust, a priori, for the development of a classification scheme for saline waters.

2. The suitability of the following measures of pollution stress in macrobenthic communities and modelling approaches for development of a classification scheme should be assessed on a selection of existing marine and estuarine datasets or on new ones as they become available:

   - univariate non-predictive model based on SAB statistics and/or a biotic index;
   - multivariate non-predictive modelling based on non-metric multidimensional scaling ordination.

3. The performance of the above measures should be assessed at species, and family levels.

4. A phased approach is recommended for the development of a classification scheme, the immediate aim being the development of an interim scheme for implementation by winter 1994. The EQI and classification scheme could then be progressively refined and developed as more data are acquired and as more estuaries and coastal waters are sampled for classification purposes. In particular, it would require relatively little extra effort to develop a univariate predictive model as this could be a natural progression or development from the univariate non-predictive approach.

5. A number of existing estuarine and coastal waters datasets were identified which potentially could be used in the development of the interim EQI and classification scheme.

6. In addition, a proportion of the identified surveys are ongoing and with only a small alteration to the existing sampling programmes, to standardised and agreed methods, could also be used in the development of the classification.

7. It is recommended that 23 estuaries, including those in the NRA baseline estuary monitoring programme, are initially selected for inclusion in the database. If there were a minimum of three sites per estuary, there would be 69 sampling sites. If four replicate samples were taken at each site there would be 276 samples per survey.

8. It is recommended that a total of 22 coastal locations are initially selected for inclusion in the classification database. Three sites spanning the inshore and offshore zones should be sampled at each location and with four replicates at each site there would be a total of 264 samples per survey.

9. Sample sites should also be located away from the zone of immediate impact (mixing zone) of any discharges, and at points where they reflect more general levels of water quality.

10. It is recommended that supportive physico-chemical measurements are undertaken during sampling for the macrobenthos. Other supportive data would also be required for each sampling site.

11. It is recommended that appropriate AQC and QA procedures for both chemical and biological determinands are adopted and that these should be established before any data collection is undertaken.

12. It is estimated that the cost to the NRA of collecting and analysing the samples (macrobenthos and physico-chemical determinands) would be in the order of £108K a year for the coastal scheme and £111K a year for the estuarine, depending on the sampling regime adopted.

13. There would be additional costs involved with; the management of the project, the assessment of existing datasets, the establishment of QA and audit trail procedures, the collation of data and with the development of the model, amounting to approximately £300K over three years.

14. A more extensive database would be required to develop a multivariate predictive, RIVPACS type, model for estuaries and coastal waters. This type of model would not be achievable within the immediate time constraints on the NRA but might remain a longer term aim. If so the cost of establishing the initial database was estimated to be £207K for estuaries and £411K for coastal waters for the first year of data collection. The model database would then have to be progressively developed and extended over subsequent years. As an example of the possible time scales involved the phase I development of the RIVPACS model took place between 1977 and 1981 when 268 sites on 41 river systems were sampled. During Phase II (1981-1984) this was expanded to 370 sites on 61 rivers.

REFERENCES

Codling, I.D., Nixon, S.C. and Platt, H.M. (1991) The Mersey estuary: an assessment of the biological status of intertidal sediments. NRA Project Report 106/1/NW.

Davidson, N.C., Laffoley, D.d'A., Doody, J.P., Way, L.S., Gordon, J., Key, R., Drake, C.M., Pienkowski, M.W., Mitchell, R. and Duff, K.L. (1991) Nature conservation and estuaries in Great Britain. Peterborough, Nature Conservancy Council.

Elliot, M. and O'Reilly, M.G. (1991) The variability and prediction of marine benthic community parameters. From: Estuaries and coasts: spatial and temporal intercomparisons. Eds. Elliot, M. and Ducrotoy, J.P. Published by Olsen and Olsen.

MAFF (1989) First report of the Marine Pollution Monitoring Management Group's Co-ordinating Group on Monitoring of Sewage-Sludge Disposal Sites. Aquatic Environment Monitoring Report 20. Directorate of Fisheries Research, Lowestoft.

Milner, N.J. (1985) Habitat evaluation as a fisheries management tool. *Journal of Fish Biology*, 27, (Supplement A), 85-108.

MPMMG (1991) The principles and practice of monitoring in UK coastal waters. A report from the Marine Pollution Monitoring Management Group (MPMMG). Department of the Environment.

Nixon, S.C., Codling, I.D., Ashley, S.J., Ashby-Crane, R.E. and Crane, M. (1992) Predictive invertebrate community models for estuaries and coastal waters - project definition study. NRA Project Record 324/4/S.

NRA (1991a) NRA baseline estuary and coastal waters monitoring programme. NRA internal document dated 2 January 1991.

NRA (1991b) Proposals for statutory water quality objectives. Water Quality Series No.5, December 1991.

Owens, M. (1991) Estuarine and coastal water quality classification - Phase I: A review of the proposals of the NRA Water Quality Survey Sub-Group. NRA R&D Note 23.

Pearson, T.H. and Rosenburg, R. (1978) Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanogr. Mar. Biol. Ann. Rev.* ***16***, 229-311.

Rees, H.L., Moore, D.C., Pearson, T.H., Elliot, M., Service, M., Pomfret, J. and Johnson, D. (1990) Procedures for the Monitoring of Marine Benthic Communities at UK Sewage Sludge Disposal Sites. Scottish Fisheries Pamphlet No. 18.

Warwick, R.M. (1988) The level of taxonomic discrimination required to detect pollution effects on marine benthic communities. *Marine Pollution Bulletin* **19**(6), 259-268.

Warwick, R.M. and Clarke, K.R. (1991) A comparison of some methods for analysing changes in benthic community structure. *Journal of the Marine Biological Association UK*, **71**, 225-244.

Wood, E.M. (1987) Subtidal ecology. Edward Arnold Ltd.