CEFAS
The Centre for Environment, Fisheries & Aquaculture Science

Monitoring of the quality of the marine environment, 2000-2001

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AQUACULTURE SCIENCE

AQUATIC ENVIRONMENT MONITORING REPORT
Number 56

Monitoring of the quality of the marine environment, 2000-2001

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FOREWORD

Aquatic Environment Monitoring Report No. 56 collects together work carried out in 2001 by CEFAS scientists in support of our monitoring and surveillance duties (see overleaf). The information presented covers both environmental surveillance at offshore and coastal sites and site-specific work carried out in support of risk assessments and regulatory work. Some of the science reported here forms part of wider efforts to integrate data from Departments and Agencies in the UK to provide a comprehensive picture of the quality of the marine environment via the UK National Marine Monitoring Programme (NMMP). Other components are unique to CEFAS due to our requirement to understand ecosystem response resulting from potential pressures from deposit, extraction and discharge activities.

The strategy for the NMMP programme is described in publications commissioned by the Marine Environment Monitoring Group (MEMG), formerly the Marine Pollution Monitoring Management Group (MPMMG). The programme manual, known as the Green Book, is available in downloadable format from the Fisheries Research Services, Marine Laboratory Aberdeen website at: www.marlab.ac.uk/FRS.Web/Uploads/ Documents/Main%20text1.pdf

The programme seeks to develop trend data for a limited number of sites around the UK and the work is augmented by special surveys of compounds likely to pose specific risks. In order to address the need to improve temporal resolution for more effective trend monitoring, CEFAS has developed an autonomous measurement system (SmartBuoy) capable of making high frequency observations of a range of variables. This allows data to be collected on a continuous basis whilst the instrumentation is deployed at sea. Progress to date is outlined in Chapter 2, whilst the nutrient status of the waters around England and Wales derived from traditional measurement techniques is described in Chapter 1. Biological effects methods provide an indicator of exposure to contaminants, and Chapter 4 outlines recent results relating to the determination of EROD activity in fish. The community structure of the benthic meiofauna and macrofauna at four NMMP sites and the changes observed during studies in 3 years at each site are described in Chapter 5.

There is a close link between the focused research conducted at CEFAS and the regulatory processes on which we advise government. Chapter 6 summarises the activity in licensing of deposits at sea in 2001, whilst Chapter 3 illustrates how the R&D findings from a study of contamination from a former gasworks site in England feed into both the licensing process and dredgings disposal site monitoring studies. The Defra Marine Stewardship Report '*Safeguarding Our Seas*' lays great emphasis on sustainable development, and Chapter 7 describes our studies into habitat creation as a sustainable solution for maintenance dredgings disposal. Chapter 8 summarises information on radioactivity in UK waters.

The Defra report can be downloaded at www.defra.gov.uk/environment/marine/stewardship/default.htm and this report and earlier reports in this series are available in downloadable format from the CEFAS website www.cefas.co.uk

Robin Law
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BACKGROUND TO THE WORK

As an Executive Agency of the Department for Environment, Food and Rural Affairs (Defra), CEFAS carries out work in support of the Government aim to enhance the quality of life through promoting:

- a better environment;
- thriving rural economies and communities;
- diversity and abundance of wildlife resources;
- a countryside for all to enjoy; and
- sustainable and diverse farming and food industries that work together to meet the needs of consumers.

Within these overarching objectives, environment work at CEFAS is directed at research, monitoring and assessment of the impact of potentially harmful substances or activities on the quality of the marine, coastal and estuarine environments. We are involved directly in advising on UK and international legislation and in developing policy relating to management of the aquatic environment. We provide advice to Governments, enforcement agencies and policymakers throughout the world on the development and implementation of monitoring and assessment programmes and control measures.

An important component of our work is to provide advice to Defra Ministers and other Government Departments on all aspects of non-radioactive contamination of the aquatic environment. Specifically under Part II of the Food and Environment Protection Act (1985) (FEPA) (Great Britain Parliament, 1985a), Defra has the responsibility to licence and control the deposit of material to the sea. Following the cessation of disposal of sewage sludge to sea, licensed materials are predominantly sediment, derived from maintenance and capital dredging activities. Disposal at sea is also regulated internationally by OSPAR, and our work enables the UK to carry out its obligations as a Contracting Party.

The CEFAS Inspectorate evaluates scientific and technical aspects of licence applications and makes regular visits to licence holders to ensure that any stipulated conditions are being met. Conducting monitoring programmes in support of risk assessments enables Defra to ensure the effectiveness of the assessment process and provides a basis for decisions on future policy for management of marine resources. Environmental scientists at CEFAS monitor environmental conditions at marine disposal sites and compare the results with those from more general environmental quality monitoring, allowing suitable action to be taken if unexpected or unacceptable impacts should occur.

Under the Water Resources Act (1991) (Great Britain Parliament, 1991), Defra is a statutory consultee for all discharges to controlled (tidal) waters. CEFAS scientists assess the fishery implications of applications for consent to discharge permits. Consideration is given to resources in the area, toxicity of the effluent, local hydrographic conditions and any standards set out in national policy or EU Directives.

We also provide advice to the Department of Trade and Industry (DTI) and for the Office of the Deputy Prime Minister (ODPM) concerning the control of pollution in other areas of industrial activity affecting the marine environment including the offshore oil and gas industry and marine aggregate extraction. The Statutory Offshore Chemical Notification Scheme and the Government View on the winning of aggregates respectively control these activities, and the regulatory regime for aggregates is presently also changing to a statutory scheme.

On Defra's behalf, CEFAS is responsible for monitoring intermediate and offshore stations in the UK National Marine Monitoring Programme (NMMP), which seeks to integrate national and international monitoring programmes for all UK agencies. Each year we collect samples of seawater, sediment and biota for chemical analyses and deploy a number of biological effects techniques, including water and sediment bioassays and fish disease surveys. The first phase of spatial surveys evaluated the pattern of marine quality around the UK providing a picture of generally healthy conditions in UK coastal waters. Phase II, which began in 1999, is focused on the detection of long-term temporal trends and the introduction of new biological effects studies. The NMMP allows us to ascertain the effectiveness of regulatory measures to reduce the inputs of hazardous substances to UK seas. In addition, it contributes to the UK's international monitoring obligations to demonstrate UK compliance with various EC Directives: Dangerous Substances Directive (76/464/EEC); Shellfish Waters Directive (79/923/EEC); Shellfish Hygiene Directive (91/492/EEC); Fishery Products Directive (91/493/EEC); Commission Decision 93/351/EEC concerning maximum mercury limits in fishery products, and similar requirements under OSPAR.

In order to ensure that the advice provided to Defra and other Regulators is always based on the most up-to-date knowledge and techniques, CEFAS carries out a wide range of research and development to provide for future needs of monitoring and surveillance programmes. For example, we have developed new and more sensitive bioassay techniques, analytical methods, unattended sampling and monitoring devices and we are currently leading on a Europe-wide collaborative research project on the quality assurance in biological effects testing methods.

Environment Science at CEFAS has a track record of more than 50 years experience in aquatic studies. During this period we have made a number of significant contributions to environmental protection and as a consequence of our work have established a worldwide reputation in the field of aquatic environmental research. More information on our research programmes is listed on the CEFAS web site (www.cefas.co.uk).

GLOSSARY OF TERMS

ANOSIM	Analysis of Similarities
ANOVA	Analysis of Variance
ASG	Ammonium Duodeca-molybdophosphate on Silica Gel
BNFL	British Nuclear Fuels
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CTD	Conductivity, Temperature and Depth
CYPIA	Cytochrome P4501A1
DMSO	Dimethyl Sulphoxide
DNA	Deoxyribose Nucleic Acid
EC	European Community
EHS	Environmental Heritage Service (Northern Ireland)
ERL	Effect Range-Low
ERM	Effect Range-Median
EROD	Ethoxyresorufin-O-deethylase
EU	European Union
FEPA	Food and Environmental Protection Act 1985
FRS	Fisheries Research Services
GFF	Glass Fibre Filters
IAEA	International Atomic Energy Agency
ICES	International Council for the Exploration of the Sea
JAMP	Joint Assessment and Monitoring Programme
MAFF	Ministry of Agriculture, Fisheries and Food
MDS	Multi-Dimensional Scaling
MEMG	Marine Environment Monitoring Group
MFO	Mixed Function Oxygenase
MHWS	Mean High Water Springs
MPMMG	Marine Pollution Monitoring Management Group
NADPH	β–Nicotinamide Adenine Dinucleotide Phosphate
NMCAQC	National Marine Chemical Analytical Quality Control Scheme
NMMP	National Marine Monitoring Programme
OSPAR	Oslo and Paris Commission
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
pGSI	Pseudo Gonad Somatic Index
RV	Research Vessel
SEERAD	Scottish Executive Environmental and Rural Affairs Department
SIMPER	Similarities Percentages Programme
SFI	Sea Fisheries Inspectorate
SFPA	Scottish Fisheries Protection Agency
TOxN	Total Oxidised Nitrogen
UK	United Kingdom

SEA WATER

1. WINTER 2001 NUTRIENT CONCENTRATIONS IN THE COASTAL WATERS OF ENGLAND AND WALES

Author: David Mills

1.1 Introduction

Eutrophication can result from nutrient enrichment of marine waters provided favourable conditions prevail. As interim measures are still in place for judging the extent of eutrophication and (eu)trophic status of marine waters the current assessment is based on the monitoring of nutrient concentration in coastal and offshore waters in winter (OSPAR, 1997). It is recognised that nutrient concentration alone is insufficient evidence of eutrophication and there is a need for comparable measurements of biological and chemical indicators (chlorophyll concentration, phytoplankton species composition, oxygen concentration) during winter and summer for assessment of trophic status of a particular region. OSPAR is developing common assessment methodologies for eutrophication status.

The monitoring undertaken under the auspices of the UK National Marine Monitoring Programme has been to determine winter (January to March) nutrient species (ammonium, nitrate, nitrite, phosphate and silicate) concentrations in the coastal waters of England and Wales. In addition, measurements have been taken of chlorophyll and dissolved oxygen concentrations to set the scene for the monitoring of possible eutrophication symptoms in the following spring and summer. The summer situation in the coastal waters of England and Wales is the subject of on-going work. One particular strategy that is being tested to better achieve our aim of monitoring the consequences of any nutrient enrichment is continuous measurement using automated measuring/sampling instrumentation.

1.2 Methods

The OSPAR protocols outlined in the Eutrophication Monitoring Guidelines have been adopted in carrying out the sampling and analysis programme.

1.2.1 Sampling

Water samples were collected at National Marine Monitoring Programme (NMMP) sites in the coastal and offshore waters of England and Wales in January 2001 and March 2000. The discrepancy in the timing of the surveys means that comparisons between January and March measurements must be treated cautiously. Discrete surface and subsurface water samples were taken at each station from a research vessel. Samples were collected in Niskin bottles mounted on a CTD-rosette equipped with a chlorophyll fluorometer and optical backscatter sensor for measuring turbidity. Samples for the anlysis of nutrients and supporting parameters were collected, stored and pre-treated as described in the sampling and handling sections of the JAMP Eutrophication Monitoring Guidelines (OSPAR 1997). At each site, the spot samples reported here were collected within the 30 to 35 psu salinity range.

1.2.2 Analysis of samples

Water samples were analysed immediately for TOxN (Total Oxidised Nitrogen), nitrite, phosphate, silicate and the supporting parameters; salinity, temperature, chlorophyll and suspended load. Nitrate concentration was determined by difference (TOxN minus nitrite concentration).

Nutrient determination was based on colourimetric methods developed by Bendschneider and Robinson (1952), Murphy and Riley (1962), Grasshoff *et al.* (1983) and Kirkwood (1996). Analytical quality assurance (precision and accuracy) was achieved by participation in laboratory intercomparison studies and by participation in the NMCAQC scheme.

Temperature and salinity were measured *in situ* by CTD probes; calibration was achieved by reference to discrete samples measured using a Guildline 'Autosal' 8400 laboratory salinometer.

Chlorophyll was determined by filtering a known sample volume through Whatman glass-fibre filters (GFF) and extracting into 90% neutralised acetone. A Turner Designs (Model 10) filter fluorometer was used to measure extracted pigment (Tett, 1987).

1.3 Results and discussion

1.3.1 Description of January/March 2001 NMP station nutrient distribution

Figures 1(a) to 1(e) show the spatial variability in the distribution of nutrient and chlorophyll concentrations for the NMP sites sampled in the coastal waters of England in January and Wales in March in 2001. The design and operations of the survey programme have

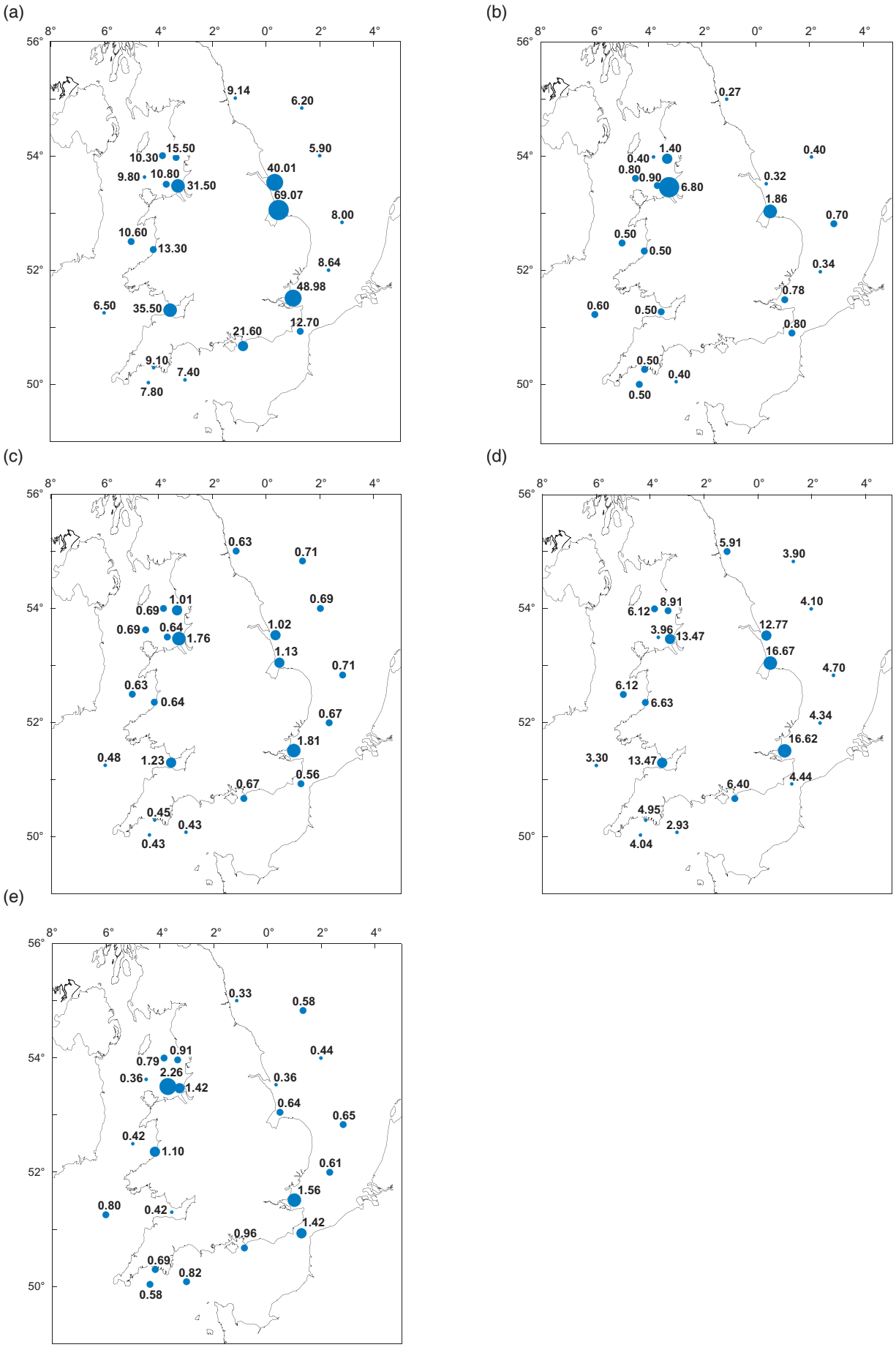

Figure 1. Surface concentrations at NMP stations in January 2001 (North Sea) and March 2001 (Irish Sea): (a) TOxN (μM), (b) ammonia (μM), (c) phosphate (μM), (d) silicate (μM) and (e) chlorophyll (μg l^{-1})

been modified to allow additional effort to be made in the deployment of automated buoys (SmartBuoy) at key NMMP sites in the North Sea. The spatial distribution figures illustrate variation in concentration through the use of circles whose diameter and degree of shading reflect the concentration. To aid interpretation the actual measured concentration is shown alongside each circle.

Total oxidised nitrogen (TOxN), Nitrate and Nitrite
The total oxidised nitrogen concentration includes both nitrate (NO_3) and nitrite (NO_2) species. Generally, the nitrite fraction is small (<1% of TOxN) compared to the nitrate contribution. TOxN concentrations fall with distance offshore due to the reducing influence of nutrient inputs from rivers, direct discharges and diffuse run-off.

The highest concentrations determined in English coastal waters were in samples from the Humber, Thames and Wash (69.07, 48.98 and 40.01 µM, respectively). These sites are located close to major riverine sources of nutrients and elevated levels are to be expected. The group of stations close to the south coast, though much lower than the North Sea coastal sites, are still elevated in TOxN with respect to more offshore sites. The lowest concentrations in English waters were found at offshore sites in the North Sea, ranging from 6.20 µM in the north to 8.64 µM in the southern Bight. These values are low with respect to the oceanic end member concentration of circa 12 µM. This discrepancy may reflect a more dynamic system with respect to nutrient cycling during the winter than would be expected. The cause of such discrepancies needs to be understood if winter values in offshore waters are to be used as reference levels when setting targets for ecological quality objectives.

For the west coast sites, the highest concentrations were recorded in the Severn estuary (35.50 µM) and Liverpool Bay (31.50 µM), with lower concentrations offshore in the Irish Sea and the lowest concentration (6.5 µM) in the Celtic Sea.

Ammonium
Apart from Liverpool Bay (6.80 µM) and the Humber (1.86 µM), levels of ammonium are generally <1.0 µM. A number of factors influence the ambient concentrations of ammonia that include the nature of the local estuaries and, for near shore sites, the presence of large urban conurbations leading to significant waste water discharge and the recycling of ammonium. The low concentrations found offshore reflect a reduction in the influence of riverine inputs due to the effects of dilution.

Phosphate
Phosphate concentrations are generally elevated close to the major riverine inputs, and lower at offshore locations. As for TOxN, the Thames, Liverpool Bay, the Severn, the Wash and the Humber showed the highest concentrations.

Silicate
The highest concentrations of silicate observed in January were found in the Thames, Wash and the Humber (16.62, 16.67 and 12.77 µM respectively). On the west coast in March, Liverpool Bay yielded the highest concentrations, followed by the Severn. Silicate concentrations as all other sites were below 10 µM during the survey periods.

Chlorophyll
Chlorophyll is the primary photosynthetic pigment in phytoplankton and can be measured chemically to provide an indicator of phytoplankton biomass. The low concentrations (<2.5 mg m^{-3}) recorded at all sites reflect the low levels of phytoplankton that persist though the winter months when the low level of light limits their growth. The highest concentrations were found in the Thames and Liverpool Bay, and may be due to either relatively higher growth rates in these regions in the winter, or the presence of chlorophyll derived from estuarine inputs from phytoplankton or benthic micoralgae.

Dissolved oxygen
Measurements of dissolved oxygen are made on water samples collected well below the water surface. Concentrations ranged from just below 6.0 mg l^{-1} off the south west coast to 6.81 mg l^{-1} in Morecambe Bay. With no thermal stratification and increased wind speeds during winter, the water column at NMMP sites will generally remain well mixed with respect to density. As a result, the water column should be well aerated with little biological activity to influence oxygen concentration.

1.4 Conclusions

The main features of the spatial survey undertaken during winter 2001 are:

- Nutrient concentrations are generally lower offshore where dilution with sea water with lower nutrient concentrations is evident.
- The major estuarine contribution arise from the Thames, Wash and Humber estuarine systems on the east coast and the Liverpool Bay and the Severn estuarine systems on the west coast.

2. TRIAL MONITORING OPERATIONS USING AUTOMATED INSTRUMENTATION

Author: David Mills

The NMMP sampling strategy provides good spatial coverage in the annual nutrient survey, but lacks the temporal resolution necessary to resolve the underlying variability in nutrient concentrations. As a consequence of under-sampling, the results may be biased with negative impacts on the quality of advice provided to Defra. In order to address the need to improve temporal resolution for more effective trend monitoring, CEFAS has developed an autonomous measurement system (SmartBuoy) capable of making high frequency observations of a range of variables including TOxN and silicate concentrations relevant to the NMMP.

2.1 Methods

Only a brief description of the methods will be given. The measurement of nutrient concentrations reported here is restricted to TOxN and silicate. Measurements are made using a NAS2E *in situ* nutrient analyser that employs a colourimetric method for determination of nitrate+nitrite concentration. The instrument is calibrated in the laboratory prior to field use by comparison of NAS2E estimates of nutrient concentration in discrete seawater samples with known concentrations. In the field, an on-board standard provides additional calibration data. In addition, an automated water sampler (Aqua Monitor) collects water samples (150 ml) which are preserved with mercuric chloride for subsequent analysis in the laboratory. A water sample is collected once every 24 hours, at midnight, and TOxN and silicate are determined in the preserved water samples. The Aqua Monitor serves as a backup to the NAS2E, and also enables us to determine the silicate concentration.

2.2 Results and discussion

The data gathered from an offshore NMP site number 475 (Outer Gabbard) in the southern North Sea are shown in Figure 2. The TOxN (nitrate+nitrite) concentration was recorded every 2 hours from November 2000 until January 2002.

A composite plot (Figure 2) shows data from the standard NMMP monitoring study overlaid on the high frequency measurements derived from the nutrient analyser and water sampler. The overwinter NMP TOxN concentrations reported in Figure 1(a) are an average based on the measurements made in early January 2001. It is clear that the overwinter maxima (18.3 µM peak and 14.3 µM daily average) which occurred in late March are confirmed by the NAS2E and water sampler data. The rapid decline in ToXN concentrations is a result of algal growth during the spring bloom. The mean surface silicate concentration of 4.34 mM (Figure 1(d)) is lower than that indicated by the Aqua Monitor, with peak values of 6.5 mM in those samples.

The preliminary data set presented here illustrates the potential for automated *in situ* measurements to augment the current NMMP programme, and to provide data suitable for the investigation of temporal trends. The data shows the degree of variability that

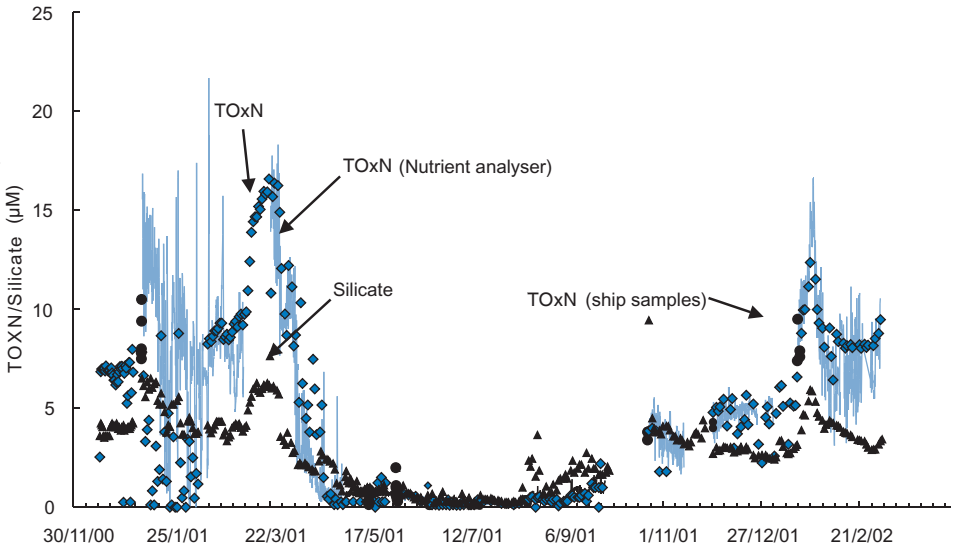

Figure 2. TOxN and silicate measurements from NMP475 (Outer Gabbard) in the southern North Sea

may be encountered in the parameters of interest and the potential shortfall of an annual survey in effectively measuring the overwinter nutrient concentration.

The results demonstrate the strength of the approach with the standard measurement set made in winter (January 2002) underestimating by nearly 50% the peak winter TOxN values. The generally good agreement between the standard ship based sampling and the results from the automated analysis *in situ* give further confidence in the effectiveness of the new approach.

BIOTA

3. PAH CONTAMINATION FROM A FORMER GASWORKS SITE AT SHOREHAM-BY-SEA, SUSSEX

Authors: Robin Law and Carole Kelly

The production of coal gas for lighting purposes began in the UK in the early 19th Century, and in 1930 there were around 1800 gas and coke works across the country. The coal carbonisation process was the major source of coal gas until after the First World War, after which the use of refinery products became more widespread. The majority of these works closed in the 1960s and 1970s as natural gas replaced coal gas. The ground beneath former gasworks sites is generally contaminated with a variety of wastes, including polycyclic aromatic hydrocarbons (PAH) which can percolate through the underlying soil in association with groundwater. One such site, by Shoreham Harbour, was in use from 1870 until the 1970s. Very high concentrations of PAH were found in ash-like material found on the former gasworks site, and samples of sediments, mussels and crustacea from the vicinity were taken for analysis (Law *et al*., 2002a). PAH were determined using an established method based upon alkaline saponification, alumina clean-up and analysis by GC-EIMS (Kelly *et al*., 2000). 18 individual PAH and groups were determined. The sampling area is shown in Figure 3.

Elevated concentrations of PAH were found in sediments and mussels taken from the beach below the former gasworks site, and in sediments at Norfolk Bridge within the Adur River. Summed PAH concentrations ranged up to 8,230 µg kg^{-1} dry weight in sediment and 6,450 µg kg^{-1} wet weight in mussels. Longshore drift along the coast off Shoreham takes the water flow to the east, and elevated, though gradually declining, PAH concentrations were found in mussels sampled as far as Brighton to the east. In contrast, mussels sampled immediately to the west of the Shoreham Harbour entrance were at background levels (summed PAH concentration 57 µg kg^{-1} wet weight).

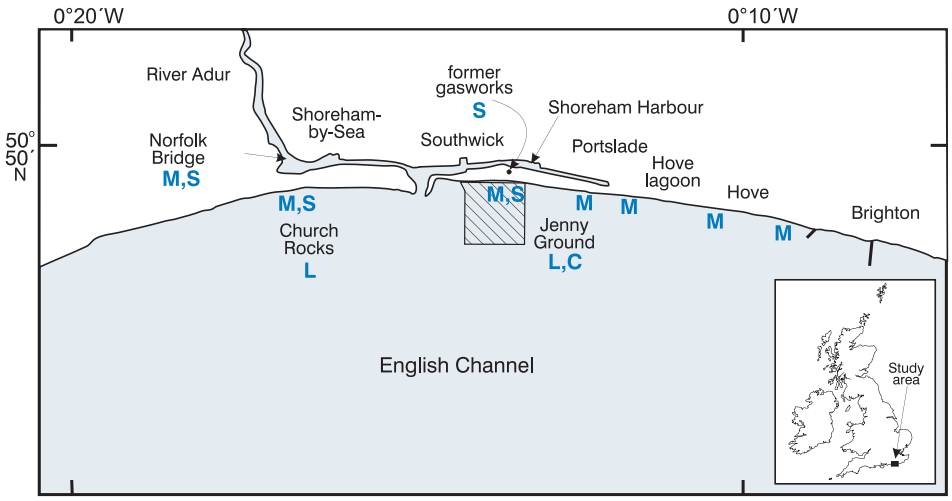

Figure 3. Location of study area and sampling points. Sample key: M, mussels; S, sediment or substrate; L, lobster; C, crab. The black hatched block shows the location of the dredged spoil disposal site at which dredged material from the port and navigation channels is deposited

These results caused some concern regarding both possible risks to human health if the mussels were consumed and for the potential for contamination of sediment in the harbour area, parts of which are dredged to maintain navigation into and out of the port. Although the mussels are not commercially exploited they are gathered casually, and heavily contaminated sediments will not be licensed for sea disposal.

As can be seen elsewhere in this report, dredgings disposal is licensed by Defra under the Food and Environment Protection Act. Prior to a licence being granted, representative samples are taken from the area to be dredged and these are analysed for a range of contaminants. In this case, a larger number of samples than usual were taken so as to give as good a picture of the levels of contamination as possible. Heavy contamination was found to be confined to an area of the inner harbour, alongside the former gasworks site and separated by a lock system from the outer harbour. The area to be dredged was much less contaminated, and dredging and disposal was approved for the 2002 season. Subsequent analysis of samples collected from the disposal site off Shoreham, have confirmed that the sediments there are relatively clean.

In order to assess the PAH concentrations in mussels in terms of human health risk we followed an approach adopted by the United States Food and Drug Administration. This involves the calculation of benzo[*a*]pyrene equivalents by summing the concentrations of the individual PAH on the basis of their comparative potency as cancer-causing chemicals. The concentrations of the summed PAH determined ranged from 4.9 to 6,450 µg kg^{-1} wet weight in mussels, crabs and lobsters, with the lower values occurring in the crustacea and the higher concentrations (1,260 to 6,450 µg kg^{-1} wet weight) in mussels. Concentrations expressed as benzo[*a*]pyrene equivalents ranged from zero in some edible tissues of crabs and lobsters, to 336 µg kg^{-1} wet weight in mussels from the lower beach below the gasworks. These concentrations showed a steady decline from west to east in mussels to the east of the gasworks site, from Shoreham to Brighton. Benzo[*a*]pyrene equivalent concentrations in the most contaminated mussels exceeded those found in mussels from the licensed beds in the Adur River by 10 to 100 times, and many exceeded the acceptable values established following oil spill incidents in the USA, where this technique is often applied. As a result, warning notices were put in place by local councils warning potential gatherers of the mussels and recommending that they should not be harvested.

Subsequently, this approach has been applied to a wider selection of monitoring data deriving from oil spills and mussel monitoring studies in the UK, the USA, and other European countries, and studies undertaken downstream of an aluminium smelter in Scotland (Law *et al*., 2002b). In all, 19 data sets were studied. Summed PAH concentrations varied from undetectable to 100,000 µg kg^{-1} wet weight, and from 0 to 800 µg kg^{-1} wet weight as benzo[*a*]pyrene equivalents. The highest summed PAH concentration was seen in mussels close to the site at which the *SEA EMPRESS* grounded in Wales in 1996, and the highest benzo[*a*]pyrene equivalent value below an aluminium smelter using Soderberg electrodes. Figure 4 shows the maxima from all studies considered, and there is an obvious distinction between those in which the primary source is oil (e.g. *EXXON VALDEZ, SEA EMPRESS*) and those where the major source is combustion, including Shoreham. The latter show higher maximum benzo[*a*]pyrene equivalent concentrations for a similar summed PAH concentration, and so pose a greater risk to the health of consumers. Contamination from diffuse sources generally falls with in the lower part of the range (benzo[*a*]pyrene equivalent concentrations up to ca. 20 µg kg^{-1} wet weight), whilst large contamination events yield much higher values.

A broader study of PAH concentrations in dredged material and at a number of disposal sites is currently underway.

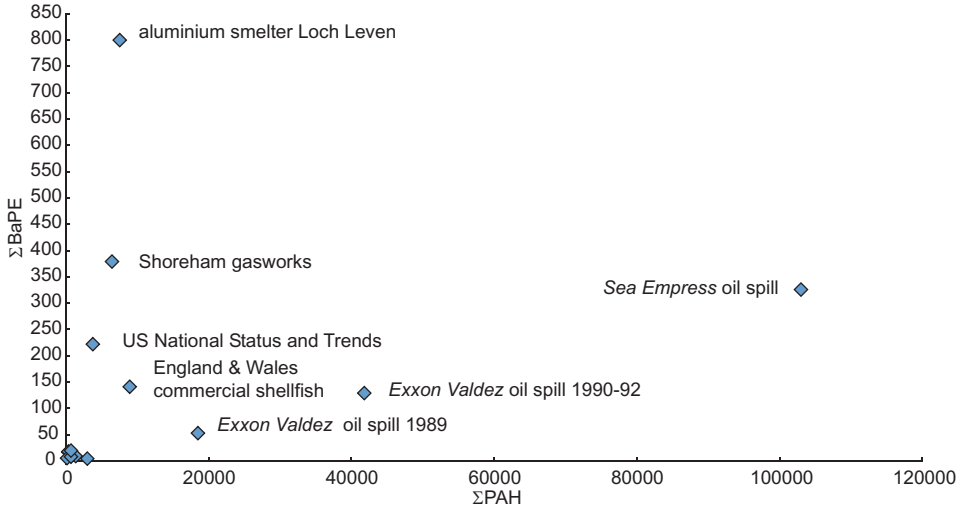

Figure 4. The relationship between maximum values of ΣPAH and ΣBaPE in the 19 datasets examined (µg kg^{-1} wet weight)

4. THE USE OF ETHOXYRESORUFIN-O-DEETHYLASE (EROD) IN FISH AS A BIOLOGICAL EFFECTS MONITORING TOOL

Author: Mark Kirby

4.1 General introduction

Some of the most biologically significant groups of contaminants in the benthic marine environment are the polycyclic aromatic hydrocarbons (PAH), the planar polychlorinated biphenyl congeners (PCB), and the dibenzo-*p*-dioxins and dibenzofurans. The PCBs are exclusively anthropogenic in origin, while the others arise from a range of natural and anthropogenic processes. As they are all extremely hydrophobic, they tend to become associated with fine sediments, and benthic flatfish may therefore experience higher exposure than their pelagic cousins. When absorbed into fish, these substances can induce synthesis of the mono-oxygenase (MFO) enzymes known as the cytochrome P450 group, which are found in large amounts in the microsomal fraction of liver cells. Cytochrome P4501A1 (CYP1A1) is the terminal component of the MFO system and EROD activity is CYP1A1 dependent, and so, EROD represents a good marker of MFO induction.

The mixed function oxygenase (MFO) enzyme system is the primary detoxification pathway for a number of planar organic contaminants, specifically polycyclic aromatic hydrocarbons (PAH) and some polychlorinated biphenyls (PCB) and is induced in fish by exposure to such compounds. Induction of the MFO system, whilst detoxifying certain xenobiotics, may also have deleterious effects. First, many carcinogenic and genotoxic compounds only become harmful after transformation to active forms by the MFO system (e.g. formation of benzo[*a*]pyrene diol-epoxide from the parent compound). Secondly, since essential endogenous substances such as steroids are regulated by the system, abnormally elevated MFO activity could have a detrimental effect upon an organism's normal functions such as growth and reproduction. With this in mind, the determination of EROD concentrations in fish tissue has become an important element of CEFAS' input to the National Marine Monitoring Programme (NMMP), within which it is used as an indicator of both contaminant exposure and of potential future health problems for the fish population.

The use of EROD in a coastal and offshore marine monitoring context was first applied by CEFAS (then the MAFF Directorate of Fisheries Research) during the early 1990s (CEFAS, 1998). The assay showed great promise as a monitoring tool and enabled coastal and offshore sites to be differentiated with respect to the level of EROD activity that was apparent in the extracts of dab (*Limanda limanda*) liver. Since 1995, the EROD assay has been deployed as a key technique for the investigation of the exposure to and effects of the contaminants mentioned above. Furthermore, as a greater understanding of how the MFO system interacts with other biological effects measures (e.g. crosstalk with vitellogenin induction system) has been built up, its determination has become an important stage in the interpretation of data from samples taken from multi-contaminant areas (e.g. esturies). The use of EROD measurements is now established within the UK NMMP. In addition it has also been shown to be of value in the investigation of estuarine contamination (Kirby *et al*., 1999a), and in the assessment of the impact of specific pollution events such as the *SEA EMPRESS* oil spill (Kirby *et al*., 1999b).

EROD data for dab have been produced for sites around the UK coast regularly since 1995. These data have been presented in previous marine environment monitoring reports (CEFAS, 1998; 2000; 2001). This report presents EROD monitoring data for coastal waters, generated from the 2001 sampling effort.

4.2 Methods

Fish were collected during June and July 2001 using *RV CIROLANA's* Granton trawl. Once on deck, target species were separated into tanks containing flowing seawater. Dissections were performed within 1 hour of capture. The liver was excised and placed in a cryovial which was immediately placed in liquid nitrogen for subsequent storage. Notes were taken of fish condition, length, sex, gonad length and the degree of parasitism. Fish over 10 cm length were taken as samples. At the laboratory, mean 'pseudo' gonad somatic index (pGSI) (gonad length/fish length x 100) and condition factors (weight/length cubed x 100) were calculated for each site from the collected data. Correlation coefficients (r) were calculated between these parameters and the EROD results obtained.

Homogenate preparation

A 200 mg (± 10 mg) slice of liver was homogenised with 1 ml of ice-cold homogenising buffer (100 mM K_2HPO_4/KH_2PO_4 pH 7.5, 1 mM EDTA, 1 mM

dithiothrietol, 150 mM KCl) using six strokes of a Potter-Elvehjem automatic homogeniser set at 700 rpm. The homogenates were then centrifuged at 10,000 g for 20 minutes in lidded eppendorf tubes using a refrigerated unit set at 4°C. The supernatants were removed and used as the raw enzyme solution.

EROD activity determination

EROD measurement was performed using the standard method established by the International Council for the Exploration of the Sea (ICES) (Stagg and McIntosh, 1998). A Perkin Elmer LS50B fluorescence spectrometer set at wavelengths of 535 nm excitation and 580 nm emission with a cuvette stirring function was used. All assay reagents were kept at 20°C (±1) in a water bath so as to control the assay temperature. The reaction mixture (final volume 2 ml) contained 1.96 ml assay buffer (100 mM K_2HPO_4/KH_2PO_4 pH 7.5, 100 mM KCl), 20 µl liver homogenate, 10 µl ethoxyresorufin substrate (0.4 mM in dimethyl sulphoxide, DMSO) and 10 µl of resorufin internal standard (25 mM, adjusted by absorbance to allow for variance in % purity in resorufin stock in DMSO). The standard equates to an addition of 250 pM of resorufin against which the assay was calibrated. The reaction was initiated by the addition of 10 µl NADPH (0.25 mM) and further emission readings were taken at the start and finish of a 60 second period from a linear section of the sample trace.

EROD activity was normalised to protein content and expressed as pM resorufin/min/mg protein. Protein analyses were carried out using a plate reader modification of the Bradford method (1976) with a bovine serum albumin standard.

4.3 Results and discussion

The 2001 survey saw dab sampled from 17 UK sites. The mean EROD values (male and female data amalgamated) are represented in Figure 5.

The 2001 data shows, in general, slightly reduced EROD values across most sites in comparison to those observed in previous years. No site produced a mean EROD value above 1000 pM/min/mg protein and those showing the highest values (≥800 pM/min/mg protein) were, as for previous years, mainly focused off the coast of NE England and in the Eastern Irish Sea. A comparatively high mean value of 858 pM/min/mg pro was also apparent from Dundrum Bay (Northern Ireland) but these data need to be treated with caution as this result is derived from only 5 fish. The routinely low values associated with samples from Rye Bay and the Cardigan Bay area continued in this dataset.

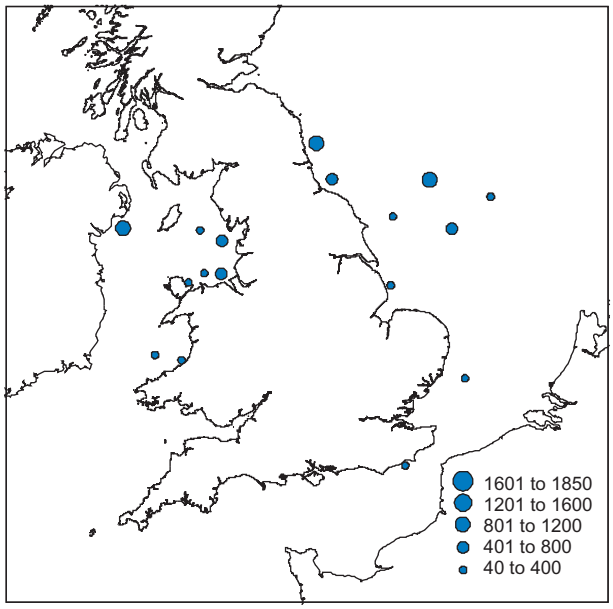

Figure 5. Mean EROD values (pM/min/mg protein) for samples taken during 2001

The 2001 data now adds a sixth consecutive year of EROD data to the CEFAS time series. As in previous years, the Northeast and Northwest coast areas demonstrated the highest concentrations. These are presumably associated with the inputs from the industrialised estuaries feeding into these zones. With only 6 years of data available trend analysis is still somewhat premature. In an earlier report (CEFAS, 2002) we studied the 5 year trend in EROD concentrations at four key sites representative of the Northwest (Red Wharf Bay on Anglesey and the Burbo Bight) and the Northeast (off the Rivers Tyne and Tees) coasts. Figure 6 shows the mean EROD levels observed at these sites with the 2001 data added. Interestingly, our most recent data appears to confirm the tentatively assigned downward trend in the Liverpool Bay area, but those for the Northeast sampling areas appear to have risen once more. Time series of 10 years or more will be required before firm conclusions can be drawn regarding temporal trends.

The somatic data were analysed and this proved to be an influencing factor in the EROD concentrations found. Mean lengths of the samples ranged between 18 and 23 cm for males and 20.1 to 26.8 cm for females. Mean weights ranged from 53 to 125 g for males and 76 to 222 g for females. It is clear, therefore, that the scarcity or size distribution of samples at certain sites meant that standardisation could not be achieved. Furthermore, ranges in pGSI (1.5 to 6.4 and 10.4 to 19.8 for males and females, respectively) suggest that even during July we were sampling fish at different stages in the reproductive cycle. Table 1 shows the calculated correlation coefficients (r values) for some of these parameters and EROD expression.

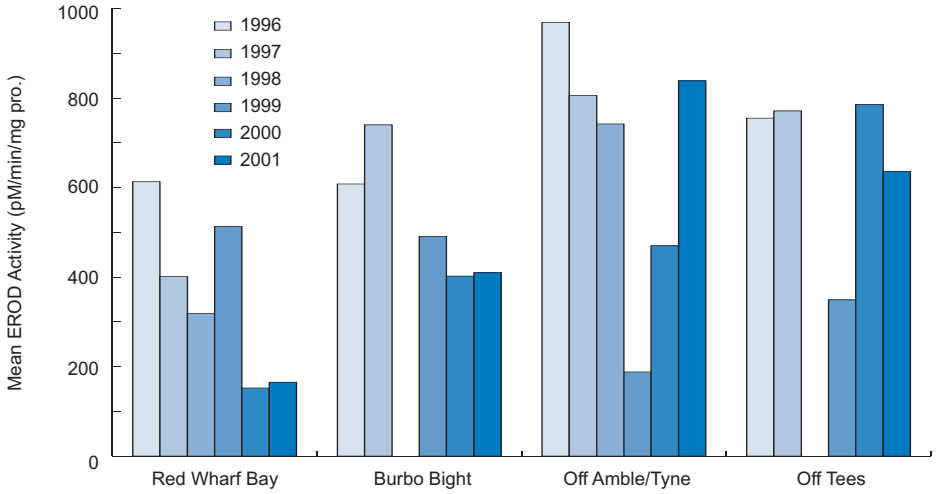

Figure 6. Six year trend data for mean EROD at selected sites

Table 1. Correlation coefficients between EROD activity and other variables

	Latitude	pGSI	Length	Weight	Condition Factor
EROD (All)	0.65	-	0.08	0.19	-0.31
EROD (Males)	0.35	0.86	-0.33	-0.45	-0.55
EROD (Females)	0.75	0.56	-0.20	-0.21	-0.38
pGSI (Males)	0.32	-	-0.24	-0.35	-0.51
pGSI (Females)	0.81	-	0.41	0.34	-0.32

Mean EROD concentrations showed a good correlation (r=0.65) with latitude, though this was much more pronounced in females (r=0.75) and indicates that EROD concentrations are higher the farther north the fish are collected. Latitudinal climatic differences will affect the timing of breeding seasons as one travels north and it is probable that the generally higher values in these regions are associated with this phenomenon. However, with relatively few sites the coincidental fact that the most contaminated areas (NE and NW coasts) happen to be in the north could partially account for this relationship. Of greater significance are the correlations with the mean pGSI values. pGSI is strongly correlated to latitude in females (r=0.81) and appears to have a substantial influence on the EROD values gained for both sexes, but especially in males (r=0.86). The lack of any significant correlations of EROD activity with size parameters (length and weight) suggests that, in this instance, the lack of standardised size sampling was not such an important issue. However, the fact that all the coefficients were negative confirms what has been previously suggested, that younger fish show generally higher EROD values.

4.4 Conclusions

Monitoring continues to produce some anomalous results (e.g. sporadic high EROD activities on the Dogger Bank) which are difficult to explain in terms of contaminant exposure. This suggests that much more needs to be known about the environmental influences on MFO activity before the monitoring data can be used to interpret biological effects of contaminants with great confidence. However, general, but clear, patterns of induction have emerged through the six annual datasets presented in recent monitoring reports. Sites in Liverpool Bay and off the northeast coast of England routinely have significantly elevated EROD activity, whilst those in areas such as Cardigan and Rye Bay have been consistently low. These general trends now demonstrated over a 6 year survey period provide compulsive evidence that fish populations in certain areas are undergoing long-term exposure to MFO-inducing chemicals. It has also been shown that flounder (*Platichthys flesus*) populations in the estuaries of the Mersey, Tyne and Tees, exhibit significantly elevated levels of EROD activity (Kirby *et al*., 1999b). It seems likely that the coastal populations of other fish species, such as dab, adjacent to these estuarine outflows are also being affected. The monitoring data presented here strongly supports this suggestion. It is also acknowledged, and demonstrated in the 2001 dataset, that the potential influences of breeding condition and specimen size on EROD activity can be very significant and, therefore, it will be important to standardise sampling time and size/sex class as much as possible in future years. The continued addition of data to this time series will provide a valuable insight into the chronic exposure of fish populations to MFO inducing contaminants.

5. STRUCTURE AND TAXONOMIC COMPOSITION OF SUBTIDAL MEIO- AND MACROFAUNA AT FOUR NMMP STATIONS AROUND THE UK COAST

Authors: Michaela Schratzberger, Paul Whomersley, Rebecca Kilbride and Hubert Rees

5.1 Summary

The diversity and structure of meiobenthic nematodes and macrobenthic infauna were studied at four widely spaced subtidal National Marine Monitoring Programme (NMMP) sites in relation to a number of measured environmental variables. Similar benthic assemblages were encountered in comparable environmental conditions. The distribution of nematode and macrofauna species was mainly governed by the geographical location of the habitat and the granulometric composition of the substrate. There was no evidence of any adverse effect on the measures of benthic assemblage structure arising from trace metal concentrations in the sediment, indicating the relatively unpolluted nature of all locations. Both types of benthic assemblages exhibited stable patterns over time periods of three years.

5.2 Introduction

The analysis of benthic community structure is a good tool for describing changes in both space (with application in point source pollution monitoring) and time (with application in the description of changes in the state of marine systems) (Heip *et al*., 1992). Benthic organisms are frequently used to monitor the biological effects of marine pollution because, as a group, they are largely sedentary and so must withstand the extremes of their local environment or perish. Macrobenthos (>500 µm) have been the historical choice of workers in the pollution monitoring field but in recent years there has been an increase in the use of the smaller sized meiofauna (500 to 63 µm) (Coull and Chandler, 1992; Schratzberger *et al*., 2000).

The initial NMMP sampling design was spatial in emphasis, involving the positioning of 87 stations within 'estuarine', 'intermediate' and 'offshore' areas, defined in accordance with hydrological (i.e. water-column) criteria. This chapter reports on the findings from a sub-set of stations occupying offshore locations around England and Wales as part of this wider programme. The sub-set comprised four sites which were sampled for benthic meiofauna and macrofauna and a number of environmental variables over a three-year period. The stations were located off the Tyne, off the Humber, in Lyme Bay and in the Celtic Deep (in water depths of 53 to 95 m) and are intended as long-term monitoring locations within the NMMP. In view of the small numbers of stations considered, these sites are not fully representative of the variety of habitats and potential impacts that prevail in these waters. In order to maximise the value of sampling effort in relation to available resources, and being mindful of the primary concern of contaminant-related effects within the NMMP, the sub-set of stations selected for temporal sampling of the marine benthos was targeted at finer sediments in relatively stable (usually deeper-water) areas, i.e. characteristics which tend to be associated with depositional rather than erosional areas.

5.3 Materials and methods

Sample collection

Meiofauna samples at all stations (Figure 7) were taken with the Bowers and Connelly Multicorer, which is designed to take four undisturbed sediment samples (23.76 cm^2 surface area each) simultaneously. The corer was deployed four times at each site. From each deployment, one whole sediment core was retained for meiofauna analysis and the top 5 cm of another core from the same deployment was retained for particle size and chemical analyses.

At each station (Figure 7), five macrofauna samples were collected by means of a 0.1 m^2 Day Grab. A subsample for particle size analysis and the determination of organic carbon content was collected with a perspex corer (3 cm diameter) to a depth of 5 cm and the remainder of the sediment was retained for macrofauna analysis. The sediment surface of five further Day Grab samples was scraped off with a stainless steel spoon for the analysis of trace metal concentrations. All benthic samples were fixed in 7% formaldehyde made up in 63 µm filtered seawater. Samples for particle size and chemical analyses were stored frozen at -20°C pending analysis.

Sample processing

Meiofauna samples were initially washed onto a 63 µm sieve to remove the fine silt fraction and the formalin. After decanting the samples five times onto a 63 µm sieve, meiofauna was extracted with Ludox™

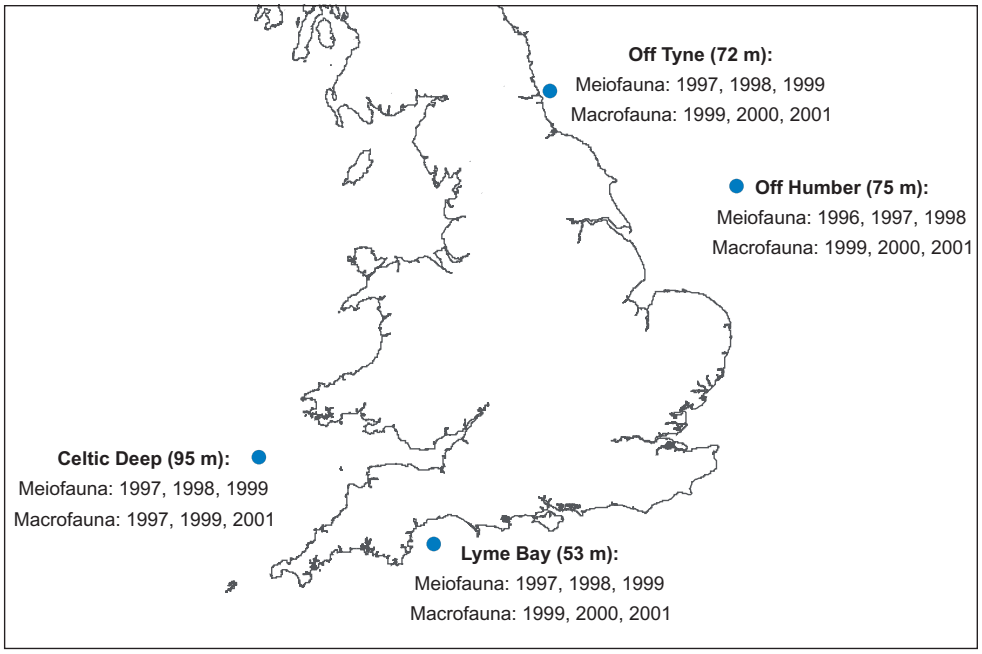

Figure 7. Offshore locations sampled for meiofauna and macrofauna. Sampling years are indicated for each site

40 with a specific gravity of 1.15 (Somerfield and Warwick, 1996). The extraction process was repeated three times. The samples were evaporated slowly in anhydrous glycerol and evenly spread on microscope slides for identification and counting of nematodes. All nematodes were counted and the first 200 specimens on each slide identified to genus or species level.

All macrofauna samples were initially washed through a 1000 µm sieve and retained individuals were counted and identified to family or species level.

Data processing

The number of species was calculated for nematode and macrofauna assemblages based on adjusted raw-data sets where all those species occurring only once during the study were excluded from the analyses. Simple regression analysis indicated that there was no significant relationship between the sample depth and the number of species. The effect of both 'site' and 'year' on the number of nematode and macrofauna species was investigated using a two-way analysis of variance (ANOVA).

Non-metric multi-dimensional scaling (MDS) ordination using the Bray-Curtis similarity measure was applied to relative species abundance data (Clarke and Warwick, 1994). Two-way crossed analysis of similarities (ANOSIM) was used to test for statistically significant effects of the factors 'site' and 'year' on benthic assemblage structure and the similarity percentages programme (SIMPER) was used to determine the contribution of individual species to the average dissimilarity between geographic locations.

The relationships between multivariate community structure and environmental variables were assessed using the BIOENV programme, defining suites of environmental variables which best explain the biotic structure (Clarke and Warwick, 1994).

5.4 Results

Sediment characteristics

Sediment samples collected using the Day Grab (Table 2) were characterised by a lower silt/clay content than those sampled with the Multicorer (Table 3). All sediments fell within the category of muddy sands or sandy muds and were generally poorly sorted. Sediments collected off the Tyne and in the Celtic Deep were significantly finer than those collected at other locations. Organic content was highest at the sampling site off the Tyne. The concentrations of trace metals were relatively low and gave no cause for concern. Concentrations of most trace metals were higher off the North Sea coast of the UK (off the Tyne and off the Humber) than off the south coast (Lyme Bay) or in the Celtic Sea (Celtic Deep). There was no statistically significant co-variation of the concentrations of trace metals and the silt/clay content of the sediments.

Table 2. Sediment characteristics obtained from Multicorer samples. Mean is in µm, silt/clay and organic carbon contents are in % and metal concentrations are in mg kg^{-1}

	Off Tyne			Off Humber			Lyme Bay			Celtic Deep		
	1997	1998	1999	1996	1997	1998	1997	1998	1999	1997	1998	1999
Mean	40.8	38.5	38.4	99.7	73.8	95.0	108.1	101.0	109.2	57.9	54.0	53.9
Sorting	1.7	1.7	1.7	1.5	1.9	1.9	2.1	2.10	2.1	1.79	1.8	1.9
Silt/clay	51.8	56.3	56.3	18.4	28.0	23.4	23.6	26.7	23.6	36.3	38.0	38.3
Org. C	3.2	3.5	2.7	2.2	2.0	2.0	1.7	1.2	1.5	1.5	1.3	1.5
Cr	52.0	46.1	28.3	71.0	51.0	53.0	27.0	23.6	25.3	36.0	20.8	19.7
Ni	32.0	30.6	18.8	43.0	29.0	31.0	16.0	14.4	15.5	24.0	15.1	14.6
Cu	18.0	38.1	11.7	26.0	16.0	17.0	7.9	9.7	9.9	21.0	12.0	12.6
Zn	103.0	110.8	61.7	86.0	80.0	149.0	45.0	55.1	60.3	89.0	60.7	57.1
Cd	0.2	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.3	0.1	0.1
Pb	48.0	79.0	47.0	39.0	31.0	35.0	18.0	30.0	33.0	25.0	21.0	22.0
Hg	0.1	0.2	0.1	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1

Table 3. Sediment characteristics obtained from Day Grab samples. Mean is in µm, silt/clay and organic carbon contents are in % and metal concentrations are in mg kg^{-1}.

	Off Tyne			Off Humber			Lyme Bay			Celtic Deep		
	1999	2000	2001	1999	2000	2001	1999	2000	2001	1997	1999	2001
Mean	43.0	40.8	39.6	97.3	90.6	---	128.2	128.8	147.8	---	53.2	45.7
Sorting	1.9	2.0	2.1	1.36	1.5	---	1.6	1.7	1.5	---	1.8	2.1
Silt/clay	38.1	38.8	41.0	8.8	10.8	---	9.7	9.8	6.4	---	21.9	25.1
Org. C	2.4	2.5	2.8	2.3	2.0	---	2.0	2.1	2.4	---	1.7	2.3
Cr	98.1	67.2	80.8	106.8	104.2	---	81.4	58.4	75.8	---	67.3	85.0
Ni	33.0	30.4	8.4	42.0	33.8	---	24.9	24.2	21.8	---	27.8	23.6
Cu	19.0	15.0	16.8	18.9	14.2	---	14.9	12.2	11.1	---	18.4	17.4
Zn	90.4	79.8	90.8	99.6	94.8	---	82.7	78.0	79.8	---	88.2	96.6
Cd	0.1	0.1	0.2	0.1	0.2	---	0.1	0.1	0.1	---	0.1	0.17
Pb	57.0	48.0	51.4	43.0	48.0	---	39.0	30.0	44.4	---	27.0	31.0
Hg	0.2	0.2	0.2	0.1	0.1	---	0.1	0.1	0.1	---	0.1	0.1

Nematode and macrofauna assemblages

Results from the two-way ANOVA in Table 4 revealed significant differences in the number of nematode species between sites ($F = 26.60$, $p < 0.01$) whereas differences between sampling years were not significant at $p < 0.05$ ($F = 2.03$, $p = 0.13$). In contrast, the number of macrofauna species differed significantly between sites ($F = 39.52$, $p < 0.01$) and years ($F = 5.77$, $p < 0.01$).

The MDS ordination for nematode and macrofauna assemblages collected at the four offshore locations is presented in Figure 8. For both nematodes and macrofauna, samples collected at the same station in different years cluster closely together, indicating a comparatively high temporal stability of the spatial pattern in terms of species composition. Both plots display a striking similarity, with the samples collected

Table 4. Mean number of species (± SE)

Nematodes		Macrofauna	
Off Tyne		**Off Tyne**	
1997	34 ± 2	1999	17 ± 2
1998	34 ± 3	2000	20 ± 4
1999	35 ± 2	2001	17 ± 4
Off Humber		**Off Humber**	
1996	42 ± 4	1999	10 ± 2
1997	43 ± 4	2000	15 ± 4
1998	42 ± 6	2001	18 ± 3
Lyme Bay		**Lyme Bay**	
1997	37 ± 3	1999	36 ± 7
1998	42 ± 3	2000	47 ± 6
1999	43 ± 3	2001	30 ± 3
Celtic Deep		**Celtic Deep**	
1997	43 ± 4	1997	28 ± 5
1998	50 ± 3	1999	48 ± 5
1999	47 ± 2	2001	22 ± 4

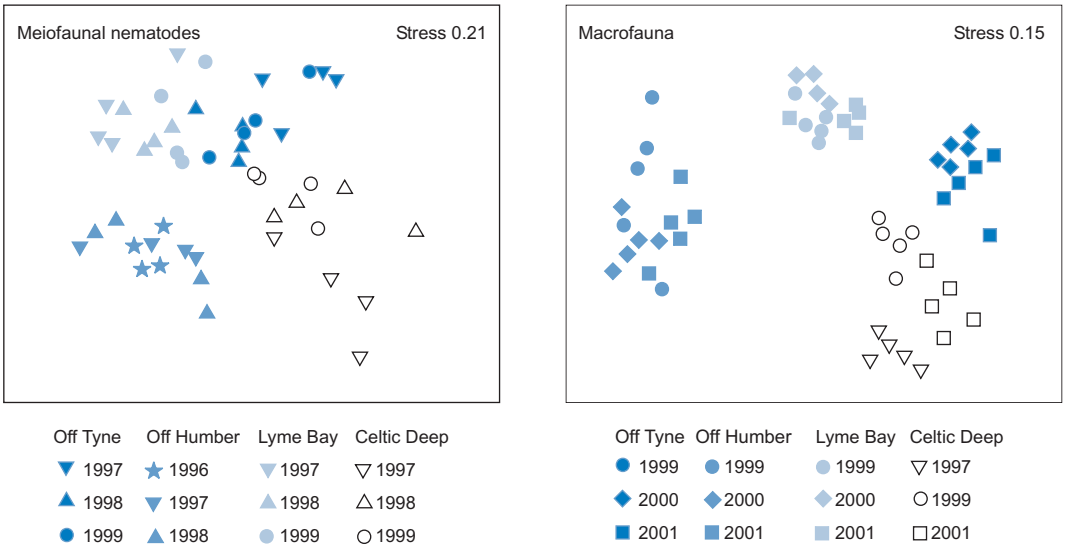

Figure 8. Non-parametric multi-dimensional scaling (MDS) ordination based on untransformed relative abundance of meiofaunal nematode and macrofauna species

off the Humber clustering separately from those obtained from other offshore stations.

The faunal assemblages at all sites and in all years can be shown, by two-way ANOSIM, to differ significantly from each other at the 5% level (nematodes: site: $R = 0.87$, $p < 0.01$; year: $R = 0.43$, $p < 0.01$ and macrofauna: site: $R = 0.99$, $p < 0.01$; year: $R = 0.73$, $p < 0.01$). As indicated by the outcome from SIMPER analyses, differences in assemblage structure recorded for any one station in different sampling years were generally less pronounced than spatial differences between study sites.

Relationships between environmental variables and benthic assemblage structure

The relationships between the distribution patterns of nematode assemblages and sediment granulometry ($p = 0.23$, $p = 0.07$) and the concentrations of trace metals ($p = - 0.04$, $p = 0.34$) were not significant at $p < 0.05$. Physical and geographical parameters including latitude, longitude and water depth were significantly correlated with nematode assemblage structure ($p = 0.60$, $p < 0.01$).

Macrofauna assemblages collected at the four offshore sites exhibited a significant correlation with both sediment characteristics ($p = 0.29$, $p = 0.04$) and physical/geographical parameters ($p = 0.34$, $p = 0.02$). As for nematode assemblages, the correlation with the concentration of selected single trace metals was not significant at $p < 0.05$ ($p = 0.10$, $p = 0.28$).

5.5 Discussion

The purpose of the study was to investigate the dynamics and population structure of benthic meiofauna and macrofauna at four muddy offshore sites around the UK coast and the natural variability of the community in relation to environmental characteristics. Additionally, the benthic assemblages were examined for temporal structure to allow a preliminary evaluation of spatial versus temporal variability.

Similar benthic assemblages were encountered in comparable environmental conditions. The main factor governing the distribution of benthic species appeared to be the geographical location of the habitat and (for macrofauna) the granulometric composition of the substrate. Water depth was potentially important as a factor affecting benthic assemblage structure, most likely because it determines other factors such as the amount and quality of phytoplankton-derived carbon reaching the seabed. Some other unmeasured but correlated factors may also be important in structuring benthic assemblages, including intricate patterns of habitat stability, recruitment patterns of individual species, predator-prey interactions and inter- and intraspecific competition. Deep water environments are characterised by a relatively high constancy of physico-chemical factors and, consequently, biological factors as opposed to physical ones are widely thought to be relatively important in such environments (Sanders, 1968). There was no evidence of any adverse effect on the measures of benthic assemblage structure

arising from trace metal concentrations in the sediment. These results are largely in agreement with the findings from previous studies (Rees *et al*., 1999; Schratzberger *et al*., 2000), indicating the relatively unpolluted nature of the offshore locations under investigation.

For both types of benthic assemblages, the number of species was lower at the sites off the Tyne and off the Humber than in Lyme Bay or the Celtic Deep. A long history of urban and industrial expansion along several east coast river systems and their associated estuaries, including those of the Tyne and Humber, has resulted in discharges of waste leading to extensive contamination of receiving waters (see Matthiessen and Law, 2002 for a recent review of environmental quality status). Most benthic studies along the east coast of the UK have therefore been carried out at estuarine or inshore locations in relation to industrial and/or sewage discharges (see Rees and Eleftheriou, 1989 for an historical review; more recent examples include Shillabeer and Tapp, 1990; Tapp *et al*., 1993; Hall *et al*., 1996; Hall and Frid, 1997; Hall *et al*., 1997; Waldock *et al*., 1999; Rees *et al*., 2001; Warwick *et al*., 2002). Surveys extending somewhat further offshore have concentrated mainly upon the effects of the sea disposal from ships, of sewage sludge, colliery waste, fly ash and dredged material (e.g. Bamber, 1984; Eagle *et al*., 1979; Rees *et al*., 1992; Herrando-Perez and Frid, 1998) or, off the Cleveland coast, the consequences of a potash mine-waste outfall (Brown and Shillabeer, 1997). These studies provide evidence of localised rather than widespread adverse effects, and would support the conclusion that, to date, there is no evidence of a causal relationship between the lower diversity assemblages at the North Sea stations sampled in the present study and the longer-term effects of human activities inshore.

In order to assess the nature and extent of adverse anthropogenic effects on the benthic ecosystem, a 'reference' or 'baseline' in terms of the structure and the degree of natural variability of the assemblages present is needed, against which perturbation effects can be evaluated (Hennig *et al*., 1983; Gourbault *et al*., 1998). The four NMMP stations under investigation here can serve as such reference points against which the outcome of more site-specific studies may be assessed and, with time, they will develop additional value as sentinels for any directional temporal changes around the UK.

Limitations on comparisons between stations are, to some extent, ameliorated by focusing on those with similar characteristics within each major stratum (i.e. transitional and offshore in the present study, see Schratzberger *et al*., 2000). Regarding temporal trends, the number of sampling occasions is, as yet, insufficient to make confident assertions about directional changes (c.f. Buchanan and Moore, 1986; Warwick *et al*., 2002), especially those of a more subtle nature. However, determination of the major characteristics of the assemblages, and their persistence, at each location has permitted an assessment of their comparability and hence utility in a monitoring context, especially in relation to the physical nature of the habitats occupied and their relative stability.

DISPOSAL AT SEA

6. LICENSING OF DEPOSITS IN THE SEA

Author: Andrew Dixon

6.1 Introduction

This section gives information about the licensing of deposits in the sea around the coasts of England and Wales during 2001 under Part II of the Food and Environment Protection Act 1985 (as amended) (FEPA) (Great Britain Parliament, 1985a). In order to provide a complete picture for the UK as a whole, licensing statistics for Scotland and Northern Ireland are also included in this section.

6.2 Legislation and licensing authorities

The deposit of substances and articles in the sea, principally the dumping of dredged material (as opposed to discharge into the sea via pipelines) and the use of material during construction and coastal defence works, is controlled by a system of licences issued under Part II of FEPA. Certain operations (e.g. the deposit of scientific equipment or navigation aids) are exempt from licensing under the Deposit in the Sea (Exemptions) Order 1985 (Great Britain Parliament, 1985b).

Following devolution in 1999, Defra (then MAFF) continued to license deposits in the sea around the Welsh coast on behalf of the Welsh Assembly Government. In Scotland, the licensing function became the responsibility of the Scottish Executive Environment and Rural Affairs Department (SEERAD). In Northern Ireland the issuing of licences remained the responsibility of the Environment and Heritage Service (EHS), an agency of the Department of the Environment for Northern Ireland.

6.3 Enforcement

Scientists from the CEFAS Burnham Laboratory have the power to enforce Licence provisions, and visits are made to both construction sites and disposal vessels. Samples are taken and records, including logbooks, are checked. Scientific staff carried out 28 inspections in 2001.

Officers of the Department's Sea Fisheries Inspectorate are charged with enforcing the provisions of FEPA (Part II) and undertake regular inspections from a network of port offices in England and Wales. During the year the SFI carried out 221 inspections in relation to construction works and the disposal of waste materials (essentially dredged materials and fish waste) at designated disposal areas.

In England and Wales 3 written warning letters were issued for apparent breaches of licensing controls as follows:

- The deposit of articles in the sea by a City Council in connection with a firework display without the authority of a miscellaneous licence;
- The deposit of builder's rubble on the foreshore to enhance boat launching facilities for a private dwelling without the authority of a construction licence; and
- The construction of a slipway by the Local County Council without the authority of a construction licence.

In Scotland, certain authorised staff of the Fisheries Research Services (FRS) Marine Laboratory, Aberdeen and the Scottish Fisheries Protection Agency (SFPA) hold similar enforcement powers. The FRS made 6 enforcement visits in 2001 and carried out 4 investigation visits. The SFPA made 14 enforcement visits in 2001 and assisted with 2 investigation visits.

In Northern Ireland the Environment and Heritage Service made 9 enforcement visits and carried out 4 investigation visits one of which resulted in a warning letter being issued to a local council that promptly removed the unlicensed deposit.

Report on licensing activity

Tables 5-7 give details for the period 1997 to 2001 of the number of sea disposal licences issued, the quantity of waste licensed and the quantity actually deposited, together with information on those contaminants in the wastes which the UK is required to report internationally to meet obligations under the OSPAR and London Conventions.

Licensing of Dredged material

Table 5 shows the number of licences issued for dredged material in 2001, the quantity licensed and the quantity deposited together with figures for the quantity of a range of trace contaminants that enter the sea in the dredged material. A proportion of the trace metals in this dredged material is natural, but held within the mineral structure and so not available for uptake by marine organisms. Figure 9 shows the main disposal sites used in 2001 and the quantities deposited at each site. Although applications for licences are required to show evidence that they have considered alternative disposal options including beneficial use, the problems of having silty materials, and matching the timing of dredging campaigns and the demand for sediments, have meant that most of the finer materials, in particular, are deposited at sea.

Other licensed activity

Under Part II of FEPA, licences are also required for certain other activities or deposits made below the mean high water springs mark for construction purposes. Each licence application is carefully considered, in particular, to assess the impact on the tidal and intertidal habitat, hydrological effects, potential interference to other users of the sea and risk to human health. Details of these licences are shown in Table 6.

Such licences have also authorised the disposal of a small amount of fish waste, details given in Tables 7(a) and 7(b). Further activities involve the use of tracers, the application of biocides, and burial at sea. Generally the anticipated environmental impact from these deposits is minimal and little or no monitoring is required. Table 6 shows the number of such licences issued in 2001.

Table 5. Summary of dredged material licensed and disposed of at sea in 2001

Country	Year	Licences issued	Licensed quantity (tonnes)	Wet tonnage deposited	Dry tonnage deposited	Quantities of metal contaminants in wastes deposited (tonnes)						
						Cd	Cr	Cu	Hg	Ni	Pb	Zn
England and Wales	1997	113	56,536,922	38,627,660	21,165,143	6.54	1,182	574	5.47	471	1,242	2,941
	1998	106	74,883,745	31,814,916	15,456,858	7.47	1,143	551	4.46	498	1,081	2,741
	1999	131	47,028,123	52,409,430	31,114,127	13.05	1,907	1,064	6.07	898	1,370	4,001
	2000	119	55,902,025	28,257,192	14,077,169	8.76	1,043	663	4.78	485	1,099	2,948
	2001	124	39,297,549	29,660,448	14,881,254	7.61	1,040	731	5.84	478	1,099	3,310
Scotland	1997	29	3,910,900	2,436,745	1,045,762	0.22	46	50	0.66	25	69	153
	1998	22	5,917,150	3,106,253	1,284,550	0.45	118	131	0.97	38	128	311
	1999	30	4,044,300	2,352,954	945,563	0.25	57	55	0.78	36	66	130
	2000	30	6,135,400	4,155,018	2,034,213	0.51	87	80	1.79	73	139	298
	2001	29	3,307,800	2,217,981	1,162,856	0.36	79	48	0.74	36	77	165
Northern Ireland	1997	7	206,000	176,919	122,289	0.17	1	1	0.03	1	1	5
	1998	11	1,121,300	803,181	617,503	0.32	16	7	0.20	17	9	33
	1999	5	1,923,000	2,058,506	768,609	0.54	32	21	0.56	18	23	92
	2000	3	3,950,000	640,815	455,222	0.13	45	7	0.05	13	14	42
	2001	3	183,000	3,420,411	2,495,714	0.72	246	37	0.42	66	76	226
UK Total	1997	149	60,653,822	41,241,324	22,333,194	6.93	1,230	624	6.16	497	1,312	3,100
	1998	139	81,922,195	35,724,350	17,358,911	8.24	1,278	689	5.63	553	1,218	3,084
	1999	166	52,995,423	56,820,890	32,828,299	13.85	1,997	1,141	7.41	953	1,459	4,223
	2000	152	65,987,425	33,053,025	16,566,605	9.39	1,176	750	6.63	571	1,252	3,289
	2001	156	42,788,349	35,298,840	18,539,824	8.69	1,365	816	7.01	579	1,251	3,701

Notes: Tonnages deposited relate to quantities in the calendar year 2001, which may be covered by 2 or more licences, including one or more issued in 2000.

Table 6. Other categories of licences issued in 2001

Licence category	Year	England and Wales	Scotland	Northern Ireland	Total
Construction - new and renewal	2001	200	133	9	342
Tracers, biocides etc.	2001	13	0	0	13
Burial at Sea	2001	16	0	0	16

Table 7(a). Fish waste licensed for disposal at sea in 2001[1]

Country	Licensed quantity (tonnes)[1]	Company and source of waste	Disposal sites	Quantity deposited (wet tonnes)	Quantity deposited (dry tonnes)
England and Wales	1,000	Quay Fresh & Frozen Foods Ltd, New Quay	New Quay	387	387
	350	Aqua-Mar Fisheries, St Helier, Jersey	St Helier	300	300
Scotland	0	Orkney Fishermens Society Ltd	Stromness C	66	53
	0	Orkney Fishermens Society Ltd	Stromness B	0	0

Notes: [1] No Fish Wastes were licensed or disposed of in Northern Ireland during the period covered by this report
For information on licensed quantities and tonnages deposited see footnote to Table 5

Table 7(b). Summary of fish waste licensed and disposed of at sea in 2001

Country	Year	Licences issued	Licensed quantity (tonnes)	Wet tonnage deposited	Dry tonnage deposited
England and Wales	1997	1	750	747	747
	1998	0	0	52	52
	1999	1	1,000	956	956
	2000	1	1,000	1,559	1,559
	2001	3	938	687	687
Scotland	1997	2	262	51	41
	1998	2	515	142	114
	1999	1	200	137	110
	2000	1	200	45	36
	2001	0	0	66	53
Northern Ireland	1997	0	0	0	0
	1998	0	0	0	0
	1999	0	0	0	0
	2000	0	0	0	0
	2001	0	0	0	0
UK Total	1997	3	1,012	798	788
	1998	2	515	194	166
	1999	2	1,200	1,093	1,066
	2000	2	1,200	1,604	1,595
	2001	3	938	753	740

Notes: For information on licensed quantities and tonnages deposited see footnote to Table 5

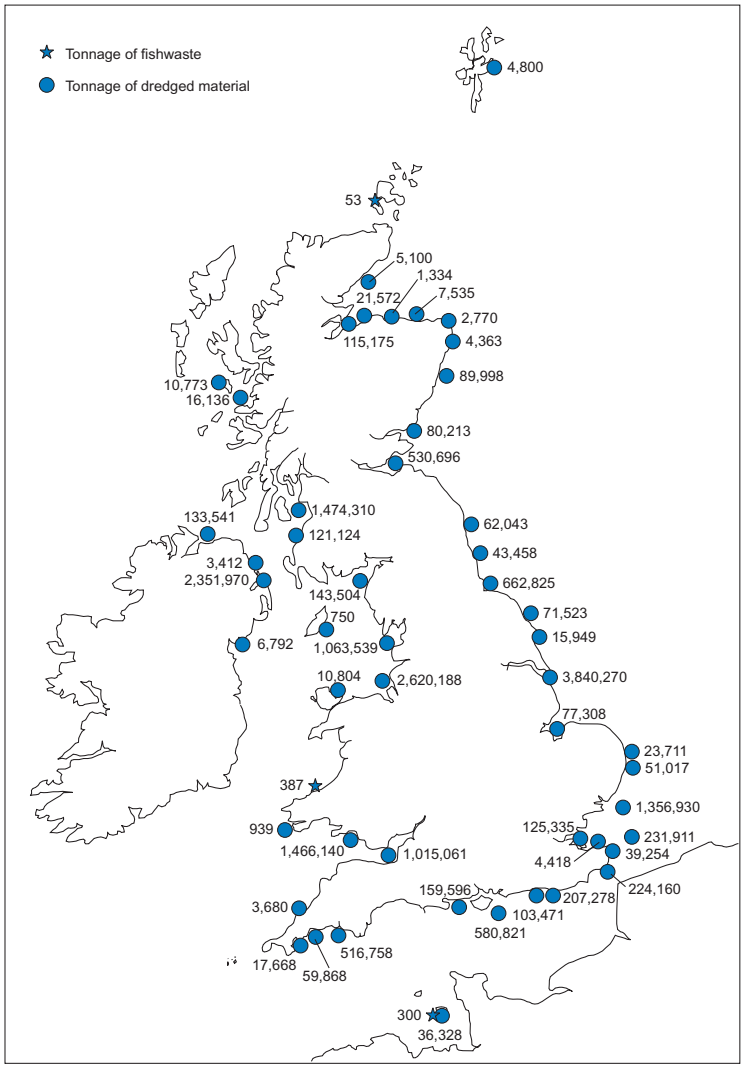

Figure 9. UK dredged material disposal sites and quantity in tonnes for 2001

ANNEX FEPA inspection and enforcement activity during 2001

Table A.1 Inspection activity by the SFI during 2001

District	No. of Inspections	No. of Infringements
North East	80	
Humber	6	
East	12	1
South East	59	3
South West	8	
West	6	
Wales	37	1
North West	12	
London	1	
Total	**221**	**5**

Table A.2 Warning letters and Prosecutions by the SFI during 2001

Court date or date of warning letter	Description	Action	Offence Date	Fine	Costs	Total
14 February 2001	Unlicensed construction works	Warning letter	12 August 2000	--	--	--
8 October 2001	Unlicensed construction works	Warning letter	13 March 2001	--	--	--
9 November 2001	Unlicensed construction works	Warning letter	10 October 2001	--	--	--

7. HABITAT CREATION: A SUSTAINABLE SOLUTION TO MAINTENANCE DREDGED MATERIAL DISPOSAL

Authors: Stefan Bolam, Jacqueline Reed and Rachel Waldock

7.1 Introduction

The disposal of dredged material constitutes one of the most important issues in coastal zone management and it is becoming increasingly important to minimise environmental impacts. Furthermore, since ocean disposal of industrial waste and sewage sludge has been phased out, there is greater focus on behalf of concerned citizens, the media and legislative bodies on dredged material disposal (Vogt and Walls, 1991). The deposit of any material below MHWS requires a licence under the Food and Environment Protection Act (FEPA) 1985 issued by Defra. It is a legal requirement that any application for a FEPA licence should identify and consider any alternatives to sea disposal. In recent years, this consideration of alternatives has shifted the emphasis from disposal *per se* to consider whether relocation can be managed in such a way as to derive environmental or other benefits (Murray, 1994). While sea disposal continues to account for the bulk of dredged material, an increasing awareness of the benefits of retaining sediments within estuaries or sediment cells has led to an increased willingness to use fine-grained sediment in beneficial use schemes. Consequently, a number of such schemes have developed involving the direct placement of dredged material to augment impoverished intertidal mudflats or to feed additional sediment into eroding saltmarshes.

Placing fine-grained dredged material onto intertidal mudflats or saltmarshes results, in the short term, in the loss of an ecologically important habitat. Effective management of such schemes therefore involves careful assessment of intertidal disposal applications. Although the sediments approved for beneficial use schemes will contain only low chemical concentrations, there is a need to consider complex chemical mixture interactions on the development of the created habitat. The presence of chemicals as mixtures may be of concern as they may act in an additive, synergistic or antagonistic manner and thus represent a risk to these sensitive environments. This section gives an overview of two Defra-funded research projects (AE0231, AE0233) being conducted at the CEFAS Burnham Laboratory to improve our understanding of these recovery processes and improve the advice given to Defra on the ecological consequences of proposed schemes.

7.2. The ecological importance of saltmarshes and mudflats

In addition to their importance in sustainable flood defence (Möller *et al*., in press), saltmarshes and mudflats have great ecological significance. For example, their international importance has resulted in legislative protection under the EU Habitats Directive.

Saltmarshes and mudflats are amongst the most productive communities known (Whittaker, 1975). The numbers of invertebrates inhabiting the sediments of these systems can be very high and, having rapid turnover rates, are very important in supporting commercial fish populations as well as large numbers of migratory wildfowl populations. The invertebrates also play a crucial role in biogeochemical processes (Aller, 1982) including indirect influences on nutrient uptake from the water column, thereby helping to reduce eutrophication in some areas. Saltmarshes are rare and specialised habitats, which are vulnerable to man-made as well as natural influences, and are becoming increasingly rare in some regions of the world.

7.3 Invertebrate recovery processes

Recovery of macroinvertebrates from dredged material placement on the intertidal zone occurs via a combination of 3 main processes (Figure 10). Each of these processes becomes more or less important depending upon factors such as the depth of the deposited sediment layer, the properties of the deposited sediment, and the spatial area and time of placement.

Planktonic recruitment will be the predominant mechanism if the material becomes suitable for recolonisation shortly prior to the main annual recruitment phase for most species (i.e., spring). During other times, lateral migration, primarily by post-juvenile stages, or burial survival if the amount deposited is not too great, will be the main recovery process.

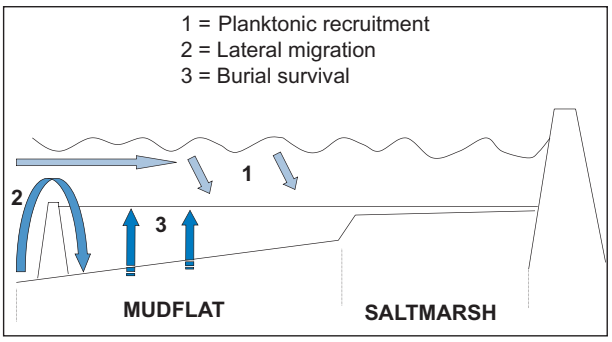

Figure 10. Recovery processes of beneficial use schemes (taken from Bolam et al., 2003)

The rate of invertebrate recovery is partly determined by which recovery mechanism prevails in each case. The seasonal nature of planktonic recruitment, together with the fact that it involves pre-metamorphic stages, implies that recovery via this mechanism alone will be more prolonged than in cases where adults are capable of migrating directly up through the recharged sediment. Lateral migration gains a more important role in small schemes where the majority of the recharged sediment is near to the surrounding sediments.

7.4 CEFAS Research

7.4.1 AE0231, Invertebrate recovery of beneficial use schemes

The research being undertaken for this project comprises two main approaches; a site-specific and a non site-specific experimental approach. The site locations of these are presented in Figure 11.

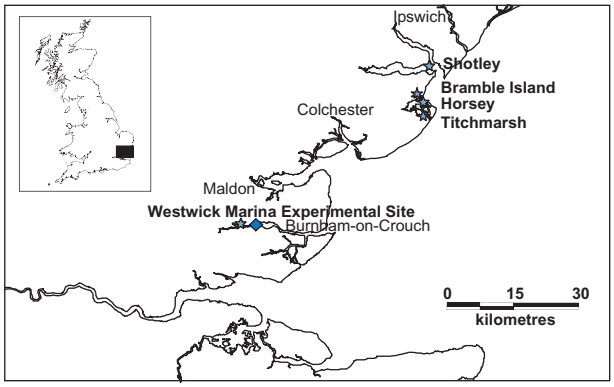

Figure 11. Sample site locations within Essex and Suffolk

The site-specific approach involves investigating invertebrate recovery in a number of representative beneficial use schemes. The study of such schemes, for example, saltmarsh creation at Horsey Island, Walton-on-the-Naze, and saltmarsh enhancement at Westwick Marina, Crouch Estuary, has the advantage that the schemes are not scale limited. However, this approach does not allow the relationship between key dredged material characteristics and invertebrate recovery to be studied. Five schemes (see Figure 11) have been investigated at sites on the Essex and Suffolk coasts. Temporal sampling (after 1 week, 3, 6, 9, and 12 months and then bi-annually) at 3 sites within the recharge area and 3 reference sites (see Figure 12). This allowed us to investigate the recovery of the invertebrates, together with a number of chemical (nitrogen and carbon, contaminants), physical (shear strength, particle size distribution) and physico-chemical (redox potential) variables.

The second component of AE0231, the experimental approach, enabled us to explicitly investigate the effects of a particular variable on invertebrate recovery while controlling for all other variables, albeit at reduced spatial scales. Two field experiments were performed:

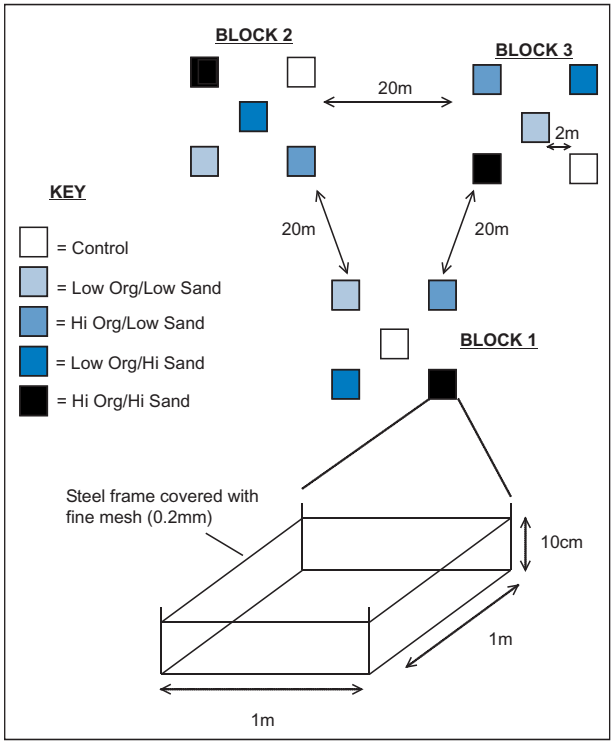

Figure 12. Design for recolonisation experiment

The effect of the organic content and particle size of dredged material on invertebrate recolonisation was investigated (Bolam *et al*., in press; Schratzberger et al., in press). Defaunated intertidal sediment was used as a surrogate for maintenance dredged material. The sediment was defaunated using a repeated freeze-thawing technique and the organic content and particle size were manipulated to give 4 sediment types, or treatments; low organic/low sand, low organic/high sand, high organic/low sand and high organic/high sand. These sediments were placed into 1 m^2, 10 cm deep, steel frames. A randomised block design was used with 3 blocks or replicates (Figure 12). The sediments were sampled after 1 week, 1, 3, 6, and 12 months.

The effects of deposition depth, organic content and particle size on invertebrate burial survival during beneficial use schemes were studied (Bolam, 2003). The sediments used for this experiment were the same as those used for the previous experiment. However, there were twice the number of treatments as this experiment incorporated recharge depth as a variable. The experimental design was a randomised block design with 3 blocks, similar to that used in the previous experiment. A perspex tube was first placed into the intertidal sediments to enclose individuals representative of the community (Figure 13). The manipulated sediments were then placed into the tubes at two recharge depths, 6 and 16 cm, and sealed with a fine mesh. The vertical distribution of the invertebrates was then determined after 14 days after sectioning the sediments into 2 cm sections.

Figure 13. Block 1 of the burial survival experiment

7.4.2 AE0233, Contaminant mixtures

The contaminant mixtures effects component aims to determine whether predicted effects (based on effects data for single chemicals) are similar to observed effects from combined chemical mixtures (Reed *et al*., 2002). A toxic unit model approach was employed based on effect concentration data (EC_{50} values) from a sub-lethal whole sediment test using the polychaete, *Arenicola marina* (Figure 14) (Reed *et al*., 2001; ICES, 2002). The toxic unit concept is deemed an appropriate model for testing the toxicity of chemical mixtures (Swartz *et al*., 1988). In addition to this approach, current CEFAS action levels (which are one of the many tools employed in the assessment and licensing of dredged material for sea disposal) were similarly evaluated. Initial investigations were directed at establishing whether the toxicity of metal mixtures were additive in nature as predicted in the literature (Parrott and Sprague, 1993). In summary, nine metal mixtures were tested based on the predicted 'toxic unit' model, (2) sediment quality guidelines taken from the literature (Long *et al*., 1995) and (3) CEFAS action levels (ALs) for assessing dredged material.

7.5 Results and discussions

The results obtained to date from sampling of beneficial use schemes imply that invertebrate recovery following intertidal placement of fine-grained dredged material can be rapid (Bolam, submitted). Large numbers of early colonisers can be found inhabiting the new sediment surface after one week. At the time of writing this component of the project is at its early stages. The recovery mechanisms and invertebrate successional sequences will be documented at a later date.

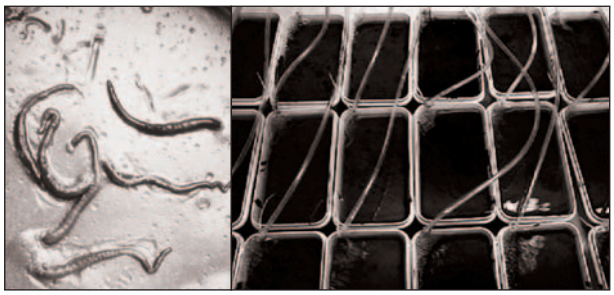

Figure 14. Test organism A. marina and test system

The results of the two field experiments have provided invaluable information regarding the effect of dredged material properties (particle size, organic content) on the recovery processes outlined in Figure 10. The recolonisation experiment indicated that the intertidal placement of maintenance dredged material with increased organic content (2.5% compared to 1.0%) resulted in a slower invertebrate recovery (Bolam *et al*., in press; Schratzberger *et al*., in press). This is highlighted in the MDS plot (Figure 15) of community composition at various stages after the experiment was initiated. The two treatments with increased organic contents are clearly separated from the control treatments and the lower organic treatments. The high organic content treatments had significantly lower oxygen contents and increased shear strengths. Increased sand content of recharged material did not appear to negatively affect recolonisation.

The second experiment indicated that for beneficial use schemes in which the amount of recharged material is relatively small (between 5-10 cm vertical depth), recovery via vertical migration is less likely when sediment organic content is high (Bolam, 2003). Again, increased sand content did not appear to negatively affect vertical migration. Additionally, vertical migration was limited in all treatments when 16 cm of material was deposited compared to 6 cm. This indicated that mudflat invertebrates are unable to vertically migrate when the amount of material above them is too great.

Initial results from the acute whole sediment bioassays have shown that the effects of metal mixtures appear to be less than additive. In most cases, the biological response was as expected and the casting rate of *A. marina* in mixtures 1-5 followed the expected metal load response. The exception was mixture 1 where there was a lower than expected casting rate (Figure 16). The response from mixture 1 was unexpected and further experiments are being conducted to further evaluate this effect.

Observed responses to contaminant mixtures against sediment quality guidelines (Effect Range-low (ERL)

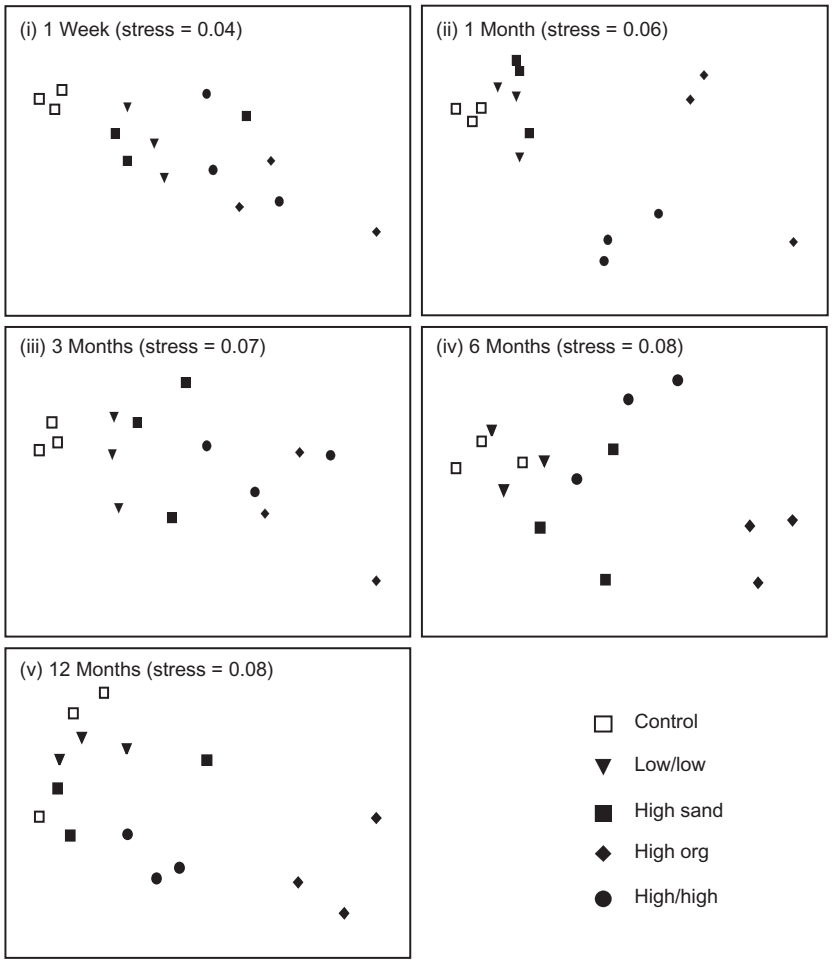

Figure 15. Non-metric MDS plots of community structure during the recolonisation experiment

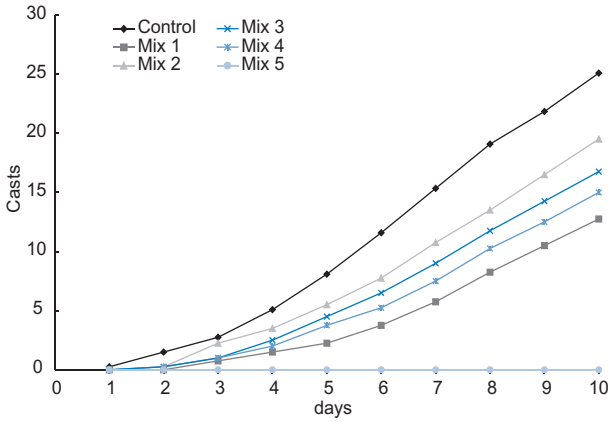

Figure 16. Effect of metal mixtures (toxic unit approach) on casting rate of A. marina over a 10-d exposure period

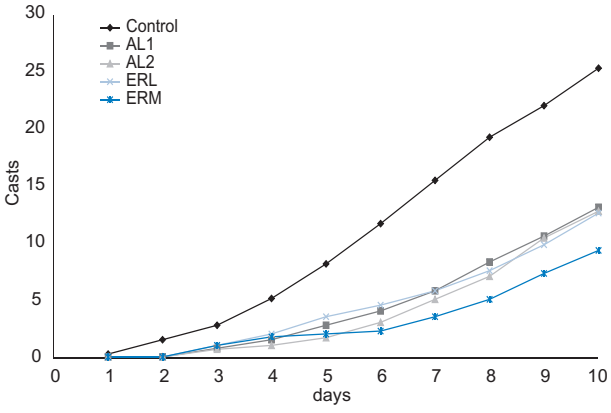

Figure 17. Effect of metal mixtures (SQGs and ALs) on casting rate of A. marina over a 10-d exposure period

and Effect Range-Median (ERM)) and CEFAS action levels are shown in Figure 17. Biological effects were as expected from the measured individual metal concentrations, except for the ERM treatment. This mixture showed a lower than expected casting rate. Results therefore seem to be somewhat unpredictable, which is not unexpected as this is a complicated research area and this study is the first attempt at addressing chemical mixtures within this context. Other research on the acute toxicity of metals have suggested there may be multiple interactions and so predicting the effects of mixtures of metals is extremely difficult (ECETOC, 2001).

Although several studies have focused on the effects of contaminants on marine species, most have used single elements or compounds (Marking, 1985). Where studies of mixtures have been undertaken, these have often been carried out in simple matrices e.g. water (Matthiessen *et al*., 1993; Abdelghani *et al*., 1995). Of the fewer studies in complex media such as sediments (Swartz *et al*., 1988; Borgmann and Norwood, 1997), results are inconclusive as research has focused on few chemical interactions, has not fully explored exposure routes and has generally been unsuccessful in quantifying the joint action of certain mixtures. Previous studies have often failed because specific chemical actions seem to depend on the models used to describe the relationship. Results from this study will contribute to the development of a more sophisticated model.

Due to the wide range of environmental effects exhibited by chemical mixtures, it is clear that their fate and behaviour in the environment are complex. Previous gaps in available data make it difficult to accurately predict the fate and effects of contaminant mixtures, particularly in the context of beneficial use of dredged material. This study is the first step in providing an assessment of the effects of metal mixtures to one estuarine species. Further experimental studies on contaminant mixtures will include using a variety of biological species and endpoints and provide an assessment of several matrices and classes of chemicals with similar toxic action, as well as those with differing but well-defined toxic endpoints.

7.6 CEFAS research and the licensing process

Research projects conducted at CEFAS, such as the two described above, underpin the assessment process undertaken under FEPA intended to ensure that the environmental implications of licensed activities such as dredged material placement are fully addressed. The results of these projects serve to increase the confidence of both the regulators and the conservation agencies in the benefit of using fine-grained dredged material in beneficial use schemes and to promote the idea that this material should be viewed as a resource rather than a waste.

7.7 Further information

For further information on the role of CEFAS and other organisations in beneficial use schemes, please visit www.cefas.co.uk/decode/default.htm.

RADIOACTIVITY

8. RADIOACTIVITY IN UK COASTAL WATERS

Author: Bryan Smith

8.1 Introduction

Seawater surveys support international studies concerned with the quality status of coastal seas (e.g. OSPAR, 2000) and provide information which can be used to distinguish different sources of man-made radioactivity (e.g. Kershaw and Baxter, 1995). In addition, the distribution of radioactivity in seawater around the British Isles is a significant factor in determining the variation in individual exposures at coastal sites, as seafood is a major contribution to food chain doses. Therefore, a programme of surveillance of the distribution of key radionuclides is maintained using research vessels and other means of sampling. Detailed historical data for ^{134}Cs and ^{137}Cs in seawater have been published in a series of reports so as to aid model development (Camplin and Steele, 1991; Baxter et al., 1992; Baxter and Camplin, 1993a-c) and have been used to derive dispersion factors for nuclear sites (Baxter and Camplin, 1994). Data have also been used to examine the long distance transport of activity to the Arctic (Kershaw *et al*., 1999).

In recent years (since 1994), discharges of ^{99}Tc from the British Nuclear Fuels plc (BNFL) facilities at Sellafield have increased significantly, against the overall trend observed for most other radionuclides. Studies of the migration behaviour of ^{99}Tc have afforded opportunities to substantiate and extend the information obtained

from earlier similar studies of ^{137}Cs. The distribution of ^{99}Tc in waters around the British Isles prior to, and immediately after, the increased ^{99}Tc discharges indicated a rapid advection of ^{99}Tc within and from the Irish Sea to the north of Scotland as compared to previous estimates (Leonard *et al*., 1997a,b; McCubbin *et al*., 2002).

8.2 Methods

8.2.1 Sampling

The research vessel programme on radionuclide distribution currently comprises cruises in the Irish Sea, Scottish waters and the North Sea every two or three years. Large volume surface seawater samples (50 litres) are collected, using the ships pumped supply, during cruises of the CEFAS research vessels, *RV CIROLANA* and *RV CORYSTES*. In 2001, surveys of the Bristol Channel and Irish Sea were carried out.

8.2.2 Sample analysis

Samples were filtered (0.45 µm) to separate dissolved and particulate phases. Analyses of dissolved ^{137}Cs involved pumping filtered seawater, acidified with nitric acid, through cartridges filled with ASG resin (ammonium duodeca-molybdophosphate on silica gel) to extract caesium. Analyses of ^{3}H involved double distillation of water samples under alkaline conditions and in the presence of holdback carriers to ensure chemical separation from all gravimetric and radiometric interference. Subsamples of distillate were assayed for ^{3}H using a Packard Tri-Carb 2550 TR/LL liquid scintillation counter.

8.3 Results and discussion

The results of the seawater surveys are given in Figures 18(a)-18(c).

8.3.1 ^{137}Cs distribution

The Irish Sea ^{137}Cs data (Figure 18(a)) indicate that the concentrations observed along a large section of the British coastline, extending from Liverpool Bay in the south to the Mull of Galloway in the north (typically 20-100 mBq kg^{-1}), were significantly greater than those observed along the Irish coastline (typically 5-20 mBq kg^{-1}). The ^{137}Cs contours extend parallel to the Cumbrian coastline with some anticlockwise displacement towards the Mull of Galloway in the north and towards Liverpool Bay in the south. Comparison of ^{137}Cs concentrations in the North Channel and at the southern entrance to the northern Irish Sea shows the predominant northwards migration. The overall distribution of ^{137}Cs is in line with that expected from our knowledge of mean surface water circulation in the Irish Sea (Dickson, 1987). The predominant flow of water is northward via input of Atlantic water from St. George's Channel, passing to the west of the Isle of Man. A minor component of the flow enters the eastern Irish Sea to the north of Anglesey and moves anti-clockwise round the Isle of Man before rejoining the main flow to exit through the North Channel.

The ^{137}Cs concentrations observed here are only a small percentage of those prevailing in the late 1970s. Levels as high as 30,000 mBq kg^{-1} have been observed in the vicinity of the Sellafield outfall (Baxter *et al*., 1992) during the period when discharges from Sellafield were substantially greater. Indeed, differences between the ^{137}Cs/^{90}Sr ratio in Sellafield discharges and seawater indicate that ^{137}Cs remobilisation, from sediments contaminated by large discharges in the 1970s, is presently the predominant (~90%) source term to the water column (Leonard *et al*., 1998).

8.3.2 ^{3}H distributions

Levels of ^{3}H in the Irish Sea (Figure 18(b)) were below the limit of detection (<2 Bq kg^{-1}) over a large proportion of the survey area. However, the impact of discharges from Sellafield and the Heysham nuclear power plant was apparent along the Cumbrian and southern Scottish coastline, extending from Morecambe Bay in the south to Luce Bay in the north. Along this section, ^{3}H concentrations were in the range 10-25 Bq kg^{-1}. Surface seawater concentrations in the vicinity of Sellafield were, therefore, similar to those in the Severn estuary near the points of release from the Amersham plc radiopharmaceutical plant at Cardiff and the Hinkley Point nuclear power station (Figure 18(c)).

In the Bristol Channel (Figure 18(c)), the greatest ^{3}H concentrations (~10 Bq kg^{-1}) were observed on the English side of the Bristol Channel, in the vicinity of the Hinkley nuclear power plant, compared with ~7 Bq kg^{-1} in the vicinity of Amersham Biosciences radiopharmaceutical plant at Cardiff. The impact of the ^{3}H inputs into the Severn estuary was most apparent upstream of both these points of discharge. Concentrations were noticeably elevated (>5 Bq kg^{-1}) to the eastern limit of the survey area. This is to be expected given the tidal nature of the Severn estuary. Tidal current speeds generally exceed 1.5 m s^{-1} at springs and 0.75 m s^{-1} at neaps, meaning water parcels can move up to 25 km during a flood or ebb tide (Uncles, 1984). Outside of the typical tidal

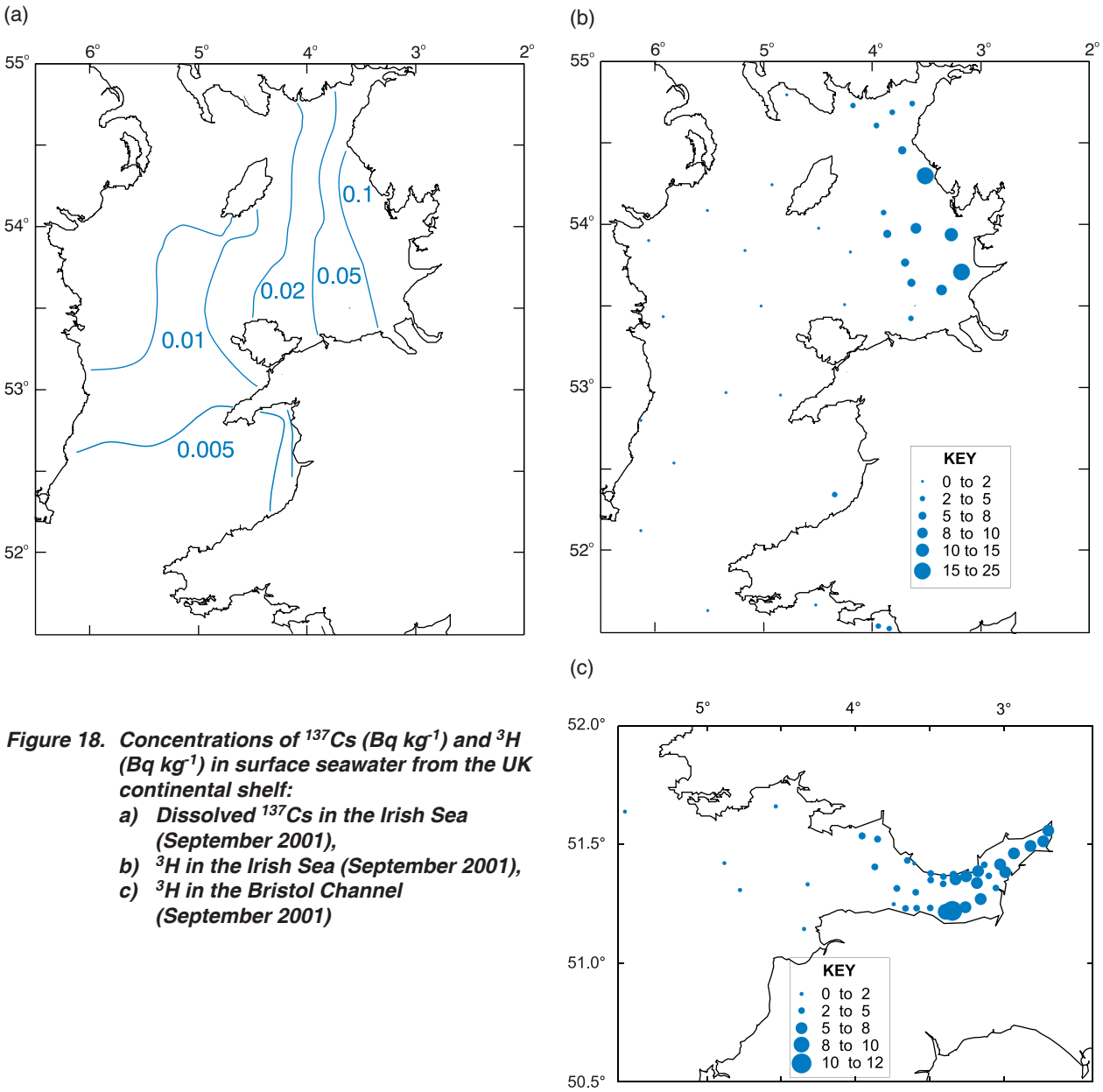

Figure 18. Concentrations of ^{137}Cs (Bq kg^{-1}) and ^{3}H (Bq kg^{-1}) in surface seawater from the UK continental shelf:
a) Dissolved ^{137}Cs in the Irish Sea (September 2001),
b) ^{3}H in the Irish Sea (September 2001),
c) ^{3}H in the Bristol Channel (September 2001)

excursion, ^{3}H concentrations decreased rapidly with distance downstream of the points of discharge (i.e. in a westerly direction). Concentrations at the mouth of the Bristol Channel were below the limit of detection (2 Bq kg^{-1}).

8.3.3 Other radionuclides

Concentrations of ^{99}Tc in seawater are now decreasing, following the substantial increases observed since 1994 due to increases in discharges of this nuclide from Sellafield. The results of research cruises involving studies of this radionuclide have been published by Leonard *et al.* (1997a and b, 2001a) and McCubbin *et al.* (2002). Trends in plutonium and americium concentrations in the seawater of the Irish Sea have been considered by Leonard *et al.* (1999). A full review of the quality status of the north Atlantic has been published by OSPAR (2000).

9. RADIONUCLIDE CONCENTRATIONS IN DREDGED SEDIMENT

Author: Bryan Smith

In England and Wales, Defra issues licences to operators for the disposal of dredge material under the Food and Environment Protection Act, 1985 (Great Britain Parliament, 1985a and b). The protection of the marine environment is considered before a licence is issued. Since dredged material may contain radioactivity, assessments are undertaken, where appropriate, for assurance that there is no significant foodchain or other risk from the disposal. No such assessments were required in 2001. Guidance on exemption criteria for radioactivity in relation to sea disposal is available from the International Atomic Energy Agency (IAEA, 1999 and IAEA, 2003).

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