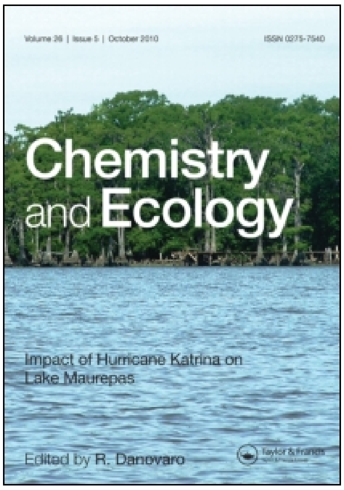

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THE MONITORING OF UK SEWAGE SLUDGE DISPOSAL SITES

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In recent years there has been an increase in the intensity and frequency of environmental monitoring surveys at UK sewage sludge disposal sites. These have been carried out by the regulatory authorities and by the licensees. In order to ensure maximum efficiency, a coordinated and harmonised programme of monitoring has been developed. The programme concentrates on sediment chemical and biological quality but also includes assessments of water and fish quality.

In England and Wales the Ministry of Agriculture, Fisheries and Food is the regulatory authority and the Water Authorities† are the licensees. The Ministry's first priority is the collection of samples for temporal trend analysis but in addition, infrequent surveys are made to check the status of the disposal site and surrounding areas. In the periods between status surveys, regular spatial surveys designed to define the area of impact are carried out by the Water Authorities.†

KEY WORDS Sewage sludge, Marine disposal, Benthos, North Sea, Sediments, Contaminants

INTRODUCTION

In England and Wales, the Ministry of Agriculture, Fisheries and Food (MAFF) has responsibility for the prevention of marine pollution by regulating the disposal of material by dumping from ships. In the early 1960s, a voluntary control scheme was introduced whereby disposal organisations applied to MAFF for approval of their activities. A consent was issued by the Ministry when it was considered that no significant adverse effects on the marine environment would occur (Norton and Rolfe, 1978). In 1972 the London and Oslo Conventions dealing with the control of waste dumping were concluded and in 1974 the UK Dumping at Sea Act came into force. This Act replaced the earlier voluntary scheme making it an offence to dump material at sea without a licence. In 1985, the DAS Act was replaced by part II of the Food and Environment Protection Act (FEPA) which broadened the area of control.

Under this Act it is the responsibility of the licensing authority when considering the issue of a licence to "have regard to the need to protect the marine environment and the living resources which it supports and human health." In order to discharge this responsibility it is necessary to exercise pre-discharge controls on waste disposal, to enforce these controls and to carry out surveys of the disposal sites to ensure that the marine environment, its living resources and human health are protected.

† Now Water Services Plcs.

The pre-discharge controls are designed to protect the marine environment by considering the nature of the waste and of the receiving area. It is then possible to determine whether a waste is suitable for disposal and what licence conditions should be placed on the disposal operation (discharge rate, time of disposal etc.). Enforcement is carried out by various inspection techniques to ensure that licence conditions are met. The monitoring work is designed primarily to ensure that the pre-discharge controls have prevented any damage to the marine environment and also to provide information on which to assess future licence applications.

In recent years there has been an increase in the intensity and frequency of environmental monitoring surveys at MAFF licensed sewage sludge disposal sites (Figure 1). These have been carried out by both the regulatory authority and the licensees. In order to ensure maximum efficiency a coordinated and harmonised programme of monitoring has been developed. The programme concentrates on sediment chemical and biological quality but also includes assessments of water and fish quality.

In Scotland licensees and the Department of Agriculture and Fisheries for Scotland (DAFS) carry out monitoring programmes while in Northern Ireland only the licensing authority is involved. Overall co-ordination and harmonisation of the various national programmes is the responsibility of the Co-ordinating Group on Monitoring of Sewage Sludge Disposal Sites, a sub-group of the Department of the Environment's Marine Pollution Monitoring and Management Group. This group also has the task of setting Environmental Quality Objectives

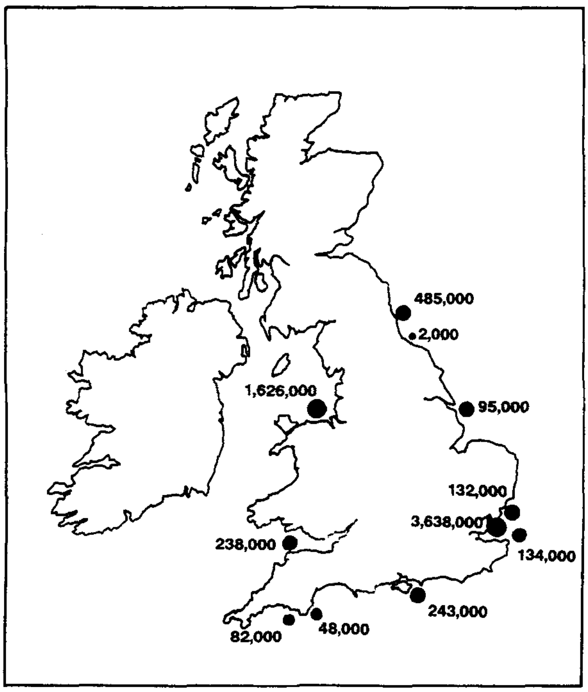


Figure 1 Sewage sludge disposal sites licensed by MAFF and tonnages deposited in 1987.

and their associated Environmental Quality Standards for disposal sites (MPMMG, 1989).

This paper describes the monitoring programme as implemented in England and Wales and gives some examples of the results from two disposal sites.

PHILOSOPHY

Recognising that sewage sludge is essentially degradable organic matter and that the levels of persistent chemicals and heavy metals are low, MAFF policy on sludge disposal to sea is to select conditions of disposal which promote dispersion and avoid significant accumulation. This aim may be redefined in terms of objectives:

1. to limit the spatial extent of the impact of disposal on the marine environment and its resources, to levels as low as reasonably achievable, and in any case below relevant environmental standards.
2. to limit intensity of the impact of disposal on the marine environment and its resources, to levels as low as reasonably achievable, and in any case below relevant environmental standards.
3. once the effects of waste inputs have stabilised there should be no worsening trend, i.e. the input does not exceed the dispersive capacity.

Monitoring therefore requires the application of methods to detect the extent and intensity of impact and to determine any variations over time. The methods used are chosen on a site specific basis to suit the particular environment of disposal, but with a view to maintaining a high degree of intercomparability between disposal sites.

Disposal site monitoring in the period 1975–84 relied heavily on widescale grid surveys carried out by MAFF. These permitted characterisation of the disposal sites and assessment of the scale and intensity of effects of disposal. However, as a monitoring tool, they had the disadvantage of being expensive in both time and money. The monitoring programme has been redesigned recently and is now a co-ordinated effort between MAFF and sewage sludge licensees.

Based on the knowledge gained in the early surveys, there has been a gradual change in emphasis in the MAFF programme from occasional large-scale spatial surveys to relatively frequent small-scale surveys in areas of known or potential impact. The primary purpose of these surveys has been to detect temporal changes in environmental quality (physical, chemical and biological). It has been supported by the development of a research programme to assess the causes and mechanisms of such changes.

In addition to the temporal surveys, MAFF undertake large scale surveys approximately every 10 years in order to reassess the choice of monitoring sites and determinands measured. Both the temporal and spatial surveys are largely sediment-based as it is this environmental compartment in which the effects of the solid components of the wastes are usually to be found.

The frequent temporal and infrequent spatial surveys undertaken by MAFF are designed to act as the core of the whole programme and will not only determine changes in environmental quality with time but also allow independent licensing decisions to be made and act as a check on the results of the licensees.

Widescale surveys of fish chemical quality and health are also carried out by MAFF (Franklin, 1987; Bucke, Norton and Rolfe, 1983). It should be noted that when such surveys are used in areas receiving several different waste inputs they may not be as sensitive as sediment-based techniques for resolving the effects of various waste disposal operations. They do, however, allow broad generalisations to be made as to the quality and health of fish in areas used for disposal of wastes relative to the quality and health of fish elsewhere.

Licensees are required, as a condition of their disposal licence, to define the extent of impact, thus complementing the MAFF core programme. The mandatory licensee studies are based on a limited range of determinands designed to highlight the spatial extent of impact. Licensees are, of course, at liberty to carry out additional studies as they see fit and this is the case at most disposal sites.

The licensee surveys are carried out annually, biennially or triennially depending on the scale and complexity of the disposal operation and the anticipated impact and a report submitted to MAFF at the end of each survey cycle.

The first phase of surveys has now been completed and the data are now being prepared for publication.

MONITORING CASE STUDIES

The following two case studies detail monitoring techniques used at two contrasting sewage sludge disposal sites.

Tyne

Background. In order to improve the water quality of the Tyne estuary, changes were made in the Tyneside sewerage system in the late 1970s. Among these, the installation of new treatment facilities has resulted in the production of quantities of primary settled sewage sludge which is deposited at sea off the river Tyne (Figure 2). The operation started at a low level in 1978 and increased to an annual deposition of approximately 500,000 wet tonnes in 1984, since when it has varied little. The chemical composition of the sludge is shown in Table 1.

Several other waste materials are deposited at designated sites off the north-east coast (Figure 2) although none are co-disposed with the sewage sludge. Fly ash originates from coal-fired power stations at Newcastle and Blyth, colliery waste from the mines to the south of Newcastle and dredged material from the ports and harbours in the areas (e.g. Newcastle, Sunderland and Seaham). Liquid industrial wastes are deposited in an area to the north of the sewage sludge disposal site although the effects of these wastes are confined largely to the water column and are not apparent at the sewage sludge site.

The sea-bed at the sewage sludge disposal ground consists of soft muddy sand and the water is 50 m deep. The tidal streams run approximately parallel with the coast with maximum velocities of 40 cm s^{-1}.

During the early stages of operation regular monitoring was undertaken with a view to detecting any effects of disposal as soon as they occurred. The

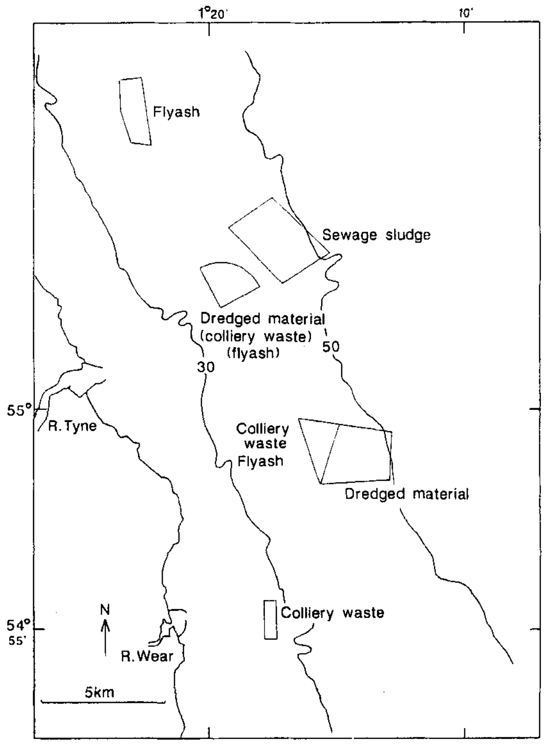


Figure 2 Tyne sewage sludge disposal ground, and other sites used for solid waste disposal off the north-east coast of England, with depth contours (m).

monitoring programme was primarily aimed at assessing the condition of the sea-bed and its associated fauna, although the area was also examined for water and fish quality as part of nation-wide monitoring programmes. The present paper deals with some surveys selected to demonstrate the approach used. They were carried out during the period 1984–1989 (see Rowlatt *et al.*, 1989).

Methods. Sea-bed samples were collected using a 0·1 m^2 Day grab. Immediately after collection a surface scrape of the sediment was taken for bacterial analysis. *E. coli* and Group D faecal streptococci were enumerated using the membrane filtration procedure described by West (1988).

Sub-samples of the surface 0–1 cm of the sediment were stored frozen for later chemical and physical analysis. On return to the laboratory the sediments for

Table 1 Chemical analysis of sewage sludge deposited in the Tyne site in 1987. Results expressed in parts per million on a wet weight basis

Hg	*Cd*	*Cr*	*Cu*	*Pb*	*Ni*	*Zn*
0.037	0.056	1.0	7.7	3.1	0.4	8.4

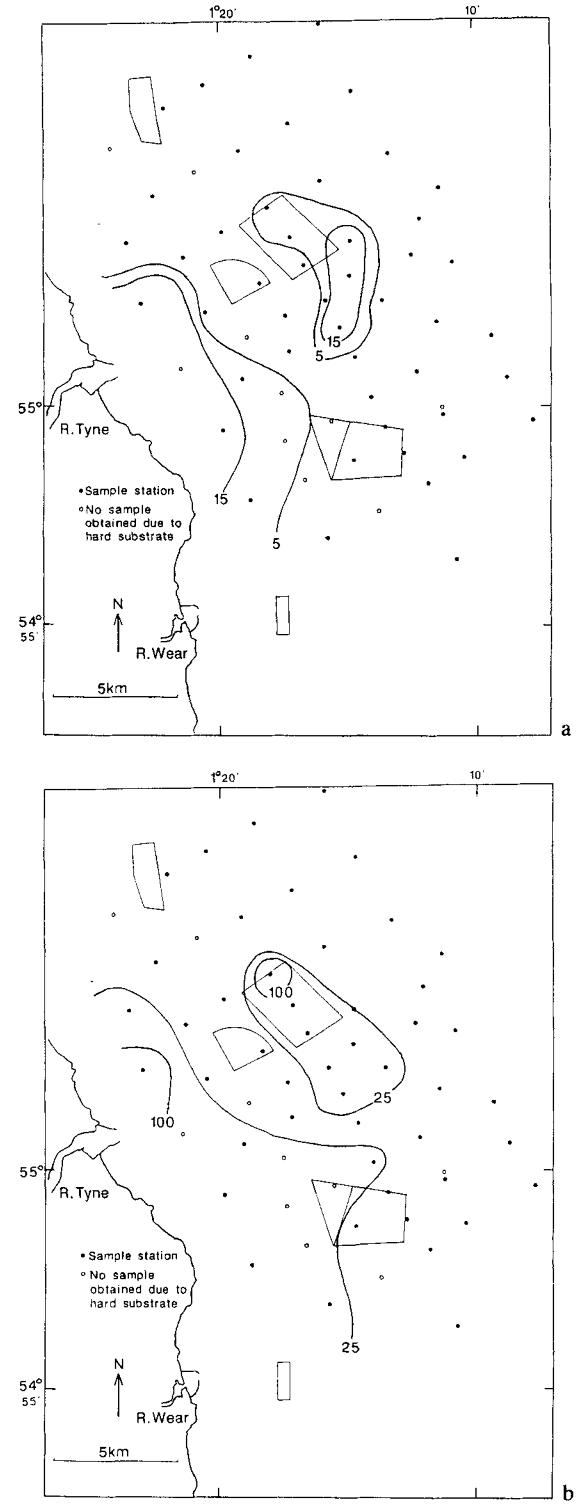


Figure 3 Distribution of faecal bacteria in the sediments around the Tyne sewage sludge disposal site, May 1988 (no's per ml sediment). a. *E. coli*, b. Group D faecal streptococci.

metal and carbon analysis were defrosted and sieved at 63 μm to extract the fine fraction. The fines were subdivided and the carbon content of one sub-sample determined instrumentally, after pretreatment with sulphurous acid to remove any carbonates present. Another sub-sample was digested with aqua regia and the metals mercury, copper, chromium, nickel, lead and zinc determined using atomic absorption spectrometry (Harper *et al.*, 1989). Samples of sediment for organic micropollutant determination were stored frozen until analysis, which was carried out using the procedures described by Allchin *et al.* (1989).

Sediment infauna was extracted from a 0.1 m^2 Day grab sample using a 0.5 mm mesh sieve and then formalin-preserved. In the laboratory, animals were identified where possible to species level and counted. Samples of litter were obtained using a 2 m beam trawl as described by Riley *et al.*, 1986. Each sample was collected from a 500 m long tow. Any litter retained by the trawl was identified and enumerated immediately after collection.

Results and discussion. The area of sludge settlement indicated by faecal bacteria is at and to the south-east of the disposal site (Figs 3a and b). These figures also show areas of sediment impacted by the outflow of the river Tyne and coastal outfalls, both of which contain sewage bacteria. The zone of settlement at the sewage sludge disposal site is confirmed by the presence of significant quantities of tomato pips in the sediments (Fig. 4). Pips also occur in the sediments at two

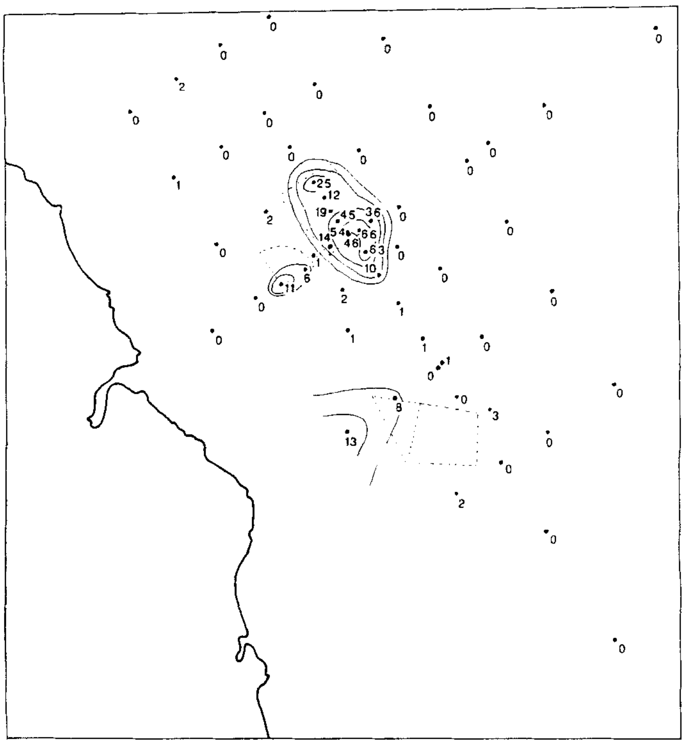


Figure 4 Distribution of tomato pips in the sediments around the Tyne sewage sludge disposal site, May 1985. (Numbers per 0.1 m^2; contours at 5, 10, 20 and 50).

dredged material disposal grounds inshore and to the south of the sewage sludge site. The occurrence of pips at these sites is to be expected as many sewage discharges flow into the area of the Tyne from which the dredgings are derived.

The presence of sludge-derived litter in beam trawl samples collected around the sludge disposal ground is indicative of an unacceptable sludge impact (Fig. 5 and Table 2). It should be noted that the disposal authority is now taking steps to eliminate litter from the sludge before sea disposal.

Tomato pips take several months to decompose and the various artefacts may take years. They should therefore be considered longer term sludge tracers than the faecal bacteria which die after only weeks of exposure to sea water. The presence of these three tracers in the same area to the south of the disposal site suggests that there is some accumulation of sludge derived material at the sea-bed.

In order to assess the impact of sludge on the chemical composition of the sediments the fine fraction, which will include any sludge-derived material, was extracted. By extracting the fines, not only is the impact of any sludge clarified but also the variable diluent effects of non-contaminant bearing fractions of the sediment (e.g. quartz) are reduced.

There is a general reduction in trace metal and carbon concentrations with distance from the shore and the effects of the outflow of the river Tyne are clear. However, with the possible exception of chromium, there is no evidence of accumulation of either metals or carbon at the disposal site (Fig. 6a–e). In the context of the riverine inputs to the nearshore zone it should be noted that the Tyne drains a catchment which includes the heavily mineralised Pennines as well

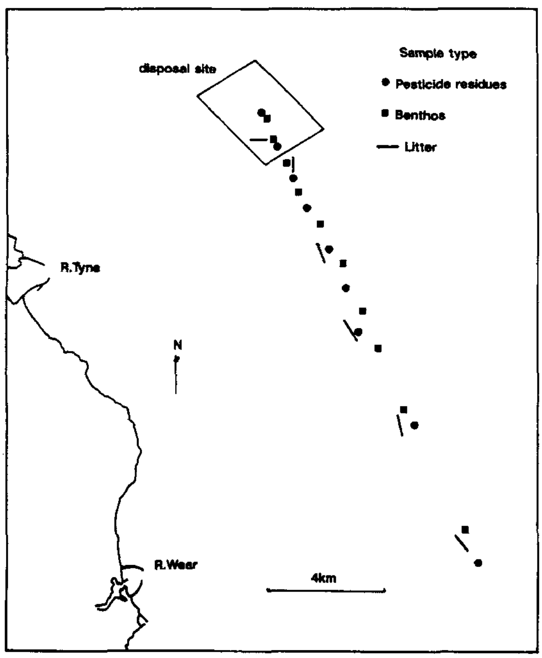
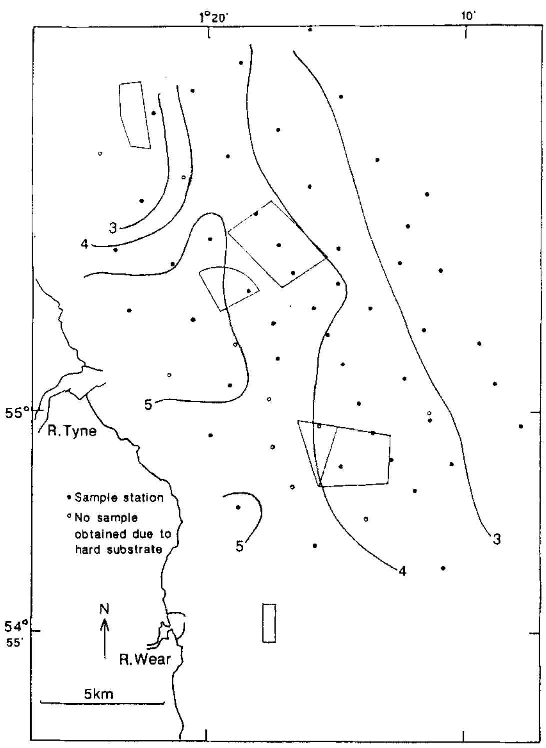


Figure 5 Transect showing stations sampled for benthos (in 1984) and pesticide residues (in 1989) using grabs and litter (in 1989) using beam trawls.

Table 2 Litter collected from beam trawls in the vicinity of the Tyne sewage sludge disposal ground

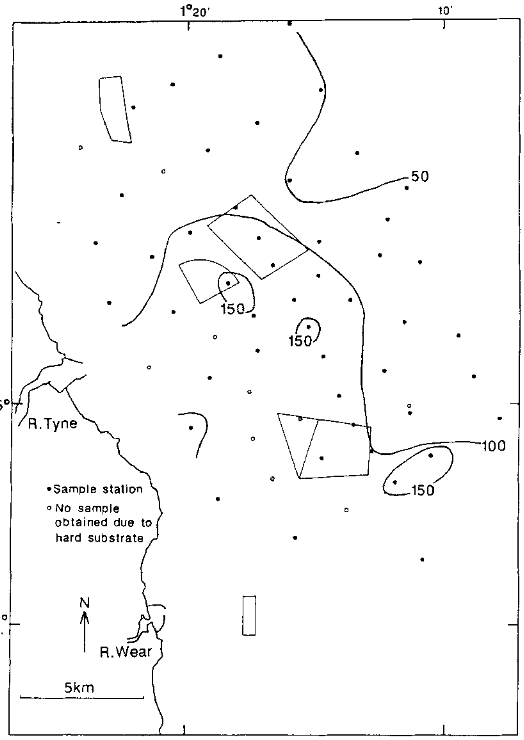
	Distance south of disposal ground centre/km					
	16.1	*11.6*	*8*	*5.2*	*2.1*	*0.9*
Sanitary towel						4
Tampon					2	8
Human hair					+	++
Cigarette filters					3	36
String						+
Rag				+	+	+
Plastic	+	+	+		+	+
Plaster						+
Match						+
Potato peel						+
Onion debris					+	+
Tin can				+		
Total 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 "++".



6a

Figure 6 Chemical composition of the <63 μm fraction of sediments around the Tyne sewage sludge disposal ground, May 1988. a. organic carbon % dry wt, b. lead mg/kg dry wt, c. zinc mg/kg dry wt, d. chromium mg/kg dry wt, e. mercury mg/kg dry wt.



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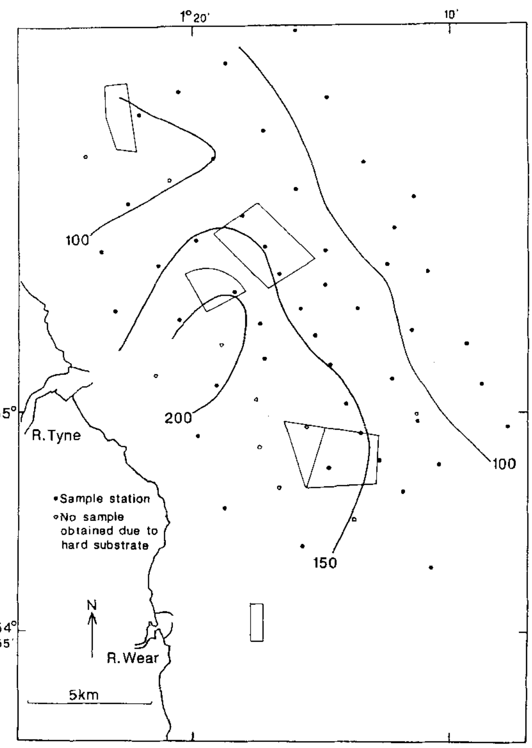

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Figure 6 (*Continued*)

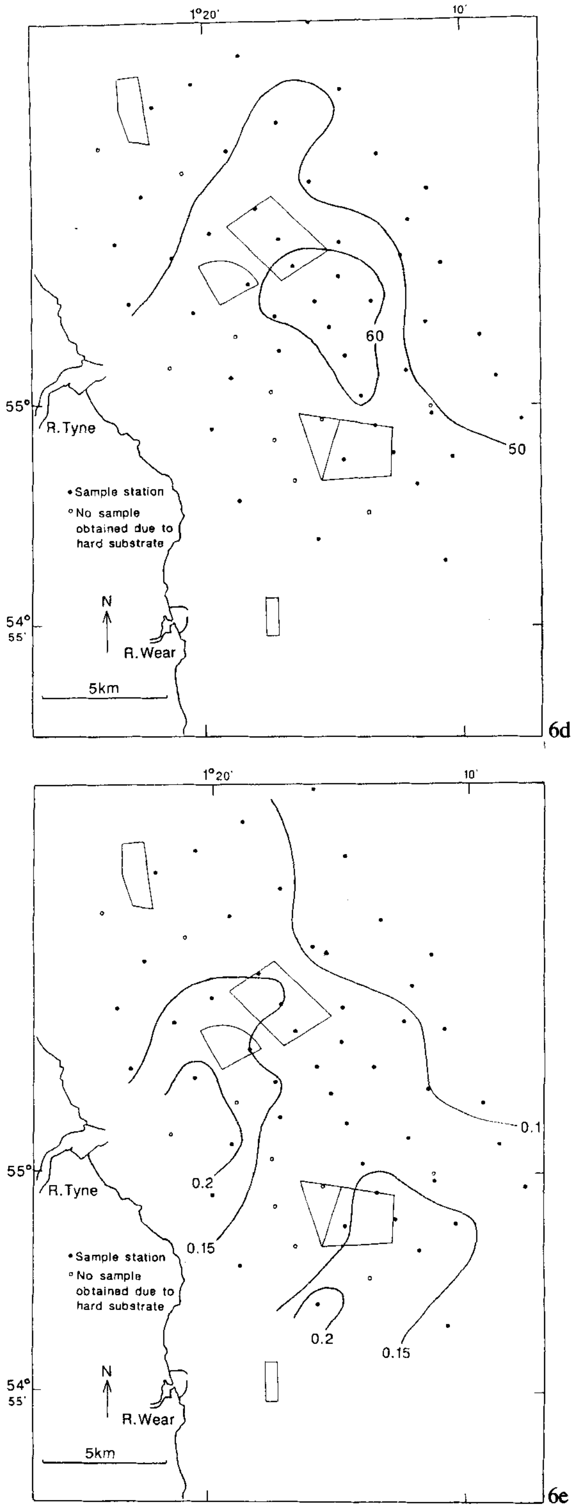

Figure 6 (*Continued*)

as industrial sources of contamination and the elevated levels of metals cannot be ascribed wholly to man-made contamination.

In order to assess any changes in sediment quality with time a system has been set up based on a stratified random design in which sediment samples collected in different years can be compared. The samples are collected from an area centred on the zone of initial settlement defined by the faecal bacteria discussed earlier and is designed to detect changes in sediment quality brought about if there is an accumulation of sludge.

This sampling system supersedes an earlier design based on transect sampling which was liable to reflect a component of the general offshore trend of decreasing metal concentrations. Although only three years' data are so far available it is clear that there is little year to year variation in the results (Fig. 7). This finding agrees with the limited effects of continued sludge disposal found in the spatial surveys.

Pesticide residues and PCB were measured in a set of sediment samples collected along a transect to the south of the disposal ground (Table 3 and Fig. 5). Concentrations are low and there is no evidence of contamination at the disposal ground compared to the sediments further south, indicating that sewage sludge inputs do not contribute significantly to the pesticide and PCB load of this area.

The benthic fauna at and to the south of the disposal area has been characterised using a transect survey, with three grabs being taken at each of 10 stations. The transect (Fig. 5) is approximately parallel to the coast and in line with the residual surface currents and runs 16 km to the south from the centre of

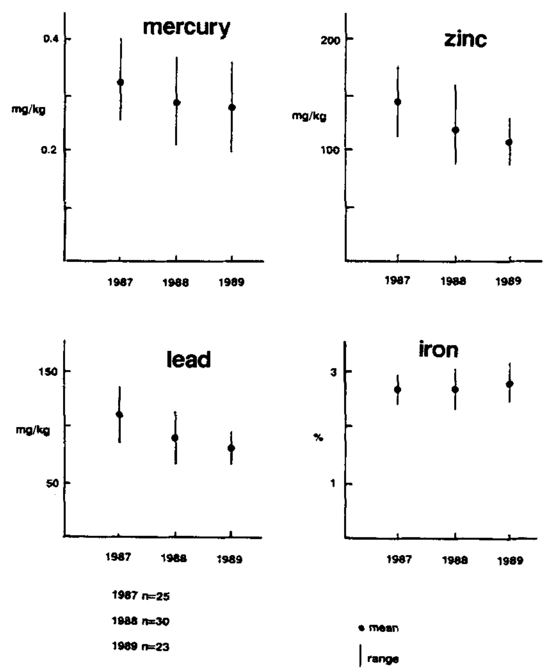

Figure 7 Temporal trends in metal content of the <63 μm fraction of sediments collected near the Tyne sewage sludge disposal ground.

Table 3 Pesticide residues and PCB in sediments ($mg\,kg^{-1}$) from the area of the Tyne sewage sludge disposal site, May 1989. See Figure 5 for station positions. HCB, Alpha-HCH, Beta-HCH, Gamma-HCH, pp DDE and pp TDE were below the detection limit at all stations (0.001 $mg\,kg^{-1}$ dry weight)

Distance south of disposal site centre/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	0.01	0.002
8.2	<0.001	0.013	0.015
11.9	<0.001	0.006	0.003
17.0	0.001	0.006	0.006

the disposal ground (Rees *et al.*, 1985). An added advantage of the survey design is that at all stations the water depth is about 50 m and the sediment is muddy sand, thus reducing extraneous environmental influences associated with variations in depth and substrate type.

Surveys along the transect in 1984 and 1986 (Fig. 8) show similar patterns with enhanced numbers of benthic organisms at and to the south of the disposal ground. Coincidence with peaks in counts of tomato pips provides circumstantial evidence for localised effects of sludge disposal. The overall difference in abundance between years can be accounted for by natural seasonal effects, the surveys being carried out at differing times of year. In neither year is there any clear trend in the numbers of taxa. This, along with the absence of any successional changes towards over-abundance of classical "pollution-indicator" species, suggests that no gross effects of enrichment are apparent.

The monitoring programme is underpinned by a research project on the transport of fine sediment off the north-east coast. This work will lead to the development of a computer model which should refine predictions of waste movement.

Implementation. Under the self monitoring scheme, MAFF will undertake annual temporal surveys, i.e. the sediment quality work in the zone of initial impact and benthos at representative sites on the transect. MAFF will also continue, off the north-east coast, its regular surveys of fish quality allied with occasional surveys of fish disease incidence. The licensee, Northumbrian Water, will carry out, as a condition of the disposal licence, a spatial survey of sediment quality every second year.

The use of beam trawls for the detection of litter will be continued by both MAFF and the licensee at two-yearly intervals at least until the effectiveness of

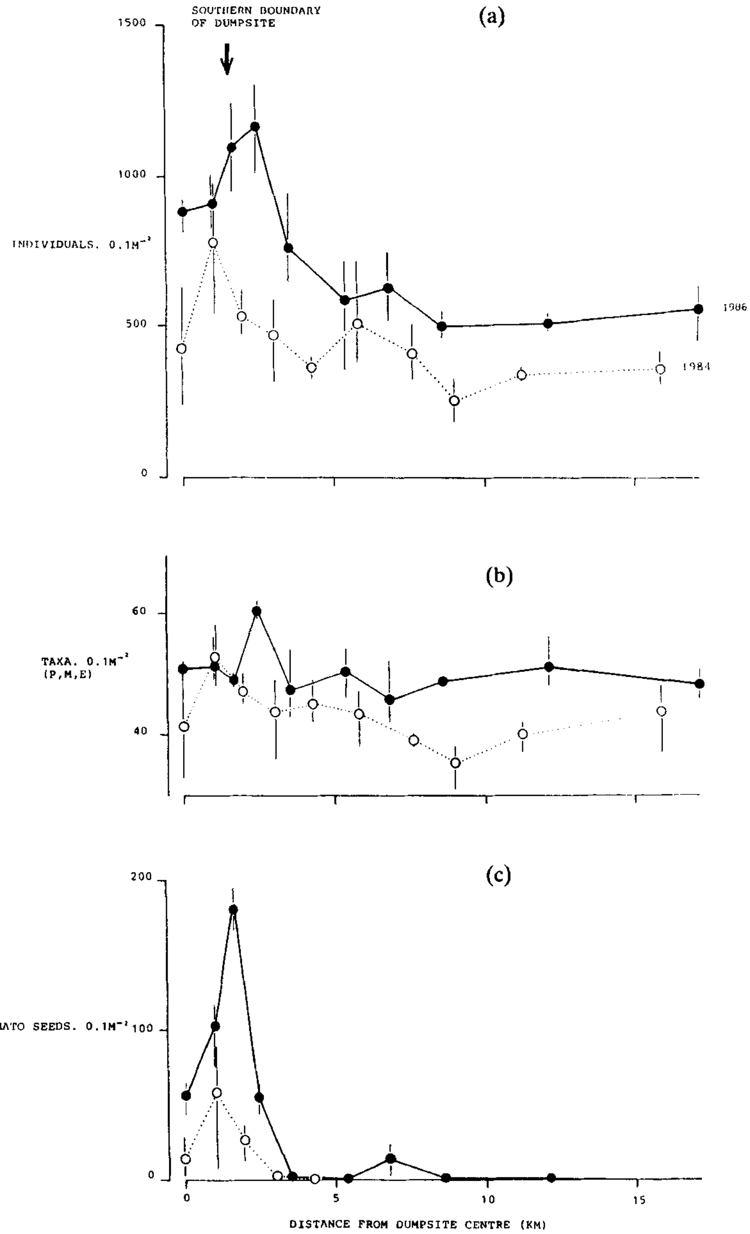

Figure 8 Distribution of benthos and tomato pips ($\bar{x}$ and range) along a transect south from the Tyne sewage sludge disposal ground, February 1984 and June 1986. a. numbers of benthic individuals; b. numbers of taxa (Polychaeta, Mollusca and Echinodermata only); c. numbers of tomato pips.

the new measures to remove this material at the treatment works has been proven.

The Humber

Background. The Humber disposal ground is situated in an area of hard gravel sediments with maximum tidal currents of 120 cm s^{-1}. Earlier monitoring studies in this area (Murray *et al.*, 1980) have shown that localised elevations in concentrations of organic carbon and certain trace metals in the sediments could be attributed to sludge disposal, although the contributory influence of the Humber estuary is also evident.

Methods

The earlier studies were hampered by the gravel and stone substrates, which were unsuited to the traditional assessment of the benthos using grabs. It is possible to use Shipek grabs for the collection of samples for chemical analysis but the samples are generally too small and variable for the determination of benthic infauna. Thus it was decided to use the growth, condition and contaminant content of *Modiolus modiolus* (horse mussel), as a possible alternative means of identifying any impact of waste disposal.

Results

Details of the method used and results obtained are given in Rees and Nicholson (1989). These authors conclude that when corrected for the effects of shell weight the mussels at the disposal ground contain a higher burden of lead than those at a control site in a clean area off north Norfolk (Fig. 9). At present it is difficult to

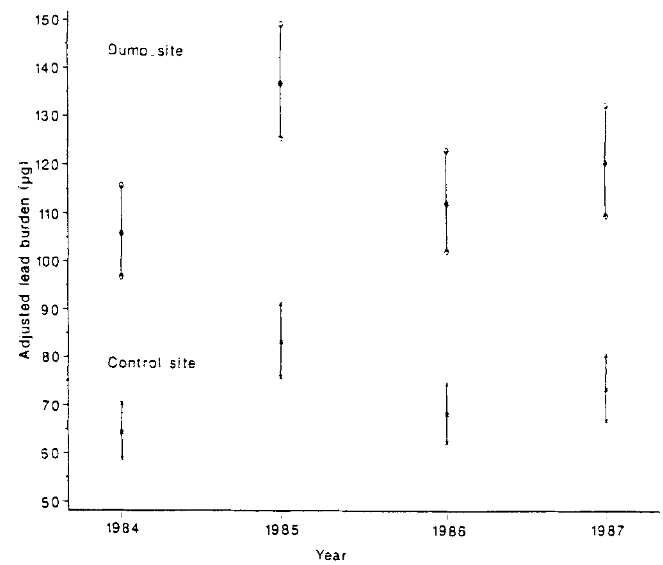

Figure 9 Estimated lead body burdens (with 95% pairwise significance bands) for *Modiolus* of shell weight 21.8 g. Data for the Humber from Rees and Nicholson, 1989.

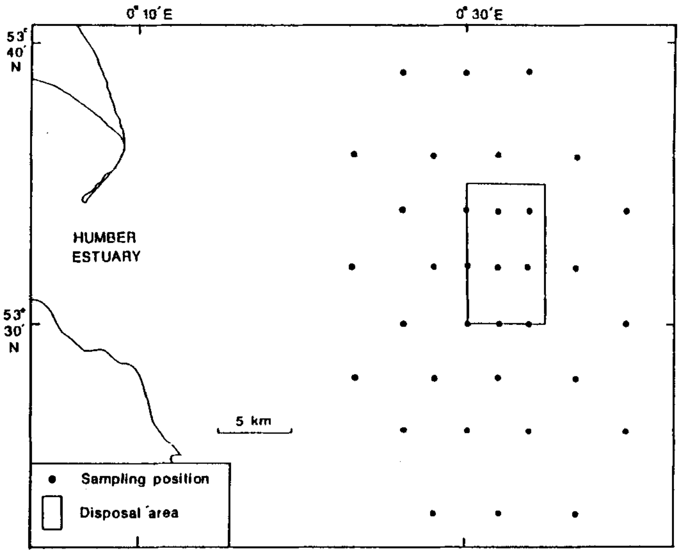

Figure 10 Sediment sampling grid used for spatial surveys at the Humber sewage sludge disposal ground.

separate the effects of sludge disposal from those of the many industrial discharges made to the Humber. Future reports will deal with a wider spatial coverage of the area.

Implementation. The temporal studies of *Modiolus* at the Humber are to be carried out by MAFF in order to determine the intensity of impact and any changes with time. The licensee will sample a grid of sediment stations (Fig. 10) every two years for bacterial, carbon and metal analysis to determine the extent of the impacted area.

Acknowledgement

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