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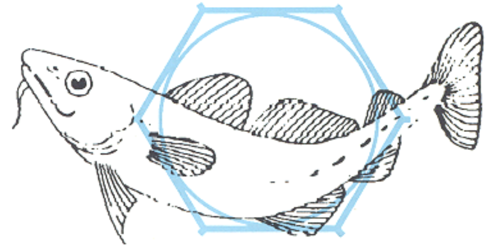

Third Report of the Marine Pollution Monitoring Management Group's Co-ordinating Group on Monitoring of Sewage-Sludge Disposal Sites

MAFF

Directorate of Fisheries Research
Lowestoft, 1991

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD
DIRECTORATE OF FISHERIES RESEARCH

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Third Report of the Marine Pollution Monitoring Management Group's Co-ordinating Group on Monitoring of Sewage-Sludge Disposal Sites

LOWESTOFT
1991

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FOREWORD

This, the third report of the Co-ordinating Group on Monitoring of Sewage-Sludge Disposal Sites (CGMSD), describes the progress made by the Group during 1990.

The Group was established in 1987 when, following a review of existing monitoring, it had become apparent to the Marine Pollution Monitoring Management Group (MPMMG) that UK effort and resources, applied to scientific investigations and monitoring of the impact of disposal of sewage sludge at sea, were uncoordinated and contained many inconsistencies.

The Group's first report addressed these problems directly and contained a set of environmental quality objectives (EQOs), with the appropriate environmental quality standards (EQSs), which have common applicability and represent good technical and environmental practice. That first report also provided details of procedures to be followed when conducting monitoring of fish diseases, certain microbiological components, benthic community structure, metals in sediments and a number of method-determined sampling and analytical procedures.

The second report continued with this theme of guidance and included details of procedures for studies on biological effects, that can be used to provide evidence of deterioration in environmental quality as a consequence of the disposal of sewage sludge. The second report also gave details of the start made in 1989 in defining EQSs for some of the EQOs which are more difficult to quantify.

That work continued throughout 1990 and there is reasonable expectation that the first proposals for EQSs, based on acceptable levels of ecological change and acceptable concentrations of contaminants in sediments, will be made by the end of 1991. Details of the likely directions which the development of these standards will take are included in this report.

The report also includes an assessment of the monitoring conducted in 1989, and the extent to which: (a) the methods used complied with the CGMSD guidance; and (b) the results demonstrate that the defined EQOs and EQSs for sewage-sludge disposal sites are being met. Details are also given of the monitoring of sewage-sludge disposal sites, carried out during 1990 by the various licensees operating throughout the UK and by the licensing authorities (SOAFD/DOE(NI)/MAFF).

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EXECUTIVE SUMMARY

In this third report, the Co-ordinating Group on Monitoring of Sewage-Sludge Disposal Sites (CGMSD) details the activities of its Task Teams, continues its evaluation of monitoring, by assessment of programmes undertaken in 1989, and summarises research activities carried out during 1990.

Work is still in progress on further defining the environmental quality objectives (EQOs) and environmental quality standards (EQSs) outlined by the CGMSD in its first report (MAFF, 1989) and developed in its second report (MAFF, 1990).

On the whole, it is apparent that most monitoring at sewage-sludge disposal sites is now being conducted according to the guidelines recommended by the CGMSD. Where other methods are still in use, in most cases, there is either an over-riding need to maintain continuity with a long time series of earlier data or the work is being specially undertaken by a licensee as a gross check on a particular situation and not to demonstrate compliance with an EQS.

From the results of the monitoring conducted in 1989, it is clear that generally the health of the ecosystem and the quality of the environment are not adversely affected by the disposed material, although sewage-derived litter was detected at a number of disposal sites. As a consequence, thorough surveys at all sites are recommended, together with the collection of data on the more general distribution of litter outside sewage-sludge disposal sites.

Marked effects on the benthos are apparent only at the Garroch Head site, which is recognised as a disposal site with only limited dispersion. Even at this site, there are no unacceptable effects outwith the mixing zone. The quality of commercially exploited fish caught on, or close to, all of the disposal sites is acceptable for human consumption in terms of contaminant levels, and there is no evidence that fish are more diseased in these areas than elsewhere. Despite this lack of an obvious relationship between disease and the disposal operation, investigations into the prevalence of fish diseases are recommended for future years. Surveys on sediment quality should also be continued to confirm that no slow, long-term build up of contaminants is occurring.

Studies on benthic species continue to offer a reliable means of establishing one of the potential primary impacts of sewage sludge. In order to be properly quantitative, these studies need to feature replicate samples at each station. In the 1989 monitoring surveys, this requirement was not met in a number of cases. Nevertheless, whilst neither single grab samples nor beam trawl surveys produce quantitative data, they do serve to show that, contrary to popular perception, sewage-sludge disposal sites are not characterised by sparse and restricted faunas.

This report refers to a new survey technique (REMOTS) which was applied at the Garroch Head site in 1989. REMOTS is an instrumental optical coring device which takes photographs remotely of the upper 20 cm profile of the sea floor and is well suited for observing organic enrichment in fine sediments. The REMOTS system appears to show considerable promise and should be applied further so that its true value can be assessed.

1. INTRODUCTION

Following a review in 1985 of monitoring, as it was then conducted at the various sewage-sludge disposal sites around the UK, the Marine Pollution Monitoring Management Group (MPMMG) concluded that proper goals for the monitoring needed to be specified and that standards were required against which it would be possible to assess whether or not detectable effects occurred and whether they were acceptable. In order to achieve this task and to coordinate monitoring as far as practicable, it was agreed that a Co-ordinating Group on Monitoring of Sewage-Sludge Disposal Sites (CGMSD) should be established. Following discussions with the then Water Authorities Association and others, the CGMSD met for the first time on 3 September 1987 with the following terms of reference:

(i) to continue to evaluate sewage-sludge monitoring programmes, and advise on their development and co-ordination, to make best use of available resources, expertise and techniques — where appropriate, recommendations should be made for the termination of ineffective programmes;

(ii) to identify and report upon those areas where research is necessary in support of monitoring;

(iii) to verify methods, develop standard protocols and intercalibrate analyses used in monitoring programmes;

(iv) to formulate environmental quality standards (EQSs) against which monitoring programmes could be designed and results assessed;

(v) to advise on responses to technical issues arising at the Oslo and London Conventions on disposal of wastes at sea;

(vi) to encourage the production of regular reports on the progress and results of monitoring by those responsible for the conduct of the programmes; and

(vii) to produce an annual review of monitoring carried out at all sites, which would be made widely available.

Arising from these terms of reference the CGMSD set itself the following aims:

(i) to define environmental quality objectives (EQOs) to be met at sewage-sludge disposal sites and the development of standards by which the meeting of those objectives could be verified;

(ii) to develop detailed guidelines for monitoring using micro-biological determinands, biological effects techniques, sediments, biota and water; and

(iii) to produce a report on monitoring conducted in 1987 and 1988.

The CGMSD has since published two reports — in the autumn of 1989 (MAFF, 1989) and spring of 1991 (MAFF, 1991(a)).

The first report laid down a set of common environmental quality objectives (EQOs) and described a set of environmental quality standards (EQSs) by which the fulfilment of the objectives could be judged. Detailed guidelines were laid down for certain types of monitoring, particularly for those parameters for which the method used determines the results such as Eh and organic carbon. Guidance was also provided on the procedures to be followed for certain types of biological monitoring (benthos and prevalence of fish disease) and for metals in sediments. A brief outline was also provided of the monitoring being carried out at sewage-sludge disposal sites in 1988.

The second report described the progress being made with the actual definition of EQSs and gave further detailed guidance on the methods to be used to monitor compliance with these standards. The report also contained a detailed review of the monitoring actually conducted in 1988 and in particular commented on the extent to which it met the needs identified by the CGMSD. A brief outline was also provided of the monitoring being conducted at sewage-sludge disposal sites in 1989.

The CGMSD continued to pursue the goals originally assigned to it throughout 1990 and the report which follows details the progress achieved in the development of standards for assessing change in the benthos, and the significance of levels of metals and organics in the environment — particularly in the sediments at sewage-sludge disposal sites. As with the two previous reports, important chapters of this third report of the CGMSD are an outline of the monitoring conducted in 1990 and a review of the results of work conducted in 1989 and the extent to which they met the CGMSD objectives. 1989 was the first year for which the CGMSD guidelines and objectives were available to the licensees and monitoring organisations. Thus, an important aspect of the review of the work done is the extent to which it meets the defined requirements.

A list of the members of the CGMSD in 1990 is given at Annex 1.

2. TASKS UNDERTAKEN BY THE CGMSD IN 1990

From the start, the CGMSD was intended to be a group which advises on policy and demonstrates through its reports the extent to which its advice is implemented, both by the licensees and by the regulatory agencies (for England and Wales: Ministry of Agriculture, Fisheries and Food (MAFF); for Scotland: Scottish Office Agriculture and Fisheries Department (SOAFD); and for Northern Ireland: Department of the Environment (Northern Ireland) (DOE (NI)). That being so, the main group has a restricted membership and much of the detailed work is undertaken by specialist Task Teams. This allows input by a wide range of organisations with relevant expertise, including several not directly associated with monitoring sewage-sludge disposal sites. By this means, every effort is taken to ensure that the work of the Group overall is kept outward looking. Three such Task Teams have been active during 1990. An Organics Task Team and a Metals Task Team undertook the following tasks:

(i) the conduct of analytical intercomparison exercises for the determination of organics or metals in sediments, the ultimate aim of which is the production of detailed guidance on procedures to be followed and possible pitfalls; and

(ii) the development of standards against which to judge the results of measurements of organics and metals in sediments and hence to assess whether or not the EQOs are met.

The Biology Task Team dealt with aspects of biological effects and undertook the following tasks:

(i) the development of qualitative and quantitative standards for assessing compliance with biological quality objectives — particularly those for benthos;

(ii) the conduct of an intercomparison exercise for benthos identification;

(iii) an evaluation of the advantages and disadvantages of pooling data on benthos identification to higher taxonomic levels; and

(iv) agreement on the use of a common coding system for details of benthic species.

In the course of 1990, the CGMSD met on three occasions to review progress by the Task Teams, plan its future activities and finalise its second report. The CGMSD also discussed the need to respond to the changing scene of sewage-sludge disposal and pressures generally to assess the impact of waste disposal practices on the marine environment.

Early in 1990, the UK Government announced that disposal of sewage sludge to sea would cease by the end of 1998. That decision took account of international pressure to end the practice and the development of alternative disposal methods perceived as having greater acceptability. The decision was not influenced by any findings of environmental damage as a consequence of the disposal of sewage sludge to sea.

The issue of licences for sea disposal will be maintained as necessary until the end of 1998. Accordingly, there is a continuing international duty to make the results of monitoring known to the signatories of the Oslo and London Dumping Conventions (Great Britain — Parliament 1972(a)(b)) and thus all licences will continue to include a monitoring requirement. That obligation apart, it is desirable that monitoring should continue at the currently used sites in order to establish whether changes occur after cessation of disposal. Such monitoring could concentrate on changes over time and would recognise the fact that carefully designed monitoring for temporal, as opposed to spatial, change is relatively new at most sites. Thus, subtle changes that may have occurred over long periods may have been missed by previous studies and will only be revealed as changes occur once disposal ceases.

3. PROGRESS BY THE TASK TEAMS

A list of the various Task Teams (and their membership) operating in 1990 is given at Annex 2.

3.1 The Biology Task Team

Having completed its assessment of the suitability for routine monitoring purposes of techniques involving sub-lethal responses of marine species to contaminants (MAFF, 1990), the Biology Task Team has concentrated on particular aspects of benthos study technique and the development of standards against which the extent of change in the benthos can be assessed.

The Task Team organised and conducted an intercomparison exercise for the identification of benthic samples, which involved twelve laboratories. Samples were taken by staff of the University College of North Wales, Menai Bridge Laboratory, from a shallow, sandy location off Anglesey. The results were generally encouraging and showed that, for important factors such as numbers of quantifiable taxa and total abundance, the coefficients of variation were less than 20%. A second and more demanding exercise, involving standardisation of the taxonomy, is being organised during 1991. It will involve samples from an offshore disposal site.

Using actual data sets for typical disposal sites, the Task Team has devoted considerable effort towards comparing the conclusions that can be drawn from data obtained by identification of benthic fauna to the species level and those from identification to higher taxonomic levels (i.e. to family level or above). It seems likely that, in most cases, identification of taxa to family level only, will result in very little loss of definition of differences between stations and over time. However, a final recommendation as to this level of pooling cannot be made until discussions on the development of practical standards for assessing change in the benthos are concluded.

The Task Team has considered several possible taxonomic coding systems and focused in particular on those proposed by the Marine Conservation Society (MCS) and the National Oceanographic Data Centre (NODC). A number of problems were identified with the comparatively simpler MCS system and the Task Team has recommended that the NODC system be adopted, chiefly on the grounds of its much greater flexibility. The CGMSD has accepted this recommendation and trials on its application are currently in progress.

The Task Team has continued to explore methods for reliably identifying changes in benthos structure. The EQS states that there should be no change relative to the natural change that occurs in similar adjacent areas, but this begs the question as to the detectable level of change. The Task Team is hoping to be able to recommend a procedure which is capable of identifying a change of 20%, at least in some measures of data structure. Achieving such a level of precision will be as much a function of the number of samples taken, as of the analytical method employed. A number of approaches have been, and continue to be, tested. Three techniques appear to show particular promise: abundance biomass comparison (ABC); multi-dimensional scaling (MDS); and species abundance biomass curves (SAB). Thus far, none appears to suffer appreciable loss in sensitivity due to pooling identification of sample material to the family level only. The various techniques are now being subjected to further testing and will be scored according to their sensitivity, amenability to statistical testing, effect on precision of pooling data, ease of use, ease of interpretation and range of applicability (i.e. dispersive sites versus sites with limited dispersion).

In the course of the debate on how to derive an EQS for change in the benthos an alternative approach was identified. This is the use of a biotic index — a system which has been successfully used in the freshwater environment for a number of years to describe variations in water quality. Such indices are based on practical knowledge of responses of a range of taxa to changes in habitat or to pollution. They are therefore based on observational ecology rather than on mathematical theory. Since certain responses of marine species can be predicted in relation to the main pollution impact of sewage sludge, viz. organic enrichment, the use of a similar approach in monitoring sewage-sludge disposal sites seems promising. The Task Team proposed a desk study to be conducted to test the applicability of the approach, and estimated that at least six months of work would be necessary. The CGMSD has endorsed the proposal and it has been adopted by the Scottish and Northern Ireland Forum For Environmental Research (SNIFFER), as part of its 1991/92 programme, with a representative from MAFF as one of the project leaders.

3.2 The Organics Task Team

During 1990, the Organics Task Team addressed two questions: the comparability of data from analysis of environmental samples for organics; and the question of how to set standards for organics in sediments.

Two intercomparison exercises were run — one for pesticides and the other for polychlorinated biphenyls (PCBs). Both involved analysis of an unknown solution and a distributed standard. Since the aim of the exercise was primarily to establish a proven protocol for a 'follow-up' exercise which would involve all of the organisations involved in monitoring sewage-sludge disposal sites, participation was deliberately restricted to the organisations represented by the Task Team. The results of both exercises were quite good, when judged in terms of the levels of accuracy and precision achieved, but the level of participation was disappointingly poor with several members claiming that pressure of routine analysis inhibited the effort which they could apply to quality control. A second intercomparison exercise for PCBs was nearing completion at the end of 1990. The preliminary results were less satisfactory and indicate that further work will be needed to bring the majority of laboratories involved in the determination of organics up to a level of achievement that will allow reliance to be placed on their results.

The Task Team is addressing the question of standards using a dual approach. The first is to consider the levels of a contaminant which may cause biological effects. The second approach is based on the premise that present international opinion would not regard an increase in concentration of a contaminant in sediments in the sewage-sludge disposal site as acceptable. Thus, the EQS is based on the increase in concentration that is detectable with a defined level of statistical confidence. Given the level of performance achievable by most laboratories at present, the Task Team is reluctant to pursue this approach on the grounds that detection of change is either simply not practicable or would only be so if the change were very large. Such a position is inconsistent with the EQS. Accordingly, the CGMSD has recommended that interim standards be set on the basis of the precision which the laboratories of the licensing authorities can achieve. The laboratories of the licensees will then have to meet this requirement and the urgency of the need for analytical improvements and quality control will be emphasised.

3.3 The Metals Task Team

During 1990, this Task Team addressed the same topics as the Organics Task Team. For the same reasons as those of the Organics Task Team, participation in its intercomparison exercise was restricted to the organisations represented on the Task Team. The intercomparison programme used a sediment sample (from the Garroch Head disposal site). Digestion was carried out by all participating laboratories; half of each digest was analysed 'in-house' by the laboratories and the other half was analysed centrally by the Water Research Centre (WRc). Taking these results, together with an earlier comparison of sieving methods, the Task Team concluded that the sieving and digestion steps of sediment processing are acceptable, but that the analytical stage needs further comparison. This will be carried out in 1991 and will be followed by an exercise comparing the whole sieving/digestion/analytical procedure and involving all organisations engaged in monitoring of sewage-sludge disposal sites.

In the light of the results of its intercomparison exercise, the Task Team is confident that it will be able to set standards based on the level of detectable change, which will clearly differ from metal to metal. There are two further disadvantages to this approach. Firstly, the standards will have to allow for a 'mixing zone'. Secondly, and perhaps more importantly, the standards will differ from disposal site to disposal site and will be less stringent in areas where the natural variability is high.

For these reasons, the Task Team is anxious to develop 'effects-based' standards. Two approaches, that appear to have been used successfully in other countries, are being investigated. The first applies water quality standards to set the maximum concentration permissible in the interstitial water of sediments. The concentration in interstitial water can be calculated using formulae, taking account of the composition and chemical equilibrium values of the sediment in question. The alternative approach relies on determination of biological effects in laboratory trials and field surveys and results in the derivation of an apparent effect threshold (AET).

Both approaches are being tested using data from sewage-sludge disposal sites and the preliminary results available at the end of 1990 were promising. It is anticipated that, during 1991, standards will be proposed for some metals using the criterion of detectable change and possibly also using the AET system.

4. REVIEW OF MONITORING AT SEWAGE-SLUDGE DISPOSAL SITES DURING 1989

4.1 Introduction

This section follows the convention established in the second report of the CGMSD (MAFF, 1991) and assesses whether various monitoring programmes meet the goals described in the first report (MAFF, 1989). It deals primarily with examples of surveys undertaken in 1989. Nearly all of these followed the CGMSD guidelines for analytical methodology (MAFF, 1989). However, in some cases, where consistency with earlier work was judged to be more important than comparability with work at other sites, long-established procedures were retained. Notable examples of this latter practice were the studies of chemical determinands in sediments from the Liverpool Bay and Bell Rock sites.

Some sewage-sludge disposal sites are surveyed in detail only every 2 or 3 years, and therefore results are not available for all sites in all years. Table 1 lists the surveys carried out in 1989 and shows that some work was undertaken at every site. However, this report does not cover all of that work, as the aim here is primarily to show examples of monitoring; many programmes are not suitable, because they are aimed at established trends over time. Accordingly, examination of data from individual surveys is of limited value.

The following discussion is arranged according to the various EQOs set by the CGMSD (MAFF, 1989) and any relevant EQSs are given at the start of each subsection.

4.2 EQO: Prevention of aesthetic problems and interference with other legitimate uses of the sea

Aesthetic problems are likely to arise if floatables and sewage debris (i.e. large detrital material of sewage origin) are present at or around sewage-sludge disposal sites. The CGMSD considers the only acceptable standard is that these should not be found to occur in the area of disposal, either in surface trawls or in bottom trawls, dredge or grab samples. If significant evidence of such solids is found in the area of disposal, screening at the sewage works of the inflow effluent or the outflow sludge may have to be undertaken. Since it is conceivable that not all of the sewage-derived solids are of sludge origin, the CGMSD recommends that subsequent compliance with the standard should be checked, primarily by monitoring sludge quality at the point of loading, to show no retention of solids on a

Table 1. Summary of procedures used in monitoring surveys at sewage-sludge disposal sites in 1989

Area/authority	Sediment					Benthos, epibenthos	Water bioassay/ quality	Fish disease	Underwater video	Litter assess-ment
	Metals	C/N	Organic micro-contam-inants	Micro-biology	Chemical tracer					
Tyne										
MAFF	+	+	+			+	+	+	+	+
Northumbrian Water plc	+					+			+	
Humber										
MAFF			+			+				
Roughs Tower										
MAFF	+	+		+		+				
Anglian Water plc	+	+			+					
Barrow (Thames Estuary)										
MAFF	+	+				+				
Nab										
MAFF	+	+				+				
Southern Water plc	+	+	+	+						
Exeter										
MAFF	+	+	+	+		+				
Plymouth										
MAFF	+	+		+		+				
Bristol Channel										
Welsh/Wessex Water plc							+			
Liverpool Bay										
MAFF	+	+	+							
North West Water plc	+				+	+	+	+		
North Channel										
DOE (NI)	+			+		+				
Garroch Head										
SRC/SMBA	+	+	+			+	+	+		
SOAFD				+				+		
Bell Rock										
LRC/FRPB	+	+	+			+		+		
SOAFD						+		+		
St Abbs Head										
LRC/FRPB	+	+	+			+		+		
SOAFD						+		+		

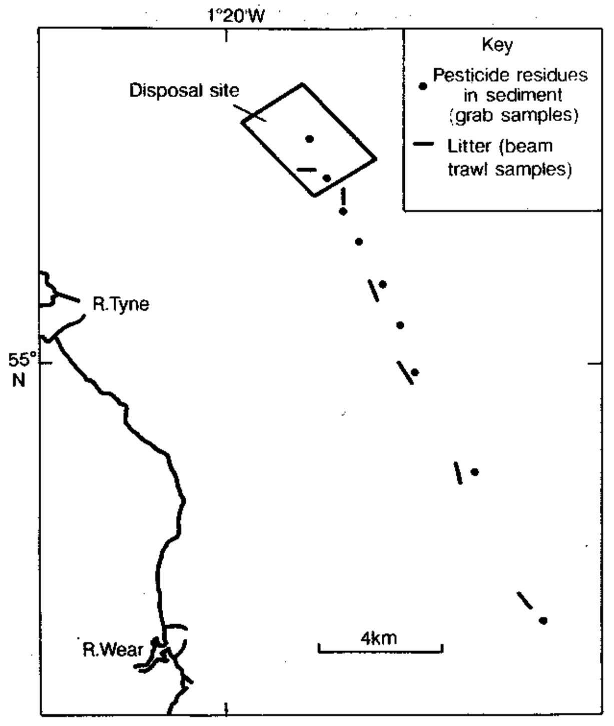

Figure 1. Transect showing stations near the Tyne sewage-sludge disposal site, sampled for pesticide residues and litter in May 1989

5 mm sieve. Turbidity and the presence of floatables and persistent sewage debris (MAFF, 1989) are suitable measures for the assessment of this EQO. No measurements of turbidity or floatables were reported for 1989 but observations of sea-bed litter were made at the Tyne and Garroch Head sites.

As in earlier surveys (MAFF, 1991(a)) litter was common in beam trawl samples collected at, and immediately south of, the Tyne site (Figure 1 and Table 2). Much of this litter was sewage-derived, including tissue paper, tampons, sanitary towels, hair and vegetable matter (largely potato peelings and onion skins). Samples collected further south showed less evidence of sludge-derived material although it should be noted that a fragment of plastic derived from a sanitary towel was found 16 km distant from the centre of the disposal site. The origin of this material must, however, remain open to question as nearby coastal discharges of sewage may also be a source of such material.

Sewage-derived debris was also observed in otter trawl samples taken at the Garroch Head disposal site. No details for 1989 were supplied to the CGMSD, although it was reported that the quantities taken across the centre of the site were similar to those collected in 1988 and considerably less than those from the period prior to 1988.

As in previous years, the value of trawl samples in observing compliance with this EQS has been shown. This is emphasised by Table 3 which lists the range of materials collected at several sewage-sludge disposal sites during the period 1985-1989 and suggests that, while rubbish is ubiquitous, sanitary products are restricted to the Tyne site. It must be noted that the trawls were used primarily for individual biological projects, and involved differing numbers of tows. Comparisons must therefore be made with caution. Further work should be carried out to sample sewage-sludge sites more generally in order to provide a more comprehensive picture of contamination. The work should be carried out by the licensing authorities who, for legal reasons, are able to use finer mesh nets than non-governmental organisations (MAFF, 1991(a)).

Table 2. Litter collected in beam trawls in the vicinity of the Tyne sewage-sludge disposal site, May 1989

	Distance south of centre of disposal site (km)					
	16.1	11.6	8	5.2	2.1	0.9
Sanitary towel						4
Tampon					2	8
Human hair					+	++
Cigarette filters					3	36
String						+
Rag				+	+	+
Plastic	+	+	+		+	+
Plaster						+
Match						+
Potato peel						+
Onion debris					+	+
Tin can				+		
Volume of artefacts (ml)	<10	<10	<10	<10	75	500

Where possible, pieces of litter have been enumerated. Where this was not possible, if the class of litter was present it is indicated by + and if frequent by ++.

Table 3. Litter recovered using a beam trawl from several sewage-sludge disposal sites in 1985 and 1988-1989

	Site and date sampled					
	Tyne (1989)	Plymouth (1988)	South Falls (1985)	Exeter (1988 and 1989)	Roughs Tower (1989)	Thames (1985)
Coal	*	*				*
Rag	*	*				*
Clinker	*	*			*	*
Cigarette filter	*	*	*			*
Tin can	*	*	*		*	
Leaf litter	*	*		*		
Tissue paper	*	*		*		
String	*	*				
Plastic strips	*	*	*	*		
Cellophane	*	*	*	*		
Aluminium foil		*		*		*
Slate		*				
Brick		*				
Bone		*				
Wire		*				
Shoe		*				
Iron		*				
Twine		*			*	
Onion skin	*					
Tomato skin	*					
Tampon	*					
Plastic (solid)	*					
Corn plaster	*					
Adhesive tape	*					
Potato peel	*					
Sanitary towel	*		*			
Clay (spoil)			*		*	
Banana skin			*			
Pottery						*
Plastic cup						*
Elastic band						*
Glass					*	*
Tomato pips	*				*	*

4.3 EQO: Maintenance of commercial marine fish and shellfish at an acceptable quality for human consumption

No data specifically relating to sewage-sludge disposal sites were reported in 1989, although the National Monitoring Programme operated by the Fisheries Departments deals with the quality of fish all round the coast of the UK and includes areas around disposal sites. These data (Table 4) continue to indicate compliance with the European Commission (EC) and Paris Commission (PARCOM) EQS for mercury of 0.30 mg kg^{-1} representative wet fish flesh (MAFF, 1991(b)), Appendix 2 of that report), and the levels of other contaminants are not such as to give concern in relation to human health. Full details of this survey work are published periodically by the Fisheries Departments (see, for example, MAFF, 1991(b)).

Table 4. Concentrations of mercury in fish muscle in 1989

Area	Species	Number of fish analysed	Mean length of fish (cm)	Mean concentration of mercury in fish muscle (mg kg^{-1} wet weight)	Range of concentrations (mg kg^{-1} wet weight)	Standard deviation of data sets
Liverpool Bay	Cod	13	33.7	0.15	0.07-0.28	0.07
	Whiting	25	32.6	0.32	0.12-0.63	0.13
	Plaice	25	30.9	0.13	0.02-0.28	0.05
	Sole	22	25.7	0.18	0.09-0.27	0.06
	Flounder	31	32.2	0.16	0.07-0.28	0.06
	Dab	34	25.0	0.24	0.08-0.65	0.12
	All fish	150		0.16 *		
Morecambe Bay	Cod	25	42.1	0.13	0.06-0.24	0.04
	Whiting	25	31.8	0.22	0.11-0.49	0.08
	Plaice	25	31.5	0.12	0.07-0.20	0.04
	Sole +	19	30.3	0.15	0.06-0.30	0.06
	Flounder	25	34.6	0.24	0.14-0.35	0.06
	Dab	24	29.6	0.30	0.16-0.50	0.11
	All fish	143		0.18 *		

* = *Weighted mean based on the relative contribution of each species to the 1989 commercial landings from the area*
+ = *Sample obtained in February 1990*

4.4 EQO: Preservation of the general well-being of commercially exploited species

Samples of fish from control and disposal areas in the general vicinity of Garroch Head sewage-sludge disposal site were examined in 1989. The numbers of fish examined were small, with 24 in the control area and 69 at the disposal site. The samples comprised 7 species at the control area and 9 species at the disposal site (Table 5). The largest number of individuals per species at both locations was plaice, with 12 at the control area and 10 at the disposal site. No significant differences were noted in either external or internal abnormalities between fish at the control area or the disposal site.

At the Bell Rock and St. Abbs Head sites, 10 common dab (*Limanda limanda*) were collected from both control areas and disposal sites in 1989. The St. Abbs Head samples showed no sign of external abnormalities, while several fish at both the control area and disposal site at Bell Rock displayed abnormalities ranging from fin haemorrhaging, ulcers infected with *Vibrio* spp. to, in one case, a missing tail. Although the sample size was very small, levels of abnormality in the fish caught at both the St. Abbs Head and Bell Rock disposal sites were considered to be similar to those found in control areas and therefore normal.

The numbers of fish collected at the Garroch Head, Bell Rock and St. Abbs Head sewage-sludge disposal sites were well short of the 50 individuals per species which the CGMSD recommends should be analysed in order to give statistically reliable data. It should, however, be recognised that the surveys in question were conducted by the licensees and, as such, were intended as a gross check on disease status. Surveys by the SOAFD Marine Laboratory at the St. Abbs Head and Bell Rock sewage-sludge disposal sites and at control areas in 1989, showed no significant differences in the major fish diseases between the sites, or from the 1988 results. Significantly lower levels of the parasite *Zoogonoides* in *Buccinum* were found in sampling areas close to the Garroch Head disposal site than in areas 3 km away from the disposal site.

Experimental studies established that the RNA/DNA ratio in dab muscle was positively related to the growth rate. Experimental exposure of dab to 0.1% and 0.01% dilutions of sewage sludge found differences in growth rate and related trends in RNA/DNA ratios. Dab samples from Bell Rock and St. Abbs Head sewage-sludge disposal sites were found to have greater gut fullness and bile volume and higher RNA/DNA ratios than fish from a control area. These observations may suggest that the organic inputs enhance the food availability to some fish species. It may be speculated that this may be linked to the lower incidence of diseased fish at St. Abbs Head than in the control area.

Table 5. Fish samples collected at the Garroch Head disposal site and the control area in 1989

Species	Number	Size range (cm)	Gross pathology
Total catch at control area			
Plaice	12	20.9-33.0	N.A.D.
Long rough dab	3	18.0-18.9	One fish with parasitic cyst on pectoral fin
Hake	2	18.0-21.6	N.A.D.
Herring	2	21.7-24.2	One fish with spinal deformity
Whiting	2	20.2-20.5	N.A.D.
Witch	2	13.5-18.4	N.A.D.
Codling	1	20	N.A.D.
Total catch at disposal site			
Codling	24	18.1-29.4	N.A.D.
Haddock	18	20.9-28.2	N.A.D.
Plaice	10	16.6-27.0	N.A.D.
Whiting	8	19.9-25.6	N.A.D.
Saithe	3	28.5-36.8	N.A.D.
Herring	2	22.2-29.7	N.A.D.
Poor cod	2	13.8-14.3	N.A.D.
Norway pout	1	17.7	N.A.D.
Dogfish	1	N.R.	N.A.D.

N.A.D. = No abnormality detected
N.R. = Not recorded

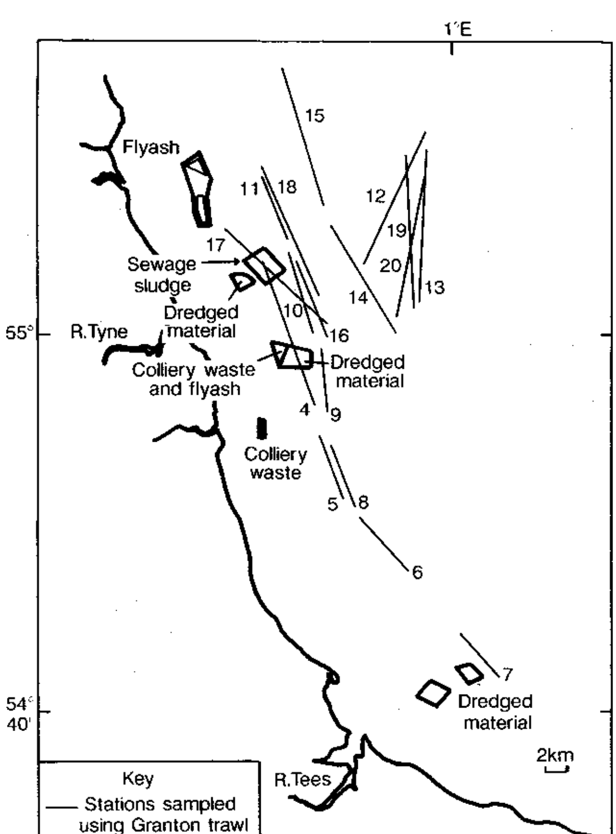

Figure 2. MAFF fish disease survey off the north-east coast of England in May 1989

Several types of waste are disposed of at sea off the north-east coast of England at a number of different sites. A survey of the prevalence of fish diseases was carried out at these sites, including the Tyne sewage-sludge disposal site, by MAFF in 1989.

A series of trawls was worked between Blyth and the Tees (Figure 2), the majority being associated with the assessment of disposal sites. Stations further offshore in deeper water were used as control areas. A total of 1548 dabs were examined, with 170 exhibiting lesions representing external diseases (Tables 6 and 7). The results revealed no significant differences in the prevalence of disease between stations.

Of the 189 livers from dabs >25 cm in length, which were subjected to histological examination, there was no macroscopical evidence of liver nodules >2 mm in diameter, but 7 were found to show changes associated with variability in cell storage. A total of 514 cod were examined, but evidence of disease was restricted to one fish with a small ulcer and 4 fish with skeletal deformities. The overall percentage prevalence of disease in cod was low, at <1% (Table 8) and was considered to be insignificantly low, both within the sewage-sludge disposal site and relative to other areas.

Table 6. Analysis of the prevalence of disease in dab around the north-east coast disposal sites in May 1989

Station	Sample Male	Sample Female	Size group (cm)	Lympho-cystis	Epi. hyp.	Ulcers	Liver nodules	Prevalence according to size (%)	Prevalence according to sample (%)
16-20	128	105	15-19	10	8	3	0	9.0	
	46	137	20-24	12	7	3	0	12.0	11.4
	0	67	>25	4	4	4	0	17.9	
10-15	140	117	15-19	10	7	5	0	8.6	
	60	188	20-24	21	10	6	0	14.9	13.1
	5	70	>25	6	4	7	0	22.7	
6-9	59	69	15-19	4	0	1	0	3.9	
	18	69	20-24	8	2	2	0	13.8	7.9
	0	26	>25	2	0	0	0	7.7	
5	18	27	15-19	4	1	0	0	11.1	
	6	24	20-24	0	0	1	0	3.3	8.2
	1	9	>25	1	0	0	0	10.0	
4	45	29	15-19	0	0	2	0	2.7	
	11	53	20-24	5	3	1	0	14.1	9.7
	0	17	>25	2	0	1	1	23.5	

Epi. hyp. = Epidermal hyperplasia

Table 7. Distribution of epidermal diseases in dab around the north-east coast disposal sites in May 1989

Station	15-19 cm size group				20-24 cm size group				>25 cm size group			
	No. exam.	No. diseased			No. exam.	No. diseased			No. exam.	No. diseased		
		Lymph-ocystis	Epi. hyp.	Ulcers		Lymph-ocystis	Epi. hyp.	Ulcers		Lymph-ocystis	Epi. hyp.	Ulcers
Disposal site	532	22	9	7	367	31	13	7	103	10	3	4
4-11 and		4.1+	1.7 +	1.3 +		8.4 +	3.5 +	1.9 +		9.7 +	2.9 +	3.9 +
16-18			(7.1%)*				(13.9%)*				(16.5%)*	
Control area	205	6	7	4	247	15	9	6	94	5	4	8
12-15 and		2.9+	3.4+	2+		6.1+	3.6+	2.4+		5.3+	4.3+	8.5+
19-20			(8.3%)*				(12.1%)*				(18.1%)*	

\+ = *Individual percentage*
* = *Combined percentage*
Epi. hyp. = Epidermal hyperplasia

Table 8. Analysis of the prevalence of disease in cod in the North Sea in April 1989

Station	Total sample	Size group (cm)	Skin ulcers	Pseudobranchial tumours	Skeletal deformity	Prevalence according to size (%)	Prevalence according to sample (%)
16-20	31	<29	0	0	0	0	
	64	30-44	0	0	0	0	0
	178	>45	0	0	0	0	
10-15	32	<29	0	0	0	0	
	46	30-44	0	0	1	2.2	1.3
	82	>45	1	0	0	1.2	
6, 9	3	<29	0	0	0	0	
	6	30-44	0	0	0	0	0
	14	>45	0	0	0	0	
5	2	<29	0	0	1	50	
	5	30-44	0	0	0	0	8.3
	5	>45	0	0	0	0	
4	0	<29	0	0	0	0	
	4	30-44	0	0	1	25	4.3
	42	>45	0	0	1	2.4	

Table 9. Summary of the prevalence of disease in dab in the Irish Sea in September 1989 (% figures in parentheses are combined external diseases)

Total number of dab examined

Area	No. dab	No. diseased	Liver samples	Nodules
Morecambe Bay	64	1 (1.56)	10	0
Disposal site (DS)	12	0 (0)	3	0
Off Rhyl (South of DS)	589	55 (9.33)	20	1
South-west of DS	40	0 (0)	10	1
	705	56 (7.9)	43	2

Figures include 12 healed ulcers; disease percentage excluding healed ulcers = 6.34

Prevalence of external disease according to sex (including healed ulcers)

Area	Female		Male	
	Normal	Diseased	Normal	Diseased
Morecambe Bay	34	0 (0)	29	1 (3.3)
Disposal site (DS)	7	0 (0)	5	0 (0)
Off Rhyl (South of DS)	307	28 (8.4)	227	27 (10.6)
South-west of DS	25	0 (0)	15	0

The problem of being unable to obtain adequate samples was experienced on a MAFF survey of Liverpool Bay in September 1989. This study repeated the previous year's investigation of the prevalence of disease in dabs from the disposal site in Liverpool Bay and control areas in Morecambe Bay. The distribution of the dab samples differed considerably from those of the previous year. Seven-hundred and five dabs were examined and the results are presented in Table 9. As insufficient numbers of dabs were caught from the selected areas, no inter-area comparison could be made from these data. However, the overall prevalence of disease (7.9%) was only slightly higher than that in 1988 (6.5%) and not particularly high for this species relative to the prevalence of disease in similar fishing areas.

It is clear from the fish disease studies undertaken at sewage-sludge disposal sites, particularly those in 1988 and 1989 that, while useful in assessing the impact of waste disposal, they are subject to variation between areas and time of year which make the collection of adequate samples very difficult. It is also difficult to collect samples from well-defined sampling sites and control areas, and it is doubtful whether surveys involving very small numbers of fish are worthwhile. However, providing fish disease surveys are carried out according to the minimum protocol recommended by the CGMSD, their value is such that they should be continued whenever possible.

4.5 EQO: Protection of the ecosystem to ensure that it is typical for the type of area concerned

As in previous years, in 1989 the sampling design used by the Scottish Marine Biological Association (SMBA) at Garroch Head took the form of two intersecting transects of stations through the disposal site (Figure 3). Two replicate grab samples were taken at each station, and a sieve with a 1 mm mesh was used to extract the macrofauna for later analysis in the laboratory.

Quantitative changes in the macrofauna conformed with classical responses to organic enrichment, with very high densities of smaller-sized species occurring in the immediate vicinity of the disposal site. The effects could be adequately described by reference to variation in total abundance, biomass and numbers of taxa.

Overall, there appeared to be a slight change in conditions at the centre of the disposal site when compared with those in 1988, accompanied by extension of the moderately enriched zone to the stations 3 km west and south of the centre. Observed changes were within the range of those occurring over the preceding ten years.

Samples from otter trawls towed through the disposal site and at a control area, provided no evidence of adverse effects on the larger epifauna.

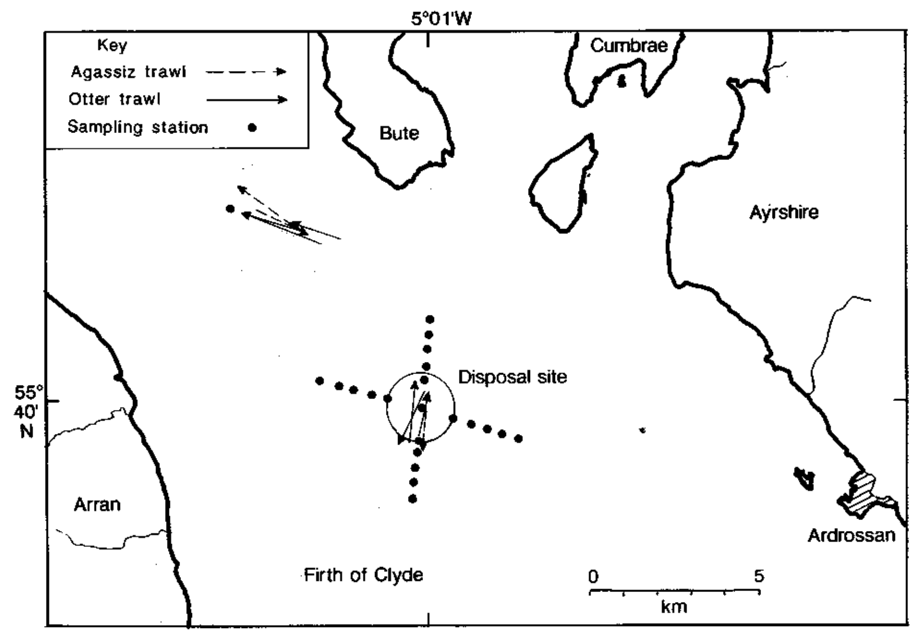

Figure 3. Strathclyde Regional Council/Scottish Marine Biological Association surveys of Garroch Head sewage-sludge disposal site in May 1989 and May 1990

Garroch Head continues to provide a 'model' for enrichment effects on the benthos, arising from the accretion of sewage-sludge particulates in a confined area. Changes of such magnitude have not been observed at other sewage-sludge disposal sites, because water movements facilitate wider dispersion of the waste material. The understanding that can be gained from analyses of the physico-chemical and biological data sets in combination, provides a convincing case for continuation of the type of work undertaken at this site.

Previous sampling has established that the magnitude of biological effect, and its spatial confinement, can be demonstrated with minimal replication or no replication of samples at each location. However, it may be advisable to increase replication to a minimum of three samples, at a limited number of stations considered to be representative of the major zones of effect. This could be particularly useful in the event of decreasing tonnages deposited at the site in future years.

The sampling schemes used by the Forth River Purification Board at the Bell Rock and St. Abbs Head sewage-sludge disposal sites, which are used for sewage sludge from the Lothian region, followed the pattern of previous years, with two macrofaunal samples being taken at several stations over the two disposal sites (Figure 4). The samples were sieved over a 0.5 mm mesh. The data were analysed using a variety of univariate, graphical and multivariate methods.

Stations at each disposal site were designated as 'impacted' or 'unimpacted' on the basis of the distribution of coprostanol (a sewage tracer) found in sediments in the same area in 1987. There were no statistically significant differences in the means of a range of univariate measures (e.g. diversity, evenness

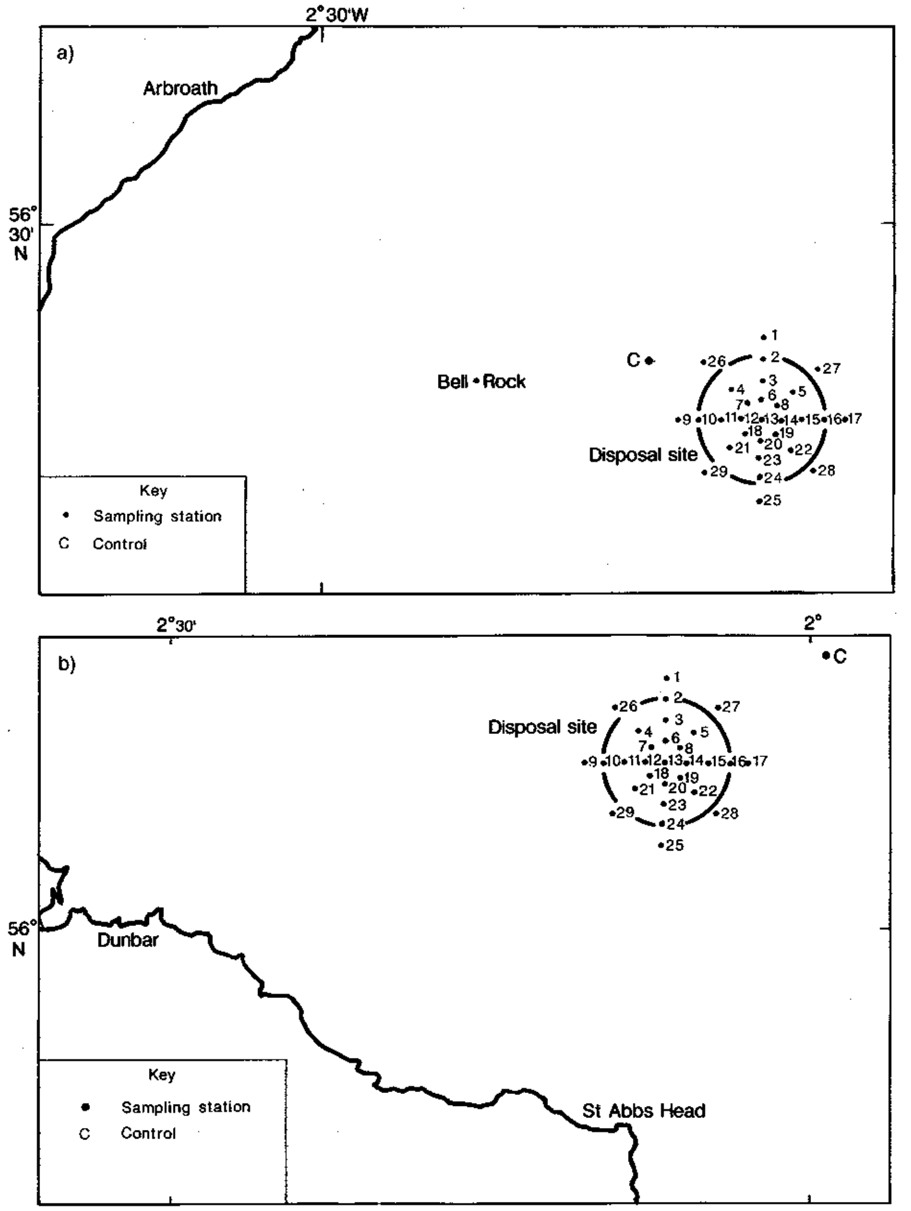

Figure 4. Positions of sampling stations at (a) Bell Rock and (b) St. Abbs Head sewage-sludge disposal sites in 1989 and 1990

and biomass). Despite this, there continued to be evidence of slight organic enrichment at the St. Abbs Head site. The presence of certain 'pollution indicator' species supported this view.

As in the case of Garroch Head, it would be advisable to take at least three replicate samples at a limited number of representative stations during future surveys, to facilitate statistical analysis of temporal trends. For such analyses, it will be important to ensure that annual sampling is conducted at the same time of year.

Surveys by MAFF of the benthos at sewage-sludge disposal sites off the English and Welsh coastlines have concentrated on evaluations of annual changes at a limited number of stations. This approach complements the spatially extensive surveys conducted by licensees under the 'self-monitoring' programme. Work has concentrated on sewage-sludge disposal sites off the Tyne, Humber and Thames. Comments on aspects of this work are given below; full accounts of extended time-series data will be given at appropriate intervals in the future.

The Humber area poses problems for quantitative sampling of the benthos because of the gravelly substrates; as a result, MAFF has conducted annual sampling for contaminant trends in the horse-mussel (*Modiolus modiolus*). This is an important component of the gravel fauna, and has the advantages of being both long-lived and sedentary in habit. The usefulness of this organism, as an indicator of anthropogenic influences, is currently being evaluated by reference to time trends for body burdens of five trace metals. (Trends in lead levels have been reported by Rees and Nicholson (1989)).

The results of MAFF sampling of the benthos off the River Tyne were reported in Rees *et al.* (1990). From a transect through the disposal site in 1986 (Figure 5), there appeared to be strong circumstantial evidence for a localised effect of sewage-sludge particulates in the immediate vicinity of the disposal site. This took the form of enhancement in counts of a range of benthic taxa, especially polychaetes. A comparison of annual trends, at a location within the disposal site with one some 7 km to the south (Figure 6), showed that the differential in counts of taxa was maintained up to 1988, and indeed continued in 1989. However, indices of diversity and evenness were generally similar, in-

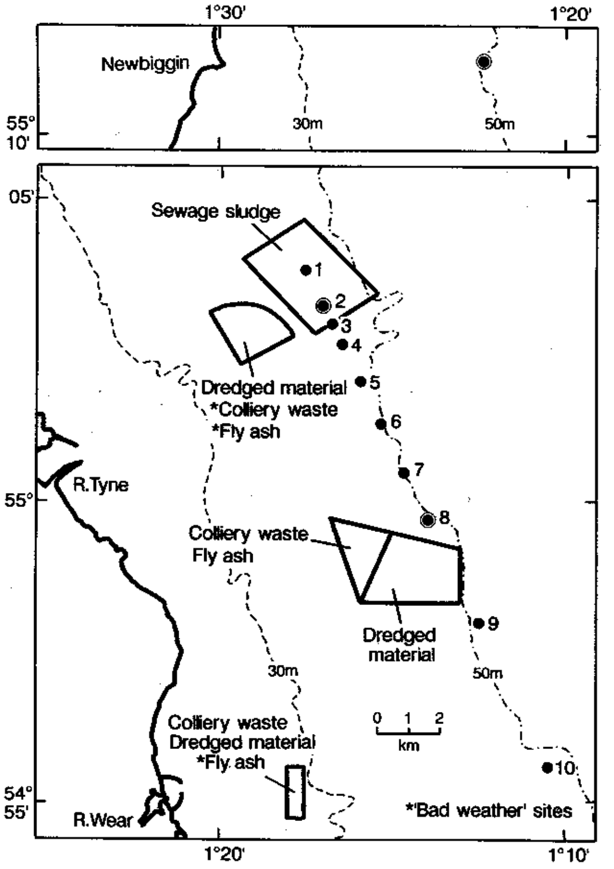

Figure 5. Benthic sampling stations. Sites currently in use for sea disposal are specified (double circles indicate stations sampled annually)

dicating that no gross structural changes in the benthos had occurred and, furthermore, there was no evidence for a 'worsening' trend with time at the disposal site.

A synthesis of results from beam trawl surveys for epibenthos and artefacts at several marine disposal sites around the English and Welsh coastlines was reported in MAFF (1991(b)). Trawl sampling is considered to be unsuitable as a method of allowing accurate quantification of benthic populations, because of high sampling variability. Nevertheless, the results can be useful in demonstrating the diversity of faunas from within disposal sites and those from surrounding areas. In most cases, the results correct a popularly held misconception that disposal sites are, by the nature of the activity, devoid of animal life.

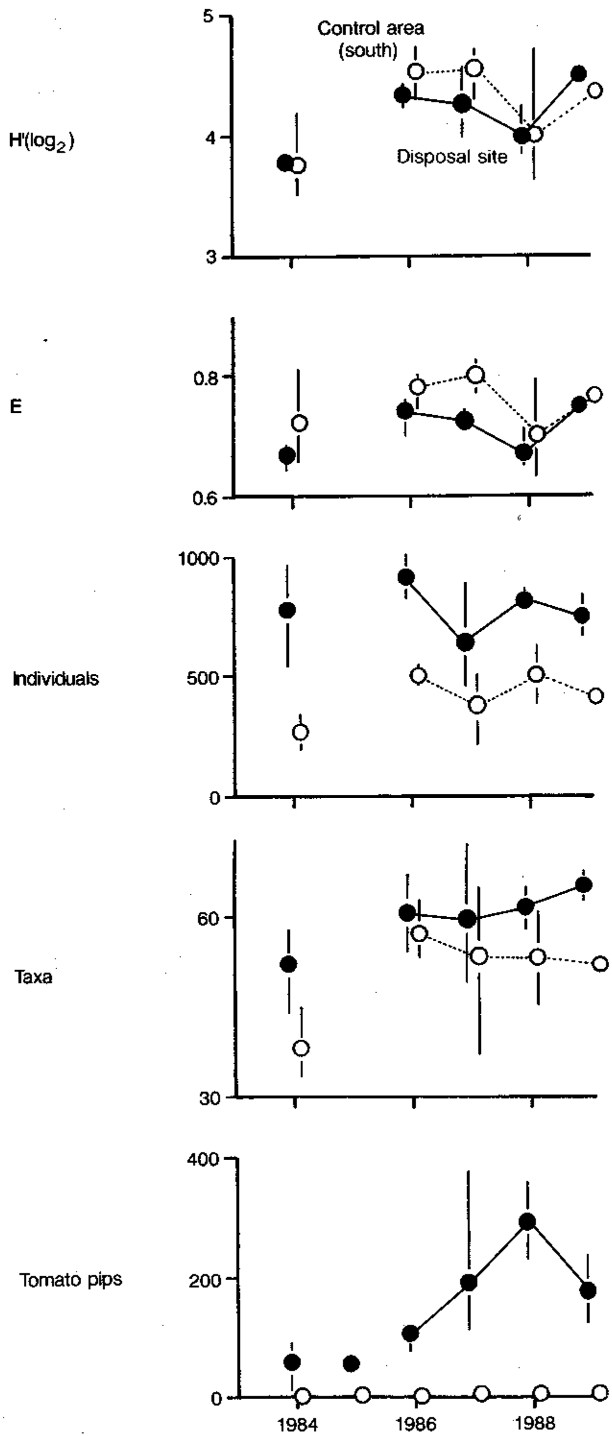

Figure 6. Temporal changes at two regularly sampled locations ($\bar{x}$ + range)

4.6 EQO: Maintenance of the receiving environment without distinguishable change

The CGMSD considers that this EQO should be assessed using surveys of the chemical quality of sediments at and around the disposal sites. This is consistent with the programmes already set in place by MAFF, SOAFD and DOE(NI).

For example, two types of sediment survey, spatial studies and temporal studies, are conducted under the 'self-monitoring' programmes defined by MAFF as part of the licence requirements. Most of the spatial surveys are carried out by the licensees, while MAFF concentrates on temporal work with relatively infrequent spatial surveys which are generally both more intensive and extensive than those carried out by the licensees. These MAFF surveys act both as a check on environmental conditions and as a comparison of results obtained respectively by the licensing authority and the licensee. The Scottish programmes also examine both spatial and temporal trends but achieve this with a single survey design. The present EQO is assessed by the spatial surveys, while any long-term changes in sediment quality will be demonstrated by the temporal studies.

Pesticide residues and PCBs were measured by MAFF in a set of sediment samples collected along a southerly transect from the Tyne sewage-sludge disposal site in May 1989 (Table 10 ; see Figure 1). Concentrations were low and the lack of evidence of contamination at the disposal site, compared to the sediments further south, indicates that inputs of sewage sludge do not contribute significantly to the pesticide and PCB loads of this area.

Table 10. Pesticide residues and PCBs in sediments (mg kg $^{-1}$) from the area of the Tyne sewage-sludge disposal site in May 1989. (See Figure 1 for station positions)

Distance south of centre of disposal site (km)	Dieldrin	pp DDT	PCB
0	0.001	0.007	0.002
1.4	<0.001	0.005	0.005
2.6	0.001	0.011	0.009
3.7	<0.001	0.006	0.003
5.2	<0.001	0.007	0.006
6.6	<0.001	0.010	0.002
8.2	<0.001	0.013	0.015
11.9	<0.001	0.006	0.003
17	0.001	0.006	0.006

HCB, alpha-HCH, beta-HCH, gamma-HCH, pp DDE and pp TDE were below the limit of detection at all stations (0.001 mg kg $^{-1}$ dry weight).

Both Anglian Water plc and MAFF carried out surveys of the Roughs Tower disposal site during 1989. The MAFF survey was restricted to the determination of faecal bacteria in sediments and was primarily carried out to aid decisions on licensing. The Anglian Water plc survey included determinations of coprostanol (used as a sewage tracer), carbon, nitrogen, mercury, cadmium, lead and zinc in sediments.

The bacterial results (Figure 7) show that the distribution of faecal bacteria is aligned with the tidal axis parallel to the coast and with little lateral dispersion. The carbon and metals data (Figure 8) do not show a pattern consistent with the distribution of sewage-related bacteria or indeed with areas where dredged material is deposited (Figure 7). Thus, it may be concluded that the disposal of sewage sludge does not significantly affect sediment quality in the vicinity of the disposal sites.

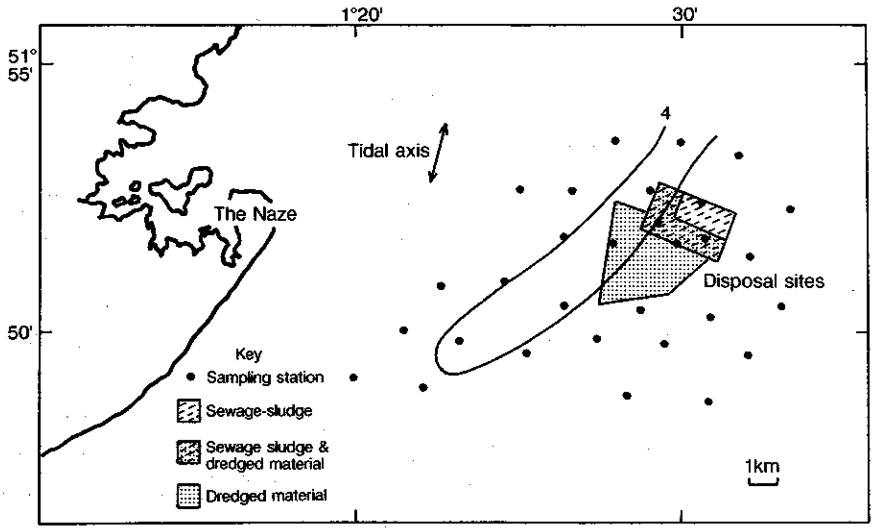

Figure 7. Faecal streptococci (no. ml⁻¹) in sediments around the Roughs Tower sewage-sludge disposal site in December 1989

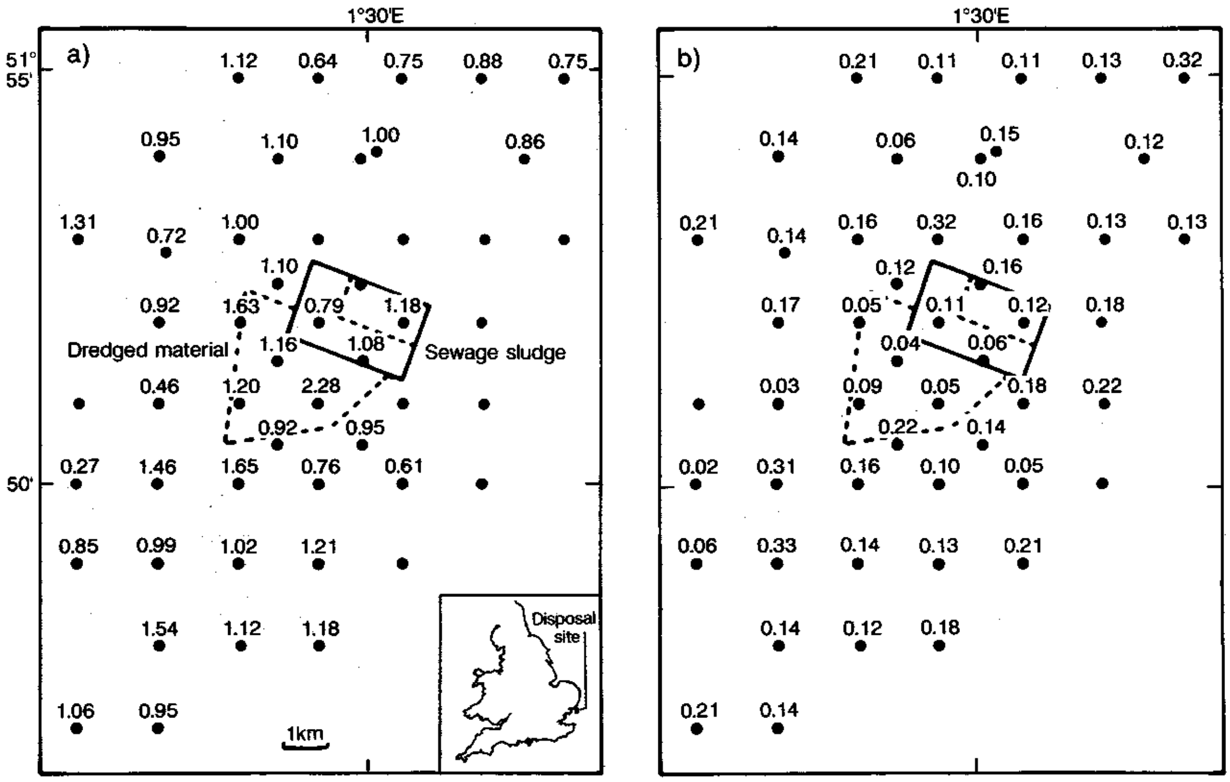

Figure 8. Concentrations of (a) carbon (%), and (b) mercury (mg kg⁻¹ dry weight), in the <63 µm fraction of sediments around the Roughs Tower disposal site in November 1989

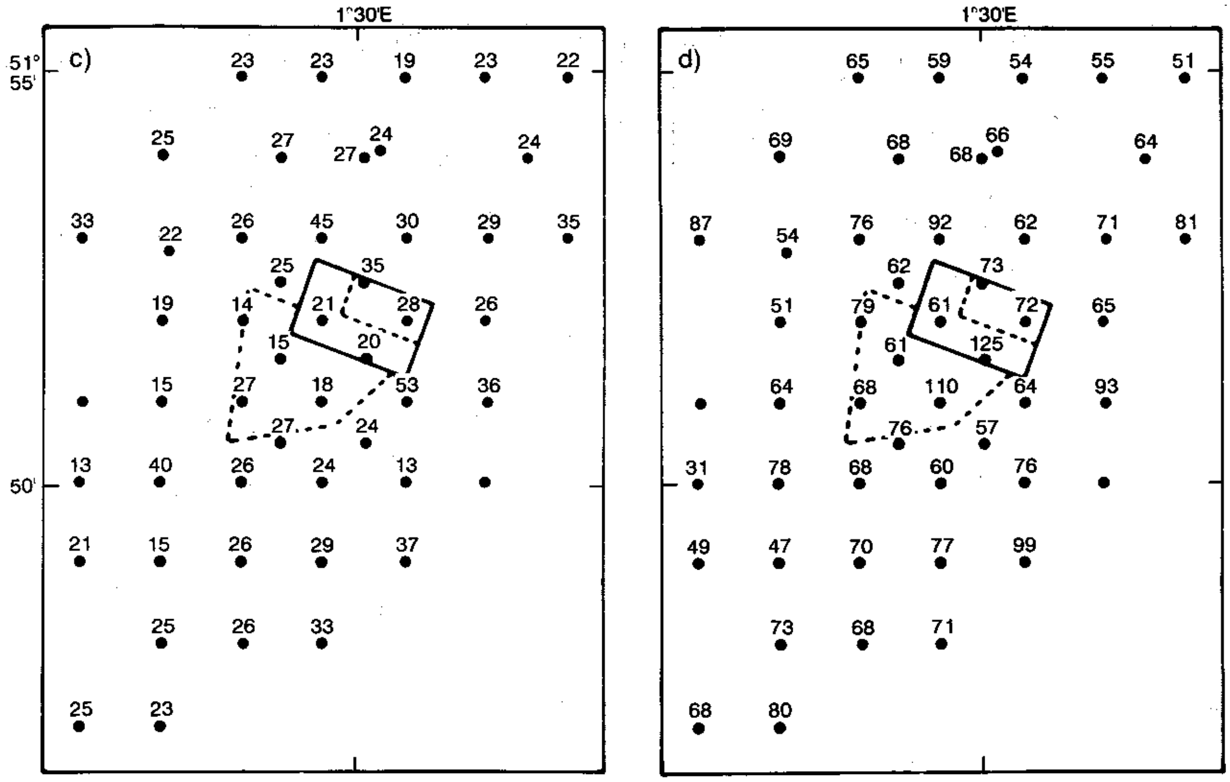

Figure 8. Continued. Concentrations of (c) lead (mg kg⁻¹ dry weight), and (d) zinc (mg kg⁻¹ dry weight) in the <63 µm fraction of sediments around the Roughs Tower disposal site in November 1989

Survey work at the Nab Tower sewage-sludge disposal site by Southern Water plc in August 1989 (Figure 9) showed no clear pattern of concentrations of bacteria, organic carbon or metals. However, whilst this suggests no significant impact of the disposal operation, it should be noted that four of the five higher mercury concentrations occurred close to, or within, the disposal site and three of the four higher copper concentrations also occurred at stations within the disposal site. While this evidence of impact is equivocal, especially as not all of the metals were elevated at the same stations, it may be that some isolated pockets of sludge had accumulated.

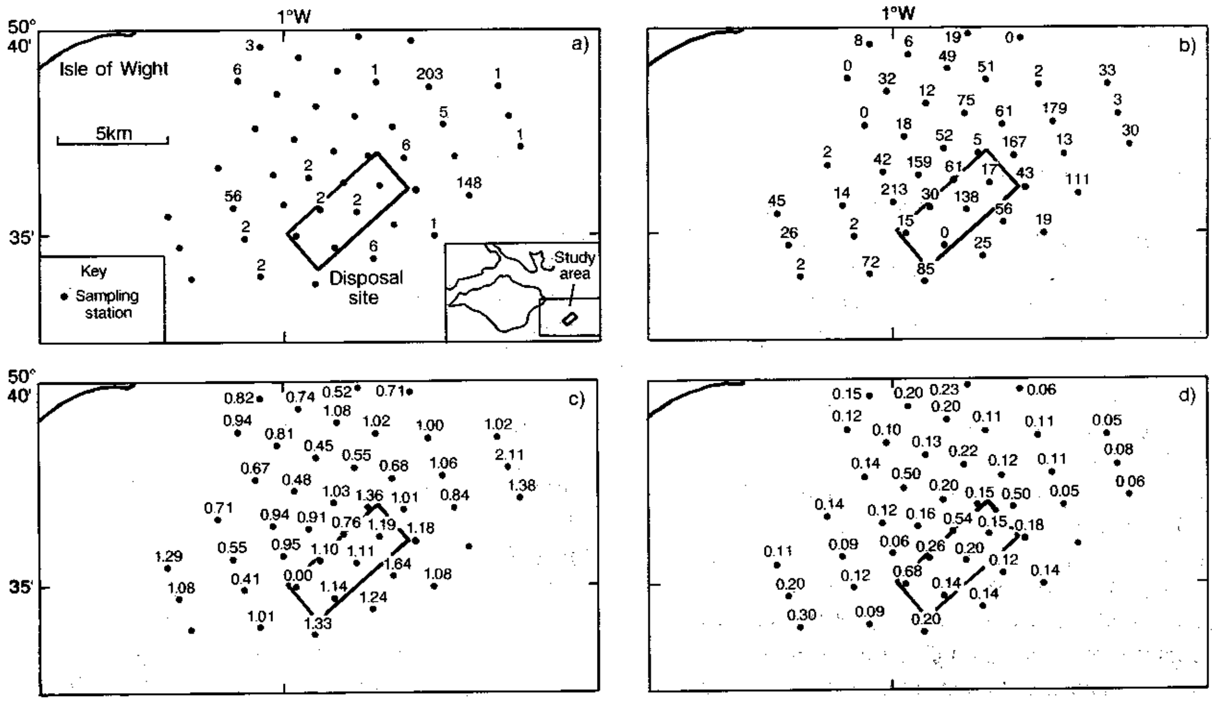

Figure 9. Concentrations of (a) faecal streptococci (no. ml⁻¹), (b) Clostridium perfringens (no. ml⁻¹), in whole sediment, (c) organic carbon (%), and (d) mercury (mg kg⁻¹), in the <63 µm fraction of sediments around the Nab Tower sewage-sludge disposal site in August 1989

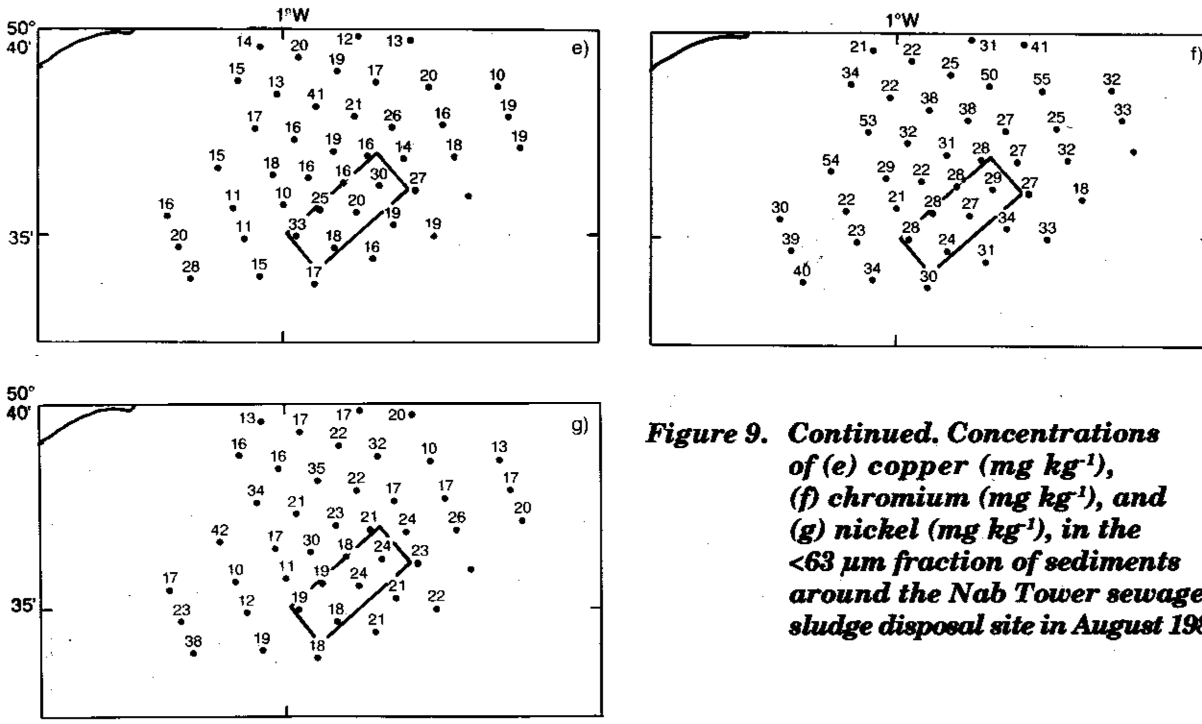

Figure 9. Continued. Concentrations of (e) copper (mg kg^{-1}), (f) chromium (mg kg^{-1}), and (g) nickel (mg kg^{-1}), in the <63 μm fraction of sediments around the Nab Tower sewage-sludge disposal site in August 1989

Correlation coefficients were calculated between all variables determined at the Nab Tower site. The only correlation significant at $P < 0.001$ was between chromium and nickel, two metals often associated in natural geological systems. There were several correlations at $P < 0.05$ between faecal bacteria and metals, suggesting a possible deposition of metal with sewage sludge, faecal streptococci and nickel, chromium and *Clostridium perfringens*, and *E. coli* with mercury. However, these correlations are rather weak and cannot be taken as conclusive evidence of a relationship. Overall, it appears that the sediments at the Nab sewage-sludge site show no clear evidence of any sludge accumulation.

A bacterial survey was carried out by MAFF at the Exeter site in December 1989 (Figure 10) prior to the introduction of the 'self-monitoring' programme by the licensees (South West Water plc). This showed the limited area of the sea bed which might be affected by sludge. A survey of the distribution of carbon and metals will be carried out by the licensees in 1991.

The work on Liverpool Bay reported by North West Water plc is an example of an annual spatial survey which has also been used to give a measure of changes through time. Figure 11 shows some of the results of the 1989 survey, which indicate elevated concentrations of metals in sediments from the vicinity of the sewage-sludge disposal site. However, the region outside the disposal site shows little difference from the adjacent regions although it must be noted that levels of metals in sediments in Liverpool Bay are higher than those in the north-eastern Irish Sea in general (Figure 12).

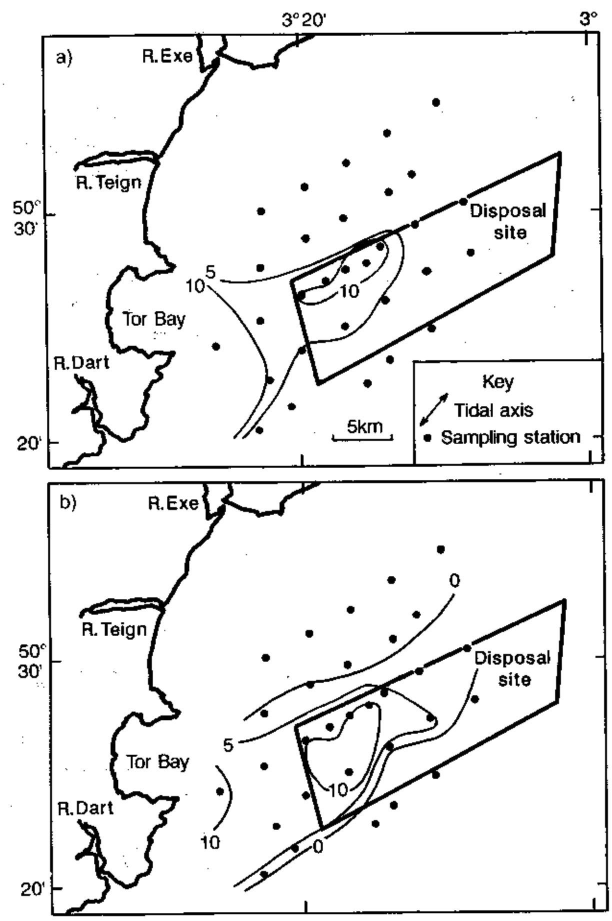

Figure 10. Concentrations of (a) faecal streptococci and (b) E. coli (no. ml^{-1}), in sediments around the Exeter sewage-sludge disposal site in December 1989

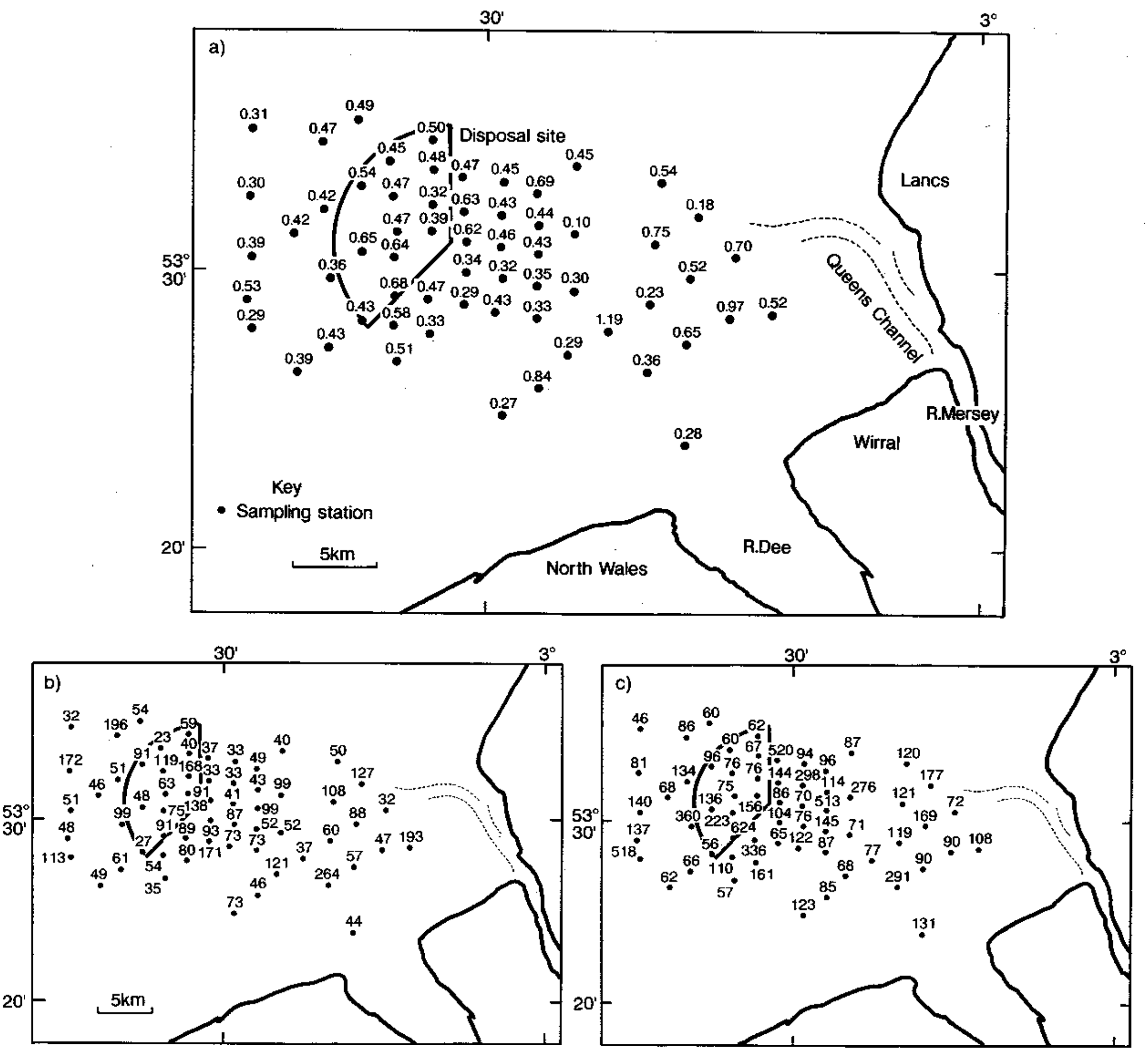

Figure 11. Concentrations of (a) mercury, (b) copper, and (c) lead (mg kg⁻¹), in the <90 µm fraction of sediments from Liverpool Bay in September 1989

Data sets for 1986, 1987, 1988 and 1989 have been combined to give an estimate of the temporal changes in sediment quality. A regression line of metal versus time was derived using 252 data points (60 - 70 samples from each year) and provides a representation of any temporal trend in the data (Figure 13). The 't' statistic was used in order to determine whether the trend line had a significant slope. Additionally, differences between years were assessed using two sample 't' tests. The results of this data analysis suggest a significant fall in levels of mercury in the bay between 1987 and 1988 and a significant decrease in levels of zinc over the period 1986-1989, while other metals show no discernible trends. It should be noted that it is difficult to determine differences over such a short time period and no further conclusions can be drawn until more data are available.

At the St. Abbs Head site, there was some evidence of an increase in the carbon content of the <63 µm fraction of the sediment between 1987 and 1989 (Table 11). Unfortunately, there were no data for the <63 µm fraction for earlier years so the significance of these changes is difficult to assess, although these data do provide *prima facie* evidence of a slight accumulation. There was, however, no indication of an increase in carbon within the <2 mm fraction of the sediment. This observation is consistent with the concept that the analysis of the < 63 µm material gives an earlier indication of sedimentary changes at disposal sites than that of a broader size range.

A comparison of the stations near the centre of the disposal site with those remote from it, shows no significant differences in concentrations of carbon. A similar result was obtained when the stations defined in

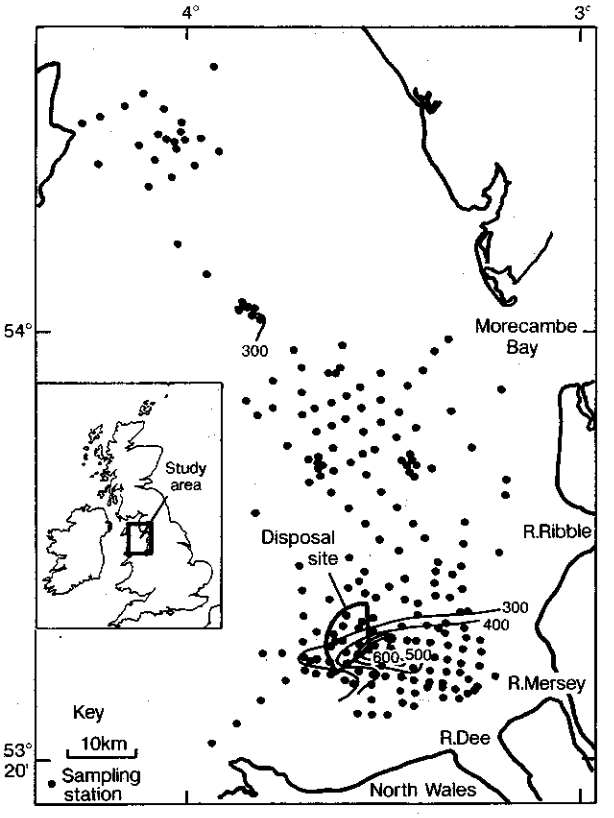

Figure 12. Concentrations of zinc (mg kg^{-1} dry weight) in the <90 µm fraction of sediments from the north-eastern Irish Sea in 1982-1983

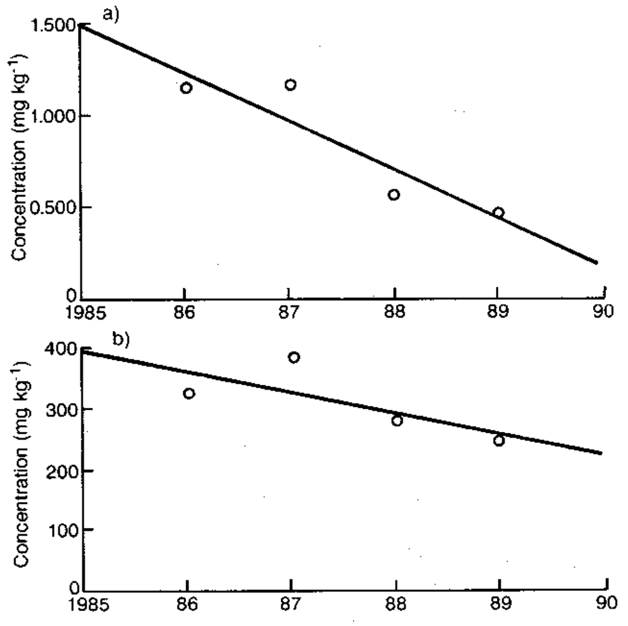

Figure 13. Regression of concentrations of (a) mercury, and (b) zinc (mg kg^{-1}), in the <90 µm fraction of sediments from Liverpool Bay against date of sampling. Data points represent the mean of samples in each year

Table 11. Concentrations of carbon and nitrogen in the <63 µm and <2 mm fractions of sediments at the St. Abbs Head sewage-sludge disposal site in 1986-1989

	< 63 µm		< 2 mm	
	C (%)	N (mg kg^{-1})	C (%)	N (mg kg^{-1})
1986	-	-	0.42	537
1987	1.56	1573	0.41	520
1988	1.63	1255	0.52	472
1989	2.18	2078	0.49	503

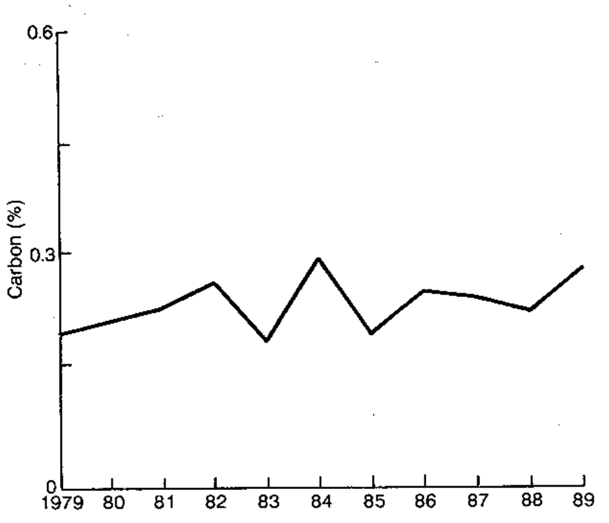

Figure 14. Trends in concentrations of carbon (percentage mean of all stations) in the <2mm sediment fraction, at the Bell Rock disposal site in 1979-1989

1988 as 'impacted', on the basis of the coprostanol measurements, were compared with others defined as 'unimpacted'. However, it must be noted that such a comparison of 'impacted' and 'unimpacted' stations may have limited validity, as the impact was defined in a previous year's survey and may no longer pertain, due to slight variations in disposal practice or in currents at the disposal site.

There are no fine sediments at Bell Rock. The results for the Bell Rock sediments therefore relate only to the <2 mm fraction of sediments and, as a consequence, may suffer from a lack of sensitivity such as discussed in the case of the St. Abbs Head site (see above). In fact, since 1979, levels of organic carbon have fluctuated only slightly around the 0.25% level (Figure 14).

A comparison of inner with outer stations (i.e. stations near to and remote from the disposal site respectively) shows no statistically significant differences in carbon concentration. No statistically significant differences between 'impacted' and 'unimpacted' stations were observed, although the definition of these two groups of stations suffers from the same problem as those at the St. Abbs Head site (see above) of not being contemporaneous with the carbon data.

Nickel is the only metal showing a statistically significant difference between the inner and outer stations at Bell Rock. This was significant at the 5% level and could be attributed to a value at a single station of almost twice the mean. The control area had values within those recorded for the disposal site, except in the case of zinc where there was a concentration of 40 mg kg^{-1} at the control area compared to a maximum of 31 mg kg^{-1} at the disposal site.

Surveys of metals in sediments at the Garroch Head site confirmed earlier observations, i.e. that concentrations of lead (Figure 15) and of the other metals — copper, zinc, cadmium and chromium — continue to be highest in the vicinity of the centre of the disposal site. At 2-3 km from the centre and beyond, the concentrations approach the values measured in sediments from the control area.

Slight increases in concentrations of mercury and arsenic, observed at two stations near the centre of the disposal site between 1985 and 1988, did not continue in 1989 (Table 12). This emphasises the fact that small fluctuations in concentrations of metals do not necessarily reflect any long-term changes in concentrations of these contaminants. Concentrations of PCBs and dieldrin were found to be generally lower than those in 1988 and in all cases lower than those in 1984.

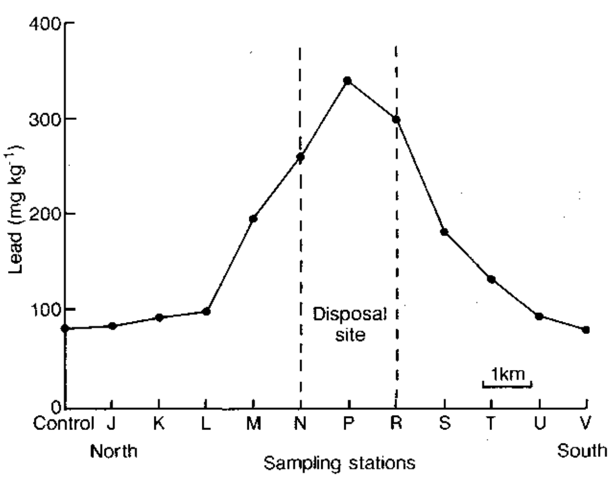

Figure 15. Concentrations of lead in whole sediment (mg kg^{-1}), along a N-S transect through the Garroch Head sewage-sludge disposal site in May 1989

Table 12. Concentrations of mercury and arsenic (mg kg^{-1} dry solids) in sediments at 1 km from the centre of the Garroch Head sewage-sludge disposal site in 1986-1989

Position	Year	Hg	As
1 km W	1986	0.7	29
	1987	0.8	33
	1988	1	36
	1989	1	36
1 km E	1986	0.7	23
	1987	1.3	29
	1988	1.3	49
	1989	1.2	30

The comparison of sediments at the disposal site with those remote from the site shows any chemical impact at the sea bed and demonstrates the utility of sediment surveys for assessing compliance with the EQO listed at the beginning of this section. Both the Metals and Organics Task Teams are presently developing standards which will provide a more rigorous framework for the consideration of such data.

SOAFD surveys at Bell Rock and St. Abbs Head sewage-sludge disposal sites confirmed previous sampling results. There was no evidence of significant accumulation of heavy metals, and levels at the control areas were within the range of concentrations at the disposal sites. At the sewage-sludge disposal sites, the range of concentrations was similar to that found in previous years, and there was no consistent pattern of distribution of stations showing higher concentrations. Analysis of samples collected from an extensive survey of water, sediment, and particulate material for organic contaminants has not been completed.

Low levels of faecal coliforms and faecal streptococci were detected at both the Bell Rock and St. Abbs Head sewage-sludge disposal sites, confirming the dispersive nature of the sites. Faecal coliforms were also detected at the St. Abbs Head control area, perhaps indicating that this area is unsuitable as a control. This will be investigated further during forthcoming surveys. The levels found were similar at both disposal sites, although operations had recently been transferred from the St. Abbs Head to the Bell Rock site. As there is no evidence of coastal sewage discharges impacting the St. Abbs Head site, it must be assumed that a proportion of the faecal coliforms survive at the disposal site for periods in excess of two weeks.

Echo sounder, transmissometer, and chemical studies of the dispersion and fate of metallic contaminants in sewage sludge were continued at the Garroch Head sewage-sludge disposal site, but the data are not yet fully assessed.

Echo sounder and transmissometer studies at St. Abbs Head confirmed that the sewage sludge impacted a fairly small area, and was mainly confined to the immediate vicinity of the disposal site. Heavier material fell directly to the sea bed; intermediate material was noted to accumulate above the thermocline until the concentration of such material seemed to be such that it could 'break through' the thermocline and fall to the sea bed. Fine material was noted to remain in the water column, mainly in the surface layer, for significant periods of time. Intermediate and finer particles moved with tidal currents along a NW/SE axis, but most had impacted the sea bed before being transported outside the immediate vicinity of the disposal site. Fine material was transported outside the licensed area, but then returned as the tide changed direction. The plume could be followed for approximately 4 hours, and finer materials for 6 hours. After 4 hours, all significant transport of material to the sea bed was completed, and only finer material remained in the water column. Detection of the fines became progressively more difficult, until after 6 hours they could not be separated from the natural background of particulate material in the water column. All of the observations were in line with theoretical calculations of sludge behaviour, based on hydrographic modelling.

In all cases, other than those mentioned above, no significant effects were observed.

4.7 REMOTS survey of the Garroch Head sewage-sludge disposal site

The REMOTS system is an instrumental optical coring device that photographs the upper 20 cm profile of sea floor. No sediment samples are recovered. The system is particularly suited to the observation of organic enrichment in fine sediments, although it may also be applied in sandy areas.

A series of photographs was taken in the area of the Garroch Head disposal site during one day in May 1989. Figure 16 shows the distribution of stations: seventeen were situated on an east-west line through the middle of the disposal site, a further five to the north of this and a control station to the north-east. Figure 17 shows the depth of the apparent redox potential discontinuity (ARPD) along the E-W transect. This may be interpreted as the effect of high organic loading in the central region of the disposal site.

This work demonstrates the utility of the REMOTS camera in areas of organic enrichment. Although it is unclear at this stage how valuable it will be in more dispersive areas, it is recommended that its use is pursued and its value assessed.

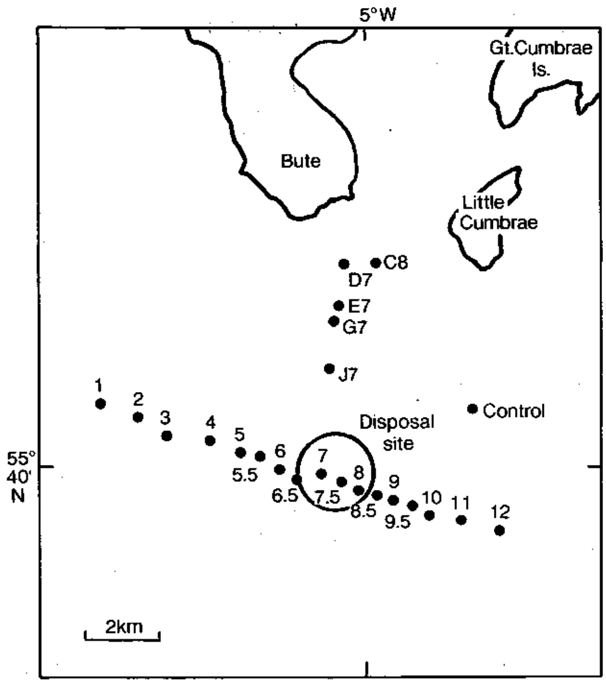

Figure 16. Stations used in the REMOTS survey of the Garroch Head disposal site in May 1989. (No reading was taken at Station 2)

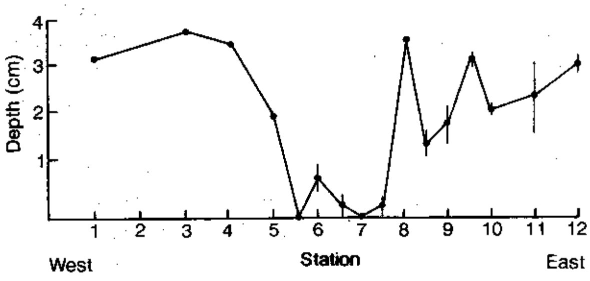

Figure 17. Apparent discontinuity of redox potential along an E-W transect (see Figure 16) across the Garroch Head sewage-sludge disposal site in May 1989

4.8 Overall conclusions from the review of monitoring in 1989

- Surveys of sewage-derived litter should be undertaken at all UK sewage-sludge disposal sites.
- Studies on fish diseases should be continued but every effort should be made to adhere to the specified minimum sample size.
- Surveys on the chemical quality of sediment should be continued.

- The REMOTS technique should be further evaluated at a range of sites, with particular emphasis on the muddy sites.

- The usefulness of benthic surveys as a means of assessing the impact of sewage sludge is confirmed, but the desirability of taking an adequate number of replicate samples at each station is emphasised.

- Beam trawl or dredge surveys are not satisfactory as a means of collecting quantitative samples of epibenthos, but they do serve to demonstrate the presence (often abundant) of such species, confirming that sewage-sludge disposal sites are far from devoid of life.

- The majority of the monitoring conducted in 1989 complied with the procedures recommended by the CGMSD. Where this was not the case, it was usually because of the overriding importance of continuity with methods used for many years.

5. MONITORING ACTIVITIES AT SEWAGE-SLUDGE DISPOSAL SITES IN 1990

5.1 Introduction

During 1990, surveys were carried out at the following disposal sites: Tyne, Humber, Roughs Tower, Thames (Barrow Deep), Nab, Plymouth, Bristol Channel, Liverpool Bay, North Channel, Garroch Head, Bell Rock and St. Abbs Head.

Short summaries of all of the surveys are given in the following sub-sections. As far as possible, the surveys were carried out in accordance with the methods now recommended by the CGMSD.

Methods may differ from those recommended, where environmental characteristics of disposal sites (e.g. substrate type or hydrography) render them inappropriate, or where comparability with previous surveys can only be ensured by retaining existing methods.

A summary of the techniques used at each disposal site in 1990 is given in Table 13.

Table 13. Summary of measurements made in monitoring surveys at sewage-sludge disposal sites in 1990

Area/Authority	Sediment				Benthos, epibenthos	Water bioassay /quality	Fish sampling	Litter assessment
	Metals	Pesticides /PCBs	Toxicity	Micro-biology				
Tyne								
MAFF	*			*	*			*
Northumbrian Water plc					*			
Humber								
MAFF					*			
Yorkshire Water plc	*	*		*				
Barrow (Thames)								
MAFF	*							
Thames Water plc	*		*	*	*			
Nab								
Southern Water plc	*	*		*				
Plymouth								
South West Water plc	*			*	*			
Bristol Channel								
Wessex/Welsh Water plc	*			*	*		*	*
Liverpool Bay								
MAFF	*	*						
North West Water plc	*				*			
North Channel								
DOE (NI)	*			*	*			
Garroch Head								
SMBA/SRC	*				*	*	*	
SOAFD							*	
Bell Rock								
FRPB/LRC	*			*	*		*	
SOAFD							*	
ST. Abbs Head								
FRPB/LRC	*				*		*	
SOAFD							*	

5.2 MAFF survey of the Tyne sewage-sludge disposal site, May 1990

(a) Sediment samples were collected along an E-W transect through the disposal site, at the stations shown in Figure 18.

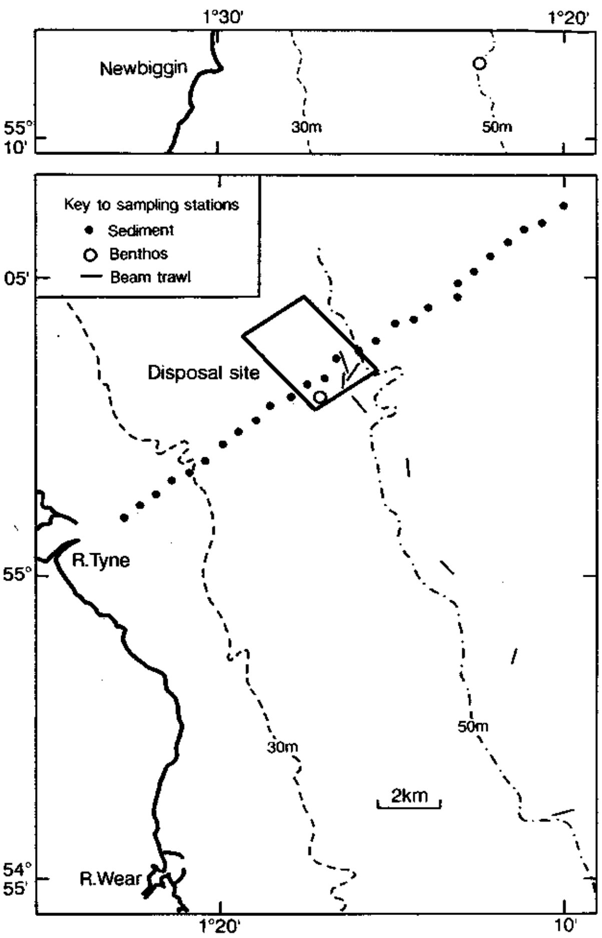

Figure 18. ***MAFF survey at the Tyne sewage-sludge disposal site in May 1990***

(b) Faecal bacteria (*Escherichia coli* and group D faecal streptococci) were enumerated in surface scrapes of the sediment.

(c) Metals (Cd, Cr, Cu, Hg, Ni, Pb and Zn) were determined in sub-samples of the surface(0-1 cm) of the sediment. Carbon and nitrogen were also determined in these samples for both the whole sediments and the <63 µm fractions.

(d) Sediment samples were collected from the stations shown in Figure 18. Benthic infauna will be identified and enumerated in these samples.

(e) Beam trawl samples were collected for an assessment of the distribution of sludge-derived litter and analysis of epifauna (Figure 18).

5.3 Northumbrian Water plc survey of the Tyne sewage-sludge disposal site, May/August 1990

(a) No sediment samples were collected from the disposal site during 1990.

(b) Trawl surveys were carried out at the sites shown in Figure 19, during May and August 1990 and January 1991. These were used for the identification and enumeration of fish species and macrofauna.

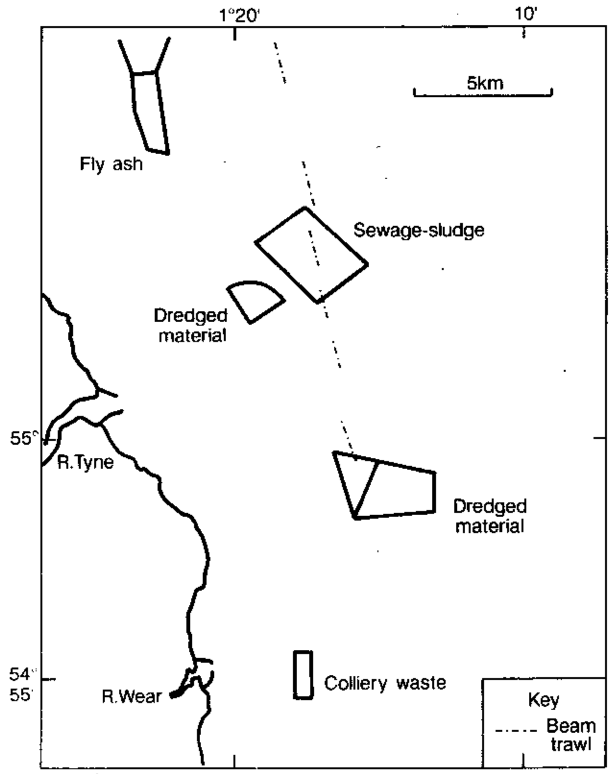

Figure 19. ***Northumbrian Water plc survey of the Tyne sewage-sludge disposal site in May/August 1990***

5.4 MAFF survey of the Humber sewage-sludge disposal site, May 1990

Samples of horse-mussel (*Modiolus modiolus*) were collected using a rock dredge at the stations shown in Figure 20. These were analysed for faecal bacteria (*E. coli* and group D faecal streptococci) and will be analysed for metals (Cd, Cu, Hg, Pb, and Zn) as part of a study on temporal trends in the chemical quality of the mussel population.

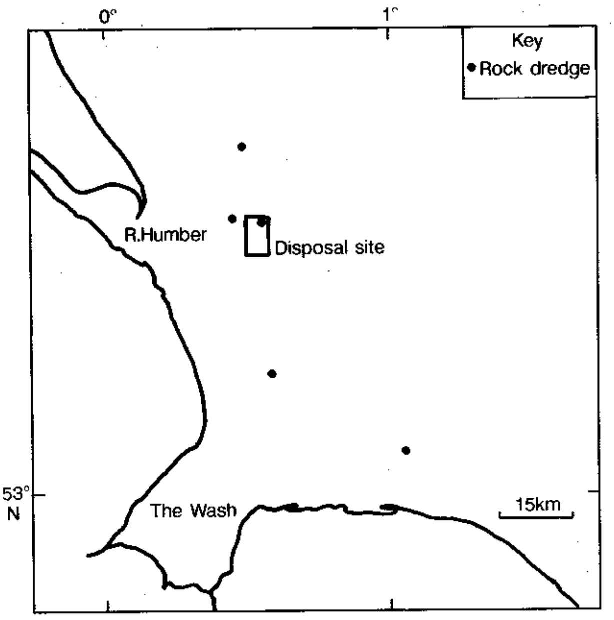

Figure 20. MAFF survey of Modiolus modiolus at the Humber sewage-sludge disposal site in May 1990

5.5 Yorkshire Water plc survey of the Humber sewage-sludge disposal site, October 1990

(a) Sediment samples were collected using a Shipek grab at the stations shown in Figure 21.

(b) Metals (Cd, Hg, Pb, and Zn) were determined in the <63 µm fraction of the sediment. Carbon and nitrogen levels were also determined in these samples.

(c) Whole sediments were analysed for faecal coliforms.

(d) Pesticide residues were also determined in whole sediments.

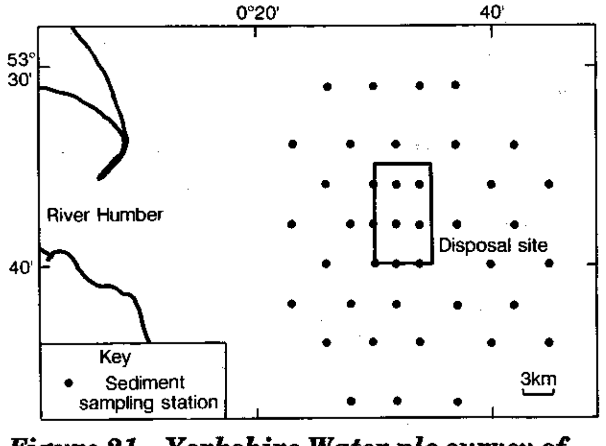

Figure 21. Yorkshire Water plc survey of the Humber sewage-sludge disposal site in October 1990

5.6 MAFF survey of the Barrow Deep (Thames Estuary) sewage-sludge disposal site, May 1990

Samples of sediment were collected from known areas of sludge settlement and will be analysed for carbon, nitrogen and metals (Cd, Cr, Cu, Hg, Ni, Pb and Zn). These form part of a study on temporal trends.

5.7 Thames Water plc survey of the Barrow Deep(Thames Estuary) sewage-sludge disposal site, July 1990

(a) Three sediment samples were collected using a Day grab, at each of the stations shown in Figure 22.

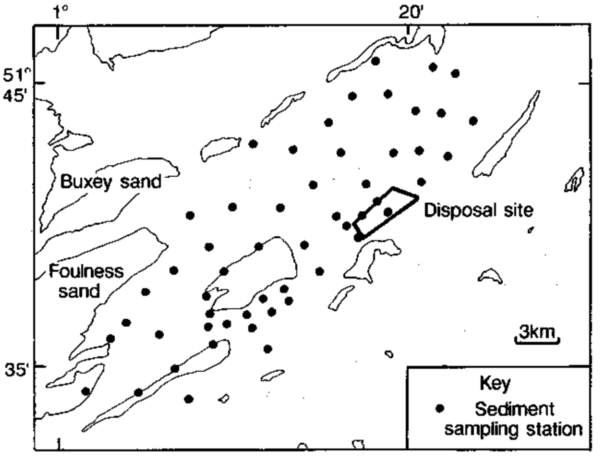

Figure 22. Thames Water plc survey of the Barrow Deep (Thames Estuary) sewage-sludge disposal site in July 1990

(b) Sub-samples were taken from the first grab for the analysis of particle size distribution.

(c) The remainder of the first grab sample was retained for the identification and enumeration of macrofauna.

(d) Faecal bacteria (coliforms, faecal streptococci and *Clostridium*) were enumerated in surface scrapes of the second grab sample.

(e) Further sub-samples were taken for application of the Microtox test.

(f) Total organic carbon and total nitrogen were determined in the remainder of the sample.

(g) Metals (Cd, Hg, Pb and Zn) were determined in both the <63 µm and the <90 µm fractions of the final sediment samples.

5.8 Southern Water plc survey of the Nab sewage-sludge disposal site, August 1990

(a) Sediment samples were collected at the stations shown in Figure 23.

(b) Metals (Cd, Cr, Cu, Hg, Ni, Pb and Zn) will be determined in the <63 μm fraction of the surface 0-1 cm of the sediment. Carbon and nitrogen will also be determined in these samples.

(c) Faecal bacteria (*E. coli*, group D faecal streptococci and *Clostridium*) were enumerated in surface scrapes of the sediment.

(d) Sediments from selected sites will be analysed for PCB and pesticide residues (Figure 23).

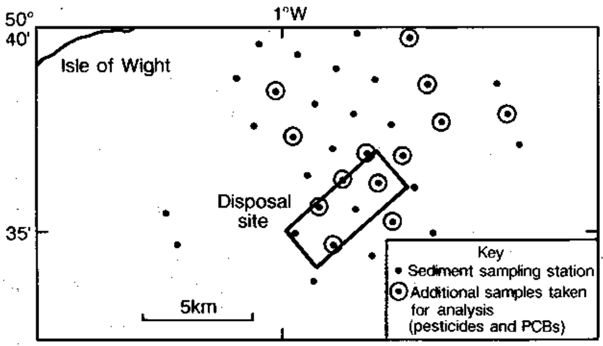

Figure 23. Southern Water plc survey of the Nab sewage-sludge disposal site in August 1990

5.9 South West Water plc survey of the Plymouth sewage-sludge disposal site, September/ October 1990

(a) Two grab samples were collected from each of the thirty-two stations shown in Figure 24.

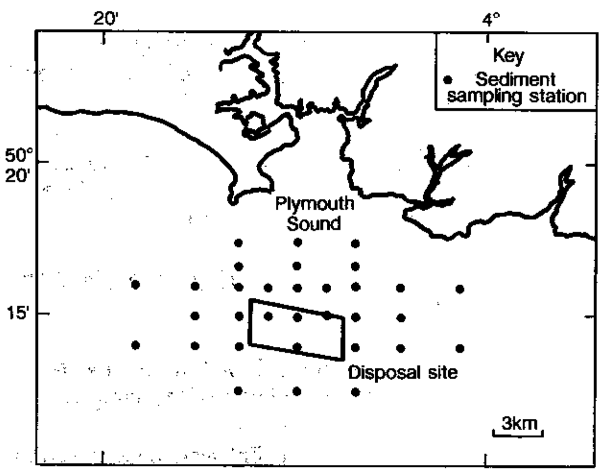

Figure 24. South West Water plc survey of the Plymouth sewage-sludge disposal site in October 1990

(b) Metals (Cd, Hg, Pb, and Zn), carbon and nitrogen were determined in the <63 μm fraction of the sediment.

(c) Faecal bacteria (*E. coli* and faecal streptococci) were enumerated in surface scrapes of the sam - ples.

(d) The second grab sample was used for particle analysis and identification and enumeration of macrofauna to species level on a 2 mm sieve.

5.10 Welsh/Wessex Water plc surveys of the Bristol Channel sewage-sludge disposal site, September/October 1990

(a) Sediment samples were collected by Day/ Shipek grab, at the stations shown in Figure 25.

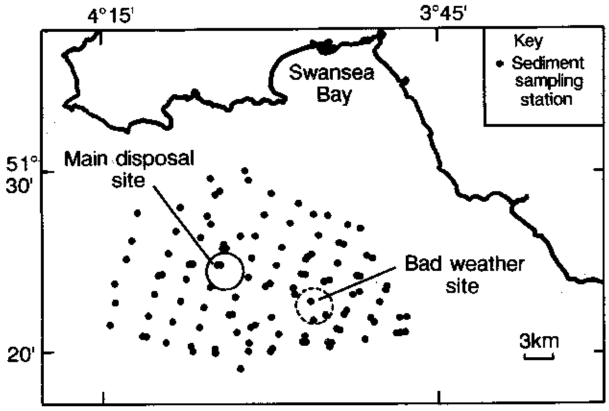

Figure 25. Welsh/Wessex Water plc survey of the Bristol Channel sewage-sludge disposal site in October 1990

(b) Metals (Cd, Cr, Cu, Hg, Ni, Pb, and Zn) will be determined in the <63 μm fraction of the surface 0-1 cm of the samples. Organic carbon and total nitrogen will also be determined in these samples.

(c) Sediment samples were also collected for the enumeration of faecal bacteria (*E. coli*, group D faecal streptococci and *Clostridium*) and analysis for entroviruses.

(d) Samples were collected by anchor dredge at the sites shown in Figure 26.

(e) Benthic infauna will be identified and enumerated in these samples.

(f) Sediment samples were also taken for particle size analysis and for the assessment of sludge-derived litter (e.g. plastic) and tomato pips.

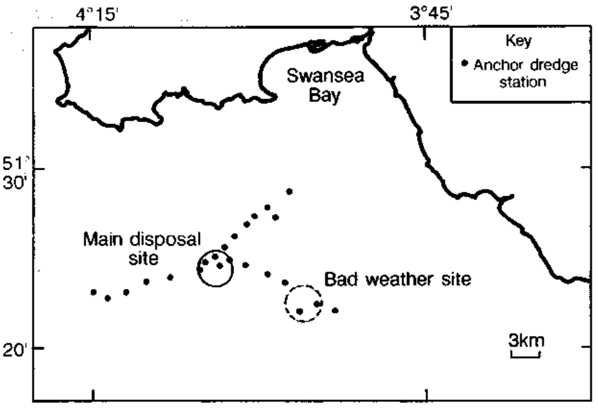

Figure 26. Welsh/Wessex Water plc anchor dredge stations at the Bristol Channel sewage-sludge disposal site in September/October 1990

(g) Otter trawl hauls were carried out within a 2 nautical mile radius of the disposal site and at Oxwich Bay. Fish were also collected from fishermen at Bideford Bay.

(h) Adult fish were examined for lesions, histopathology and parasitology.

5.11 MAFF survey of the Liverpool Bay sewage-sludge disposal site, September 1990

(a) Sediment samples were collected at the stations shown in Figure 27.

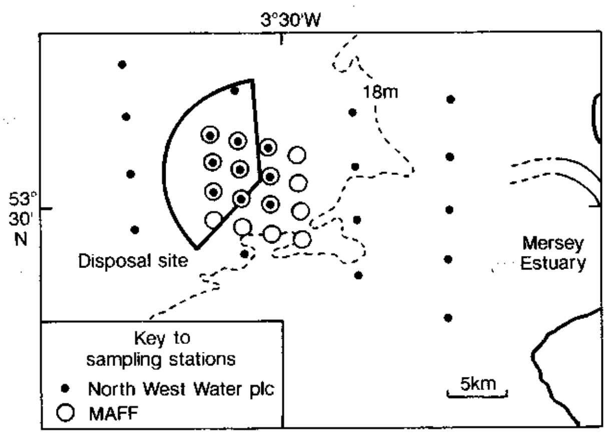

Figure 27. MAFF and North West Water plc surveys of the Liverpool Bay sewage-sludge disposal site in September 1990

(b) Metals (Cd, Cr, Cu, Hg, Ni, Pb and Zn) will be determined in the <90 µm fraction of the surface 0-1 cm of the sediment. Carbon and nitrogen will also be determined in these samples.

(c) Sediment samples were also collected for the determination of PCB's and pesticide residues.

5.12 North West Water plc survey of the Liverpool Bay sewage-sludge disposal site, September 1990

(a) Sediment samples were collected at the stations shown in Figure 27.

(b) Metals (Cd, Cr, Cu, Hg, Pb, Ni and Zn) will be determined in the <90 µm fraction of the surface 0-1 cm of the sediment. Organic carbon will be determined on the remainder of the sample.

(c) Benthic infauna will be identified and enumerated in sediment samples collected from the stations shown in Figure 27.

5.13 DOE (NI) survey of the North Channel sewage-sludge disposal site, May 1990

(a) Sediment samples were collected at the stations shown in Figure 28.

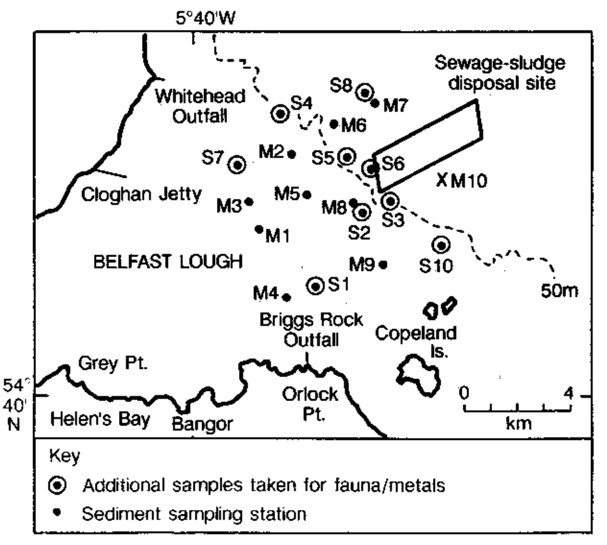

Figure 28. DOE (NI) survey of the North Channel sewage-sludge disposal site in May 1990

(b) Faecal bacteria (*Clostridium* and group D faecal streptococci) will be enumerated in surface scrapes of the sediment. Particle size distribution will also be determined in these samples.

(c) Metals (Cd, Cr, Cu, Hg, Ni, Pb and Zn) will be determined in the <63 µm fraction of the surface 0-1 cm of a selected number of sediments.

(d) Beam trawl samples for the identification and enumeration of epifauna were also collected at the sites shown in Figure 28.

5.14 Strathclyde Regional Council/ Scottish Marine Biological Association survey of the Garroch Head sewage-sludge disposal site, May 1990

(a) Sediment samples were collected at the stations shown in Figure 3.

(b) Metals (As, Cd, Cu, Cr, Hg, Ni, Pb, and Zn) will be determined in whole samples of the surface 0-1cm of the sediment. Carbon, nitrogen, PCBs and pesticide residues will be determined in these samples.

(c) Eh and pH measurements were made on the sediment sample.

(d) Temperature, salinity and oxygen content were determined in the water immediately above the sediment surface.

(e) Trawl samples were collected at the sites indicated in Figure 3. Benthic infauna and epifauna will be identified and enumerated in these samples.

(f) Histopathological and microbiological investigations will be carried out on fish samples collected in the trawls.

5.15 Lothian Regional Council/ Forth River Purification Board survey of the Bell Rock sewage-sludge disposal site, October 1990

(a) Sediment samples were collected from the stations shown in Figure 4(a).

(b) Particle size analysis, metals (As, Cd, Cr, Cu, Fe, Hg, Ni, Pb and Zn), carbon and nitrogen were determined in these samples.

(c) Two sediment samples were collected from each of the stations, C (control), 1, 3, 9, 11, 13, 15, 17, 23 and 25, for the enumeration of macrobenthos, fruit pips and faecal bacteria (group D faecal streptococci).

(d) Agassiz trawl hauls were taken at stations C and 13, for the identification and enumeration of fish species. Adult fish were examined for lesions, histopathology and microbiology.

5.16 Lothian Regional Council/ Forth River Purification Board survey of the St. Abbs Head sewage-sludge disposal site, June 1990

(a) Sediment samples were collected at stations shown in Figure 4(b), for the determination of metals (As, Cd, Cr, Cu, Fe, Hg, Ni, Pb and Zn), carbon, nitrogen and particle size analysis.

(b) Samples from stations 1, 3, 9, 11, 15, 17, 23, 27, and 29 were also taken for the enumeration of benthic infauna and fruit pips.

(c) Otter trawls were used at stations C and 13 for the assessment of fish diseases.

5.17 SOAFD surveys of the Bell Rock and St. Abbs Head sewage-sludge disposal sites, May 1990

(a) Fish samples were collected from the disposal sites and control areas, using standardised International Council for the Exploration of the Sea (ICES) sampling methodology, to assess long-term trends in prevalence of disease.

(b) Fish samples were also taken at monthly intervals, as part of a DOE-funded project, to assess the short-term spatial, biological and temporal variation in fish diseases.

5.18 SOAFD survey of the Garroch Head sewage-sludge disposal site, May 1990

(a) Samples of *Buccinum* were collected at monthly intervals for the assessment of parasitic infection.

(b) Samples of fish and sediment were collected for the analysis of organic contaminants.

(c) Samples of plaice and Norway lobster were collected from a number of areas in the Clyde, including Garroch Head, to assess the effects of waste disposal. Measurements included osmoregulatory disfunction (Na, KATP-ase) and detoxification mechanisms (mixed function oxidase, metallothionein) in plaice, and indicators of immuno-competence (e.g. blood phenol oxidase, haemoglutin, haemolysin) and bacterial clearance rates in the Norway lobster.

(d) Sediment samples were taken for supporting chemical analysis.

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ANNEX 1. MEMBERSHIP OF THE CGMSD IN 1990

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ANNEX 2. TASK TEAMS AND THEIR MEMBERSHIP IN 1990

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