

# Monitoring of the quality of the marine environment, 2005-2006



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## Foreword

Aquatic Environment Monitoring Report No. 60 collects together work carried out in 2005-06 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 procedures. 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 within the UK's nationally co-ordinated marine monitoring programme. 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 national monitoring programme is described in publications commissioned by the Marine Environment Monitoring Group (MEMG). The programme manual, known as the Green Book, is available in downloadable format from the Scottish Environmental Protection Agency's website at: [www.sepa.org.uk/marine/](http://www.sepa.org.uk/marine/).

The programme seeks to develop time trend data for a number of sites around the UK and this work is augmented by special surveys of compounds likely to pose specific risks, or for which few data exist.

The Defra report Safeguarding our Seas (Defra, 2002) set out a vision for "clean, healthy, safe, productive and biologically diverse seas". It started a process which has changed the UK's approach to monitoring and assessment of our

seas. The next stage in this process was the preparation of the first integrated assessment of our seas, Charting Progress (Defra, 2005). This provided a baseline for the state of our marine environment at that time, and much was learnt from the process of its preparation. Charting Progress outlined a number of actions, including the development of a UK Marine Monitoring and Assessment Strategy (UKMMAS). Within this strategy, three evidence groups have been established to collate data on the themes of:

- Clean and Safe Seas
- Healthy and Biologically Diverse Seas
- Productive Seas

So as to make explicit the links between the topics covered in this report and the aims of the UKMMAS, the topics have been grouped under these headings. Additionally, any policy implications have been highlighted (see page 6). The process will be taken further during 2008 in the preparation of a second integrated assessment report, currently known as Charting Progress 2. This will be followed by an OSPAR Quality Status Report for the NE Atlantic area in 2010.

This report, earlier reports in the AEMR series and other publications are also available in downloadable format from the Cefas website: [www.cefas.co.uk](http://www.cefas.co.uk).

Robin Law  
Lindsay Murray

## 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 Defra's strategic priorities, all of which underpin the overarching aim of ensuring that everyone can live within their environmental means:

Defra leads on two new Public Service Agreements, which are key cross-government priorities:

- *Secure a healthy natural environment for today and the future*
- *Lead the global effort to avoid dangerous climate change*

Defra also has eight Departmental Strategic Objectives which will be used to manage performance:

- Climate change tackled internationally and through domestic action to reduce greenhouse gas emissions
- A healthy, resilient, productive & diverse natural environment
- Sustainable patterns of consumption and production
- Economy and society resilient to environmental risk and adapted to the impacts of climate change
- A thriving farming and food sector, with an improving net environmental impact
- Championing Sustainable Development across government, across the UK, and internationally
- Strong rural communities
- A respected department delivering efficient and high quality services and outcomes

Within these priorities, 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, 1985), Defra has the responsibility to licence and control the deposit of material to sea. Following the cessation of the disposal of sewage sludge to sea, licensed materials are predominantly sediments, derived from maintenance and capital dredging activities in coastal

waters. Disposal at sea is also regulated internationally by OSPAR, and our work enables the UK to fulfil its obligations as a Contracting Party to the Convention.

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 the management of marine resources. Cefas scientists monitor the environmental conditions at marine disposal sites and compare the results with those obtained during more general monitoring studies, allowing action to be taken if unexpected impacts should occur. This also provides a feedback loop which ensures that risk assessments undertaken within the licensing process incorporate the most recent research findings.

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, the 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 Business, Enterprise and Regulatory Reform (BERR) and other departments concerning the control of pollution in other areas affecting the marine environment including the extraction of offshore oil and gas and marine aggregate. The statutory Offshore Chemical Notification Scheme and The Environmental Impact Assessment and Natural Habitats (Extraction of Minerals by Marine Dredging) (England and Northern Ireland) Regulations 2007 on the winning of aggregates, respectively, control these activities.

On Defra's behalf, Cefas is responsible for monitoring intermediate and offshore stations within the UK Clean Seas Environment Monitoring Programme (CSEMP), 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 analysis and deploy a number of biological effects techniques, including water and sediment bioassays and fish disease surveys. The current phase of the monitoring programme is focused on the detection of long-term temporal trends in contaminant concentrations and the development and deployment of a wider range of biological effects techniques studying organism response at a variety of cellular and sub-cellular levels. The CSEMP allows us to ascertain the effectiveness of regulatory measures taken 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 EU 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); the Commission Decision 93/351/EEC concerning maximum mercury limits in fishery products, and similar requirements under OSPAR. Currently, a group led from within Cefas is working to redesign the CSEMP so as to ensure that it meets current requirements and, as far as possible, to dovetail with proposed monitoring to be undertaken under the EU Water Framework Directive (2000/60/EC) in rivers, estuaries and coastal waters from 2008.

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 the future needs of monitoring and surveillance programmes. For example, we have developed new and more sensitive bioassay techniques, analytical methods and unattended sampling and monitoring devices. Within these programmes 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 available on the Cefas website: [www.cefas.co.uk](http://www.cefas.co.uk).

## Main findings and their relevance

### 1. Radioactivity in UK coastal waters

- To support the UK Government's aim to reduce concentrations in the marine environment to close to zero for artificial radioactive substances
- To support OSPAR, in implementing the 1998 OSPAR Radioactive Substances Strategy (target for 2020)
- To assess exposures from UK radiological monitoring (RIFE), ensuring doses are below Internationally agreed limits

### 2. Contaminants in marine mammals

- Perfluorinated organic acids, such as PFOS and PFOA, are widely distributed in the environment due to their widespread usage.
- Within the OSPAR Hazardous Substances Strategy, PFOS and its salts are listed as chemicals for priority action.
- The data generated for PFOS in harbour porpoises from UK waters provides a baseline from which the success of the strategy can be judged by future temporal trend studies.

### 3. Functional diversity of nematode communities in the southwestern North Sea

- To improve the UK Government's ability to assess the extent to which the seas round the UK continental shelf meet the vision for being clean, safe, healthy, productive and biologically diverse.
- To improve the value of monitoring data generated routinely by addressing functional aspects of biota ignored by the assessment tools developed previously.

### 4. The North Sea Benthos Project 2000: Species distributions and changes since 1986

- To set smaller-scale surveys undertaken, for example, in the monitoring of dredgings disposal sites into a wider context.
- To feed into the Quality Status report to be prepared by OSPAR in 2010

### 5. Fish health status in the North Sea and Irish Sea 2006

- The information collected on the health status of commercial and non-commercial fish species provides an important indicator of marine environmental health.
- New approaches for analysis of fish disease and liver pathology data are providing novel insights into relationships between locations in the North Sea and Irish Sea and is successfully being used for integration with other biological and contaminant data. Such information will be of direct relevance for the forthcoming OSPAR Quality Status Report 2010.

### 6. Licensing of deposits in the sea

- Assessment of the environmental impact of proposed disposals of dredged material using multiple lines of evidence is undertaken to protect the marine environment.

### 7. Radionuclide concentrations in dredged sediments

- Defra undertakes assessments for assurance that there is no significant foodchain or other risk from the disposal of dredged material, known to be contaminated by radionuclides, prior to the issue of licences to operators under the Food and Environment Protection Act, 1985.
- An assessment of the impact of replacing the original beach material at Carlyon Bay (Cornwall) with material from the china clay works at St Austell concluded that the china clay material contained only low levels of natural radionuclides and that the impact of the disposal operation was below the '*de minimis*' criterion.

### 8. Advice on fishery implications of pipeline discharges

Within general considerations of impact on the marine environment the specific considerations for fisheries are

- Improvement and protection of shellfish waters and growing areas
- Protection of fishery products edible by man
- Support for sustainable inshore fisheries

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## 9. Comparison of methods used for trace metal analysis by FEPA regulators and the FEPA monitoring programme: Rame Head 2005 case study

- Comparative studies have demonstrated a need for better integration of assessments of trace metal concentrations in dredged material and at disposal sites

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## 10. Swanage Bay

- Field evaluation of dredged material disposal sites in support of FEPA
- Scientific advice supporting the issuing of licences for the disposal of dredged material at sea
- Provide information on the ecological impacts of ongoing dredged material disposal activities at Swanage Bay disposal ground

## Glossary of terms

AEMR	Aquatic Environment Monitoring Report
ANOSIM	Analysis of similarities
BAC	Background Assessment Concentrations
BEQUALM	Biological Effects Quality Assurance in Monitoring Programmes
BERR	Department of Business, Enterprise and Regulatory Reform
BST	Bacterial Source Tracking
CSO	Combined Sewer Overflows
CEMP	Co-coordinated Environmental Monitoring Programme (of OSPAR)
CSEMP	Clean Seas Environment Monitoring Programme
EA	Environment Agency
EARP	Enhanced Actinide Removal Plant (at BNFL Sellafield)
EHS	Environment & Heritage Service (of Northern Ireland)
EU	European Union
FCA	foci of cell alteration
FEPA	Food and Environment Protection Act 1985
FRS MLA	Fisheries Research Services Marine Laboratory, Aberdeen
GIS	Geographic Information System
HELCOM	Helsinki Commission
ICE	Institute of Civil Engineers
ICES	International Council for the Exploration of the Seas
ICP-MS	Inductively Coupled Plasma-Mass Spectrometry
LC/MS	Liquid chromatography/mass spectrometry
MAFF	Ministry of Agriculture Fisheries & Food
MDS	Multi-dimensional scaling
MEMG	Marine Environment Monitoring Group
MFA	Marine and Fisheries Agency
NAD	No Abnormalities Detected
NAO	North Atlantic Oscillation
NSBP	North Sea Benthos Project
NSBS	North Sea Benthos Survey
OSPAR	Oslo and Paris Commission
PCA	Principal Component Analysis
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulphonate
PRIMER	Plymouth Routines in Multivariate Ecological Research
QSR	Quality Status Report
RELATE	This is a multivariate analysis performed in PRIMER® (Clarke <i>et al.</i> , 2001)
REDRISK	A pan-European research project
RIFE	Radioactivity in food and the environment
Ro-Ro	Roll-on Roll-off ferry
SEERAD	Scottish Executive Environment & Rural Affairs Department
SFPA	Scottish Fisheries Protection Agency
SIMPER	Similarity Percentages Routine
SIXEP	Site Ion Exchange Effluent Plant (at BNFL Sellafield)
STW	Sewage treatment works
THORP	Thermal Oxide Reprocessing Plant (at BNFL Sellafield)
UK	United Kingdom
UKMMAS	UK Marine Monitoring and Assessment Strategy
WGPDMO	The ICES Working Group on Pathology and Diseases of Marine Organisms

## Clean and safe seas

# 1. Radioactivity in UK coastal waters

*Authors: Carol Smedley, David McCubbin and Kins Leonard*

### 1.1 Introduction

The UK government is committed to preventing pollution of the marine environment from hazardous substances, which includes ionising radiation. The ultimate aim is to reduce concentrations in the environment to close to background values for naturally occurring radioactive substances, and close to zero for artificial radioactive substances (Defra, 2002).

A long-term programme of surveillance into the distribution of key radionuclides is maintained using research vessel, and other means of sampling. The results obtained from the seawater surveys reported here provide evidence of progress towards achievement of the Government's vision. Summary data are also set out in a recent report (Marine Environment Monitoring Group, 2005) and this provides information that can be used to distinguish different sources of man-made radioactivity (eg Kershaw and Baxter, 1995). In addition, these surveys support international studies concerned with the quality status of coastal seas (eg OSPAR, 2000).

In 2006, OSPAR adopted the Periodic Evaluation of the Progress in Implementing the OSPAR Radioactive Substances Strategy (concerning progressive and substantial reductions in discharges of radioactive substances, as compared with the agreed baseline) (OSPAR 2006). The programme of radiological surveillance work provides the source data and therefore the means to monitor and make an assessment of progress in line with the UK's commitments towards OSPAR's Strategy for Radioactive Substances target for 2020 (OSPAR, 1998). Data are also compiled (on an annual basis), and an assessment is reported in the ongoing RIFE (Radioactivity in the Food and the Environment) report series (eg RIFE-11).

Detailed historical data for  $^{134}\text{Cs}$  and  $^{137}\text{Cs}$  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). These data have also been used to examine the long distance transport of activity to the Arctic (Kershaw *et al.*, 1999) and long-term trends in Northern European seas (Povinec *et al.*, 2003). Discharges from Sellafield peaked in the mid 1970s.

A number of counter-measures were introduced, including the Site Ion Exchange Effluent Plant (SIXEP, in 1986), which controlled Cs discharges, and the Enhanced Actinide Removal Plant (EARP, in 1994). EARP allowed the treatment of medium-active, stored liquors, which also contained  $^{99}\text{Tc}$  – not treated by EARP- and consequently these discharges

(which are of limited radiological significance) rose in 1994. However, following a successful trial of new abatement technology, discharges once again decreased in 2003 (Mayall, 2005). Discharges of  $^{129}\text{I}$ ,  $^{90}\text{Sr}$ ,  $^{14}\text{C}$ ,  $^{60}\text{Co}$ , and  $^3\text{H}$  also increased in the mid 1990s, as a result of operational changes at the site, including the starting up of the Thermal Oxide Reprocessing Plant (THORP) in 1995.

Studies of the migration behaviour of  $^{99}\text{Tc}$  have afforded opportunities to substantiate and extend the information obtained from earlier similar studies of  $^{137}\text{Cs}$ . The distribution of  $^{99}\text{Tc}$  in waters around the British Isles prior to, and immediately after, the increased  $^{99}\text{Tc}$  discharges (in 1994) indicated a rapid advection of  $^{99}\text{Tc}$  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). The subsequent transport rate out of the North Sea and northwards with the Norwegian Coastal Current and West Spitsbergen Current slowed markedly, in apparent correspondence with variations in the North Atlantic Oscillation (NAO) winter index (Kershaw *et al.*, 2004).

### 1.2 Methods

#### 1.2.1 Sampling

The research vessel programme on radionuclide distribution currently comprises an annual survey of the Bristol Channel together with biennial surveys of the Irish Sea and the North Sea. Large volume surface seawater samples (50 litres) are collected, using the ships pumped supply, during cruises of the research vessels *Cefas Endeavour* and *Corystes*. Surveys of the Bristol Channel, North Sea and the western English Channel were carried out by Cefas between August and November 2006.

#### 1.2.2 Sample analysis

Samples were filtered (0.45  $\mu\text{m}$ ) to separate dissolved and particulate phases. Analyses of dissolved  $^{137}\text{Cs}$  involved pumping filtered seawater, acidified with nitric acid, through cartridges filled with ASG resin (ammonium duodecamolybdophosphate on silica gel) to extract caesium. Analyses of  $^3\text{H}$  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  $^3\text{H}$  using a Packard Tri-Carb 2550 TR/LL liquid scintillation counter.

## 1.3 Results and discussion

The results of the seawater surveys are given in Figures 1.1a to 1.1d.

### 1.3.1 $^{137}\text{Cs}$ distribution

The  $^{137}\text{Cs}$  data for the North Sea (Figure 1.1a) show very low concentrations ( $<0.01 \text{ Bq kg}^{-1}$ ) throughout the survey area that are only slightly above the global fallout levels ( $\sim 0.002 \text{ Bq kg}^{-1}$ ) in North Atlantic surface waters (McCubbin *et al.*, 2002). The distribution in the North Sea is typical of that observed in the last 5 years. The highest concentrations were observed at two stations sites close to the Norwegian coast, due to the input of Chernobyl-derived  $^{137}\text{Cs}$  from the Baltic Sea via the Skagerrak. In the previous three decades the impact of discharges from the reprocessing plants at Sellafield and La Hague has been readily apparent, carried by the prevailing residual currents from the Irish Sea and the English Channel, respectively (Povinec *et al.*, 2003). The concentrations of  $^{137}\text{Cs}$  in the North Sea have tended to follow the temporal trends of the aforementioned discharges, albeit with a time lag. The maximum discharge of  $^{137}\text{Cs}$  occurred at Sellafield in 1975 and  $^{137}\text{Cs}$  concentrations of up to  $0.5 \text{ Bq kg}^{-1}$  were measured in the late 1970s. Due to significantly decreasing discharges after 1978, remobilisation of  $^{137}\text{Cs}$  from contaminated sediments in the Irish Sea appears to be the dominant source of water contamination for much of the North Sea (McCubbin *et al.*, 2002).

Concentrations in the western English Channel (average activity  $0.002 \text{ Bq kg}^{-1}$ ) were only slightly, if at all, enhanced compared with the background level resulting from global fallout (Figure 1.1b).

### 1.3.2 $^3\text{H}$ distributions

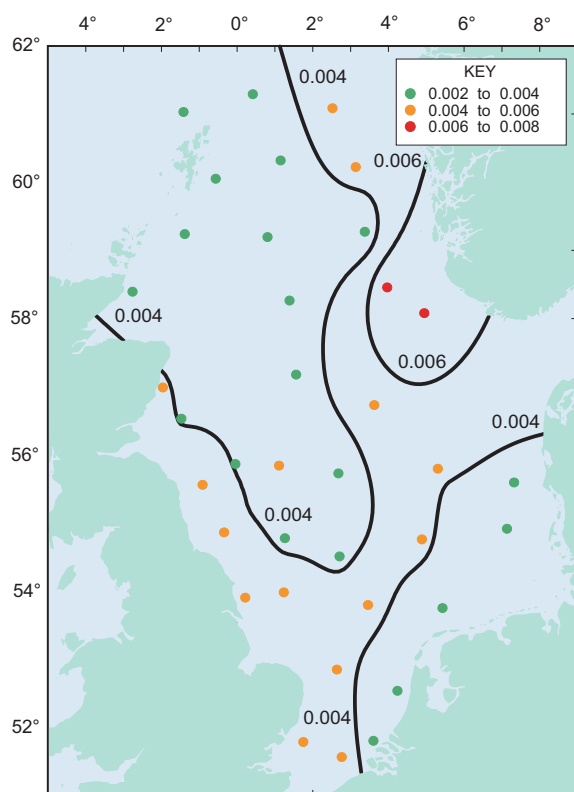
The concentrations of tritium observed in the North Sea (Figure 1.1c) were mostly were below the limit of detection ( $\sim 2 \text{ Bq kg}^{-1}$ ) over most of the survey area. However, slightly enhanced levels were apparent along some of the European coastline. These were likely to be a result of discharges from the La Hague (France) nuclear fuel reprocessing plant.

In the Bristol Channel (Figure 1.1d), the greatest  $^3\text{H}$  concentrations in 2006 (upto  $8 \text{ Bq kg}^{-1}$ ) were observed in the Severn estuary close to the Welsh and English coastlines. These data indicate measurable elevation in levels close to the Hinkley nuclear power plant and the Amersham radio-pharmaceutical plant at Cardiff.  $^3\text{H}$  concentrations decreased rapidly with distance downstream of the points of discharge (ie, in a westerly direction). Concentrations at the mouth of the Bristol Channel were below the limit of detection ( $2 \text{ Bq kg}^{-1}$ ). The spatial distribution is consistent with conservative dispersion behaviour in the macrotidal Severn estuary. Tidal current speeds generally exceed  $1.5 \text{ m s}^{-1}$  at springs and  $0.75 \text{ m s}^{-1}$  at neaps, meaning water parcels can move up to 25km during a flood or ebb tide (Uncles, 1984).

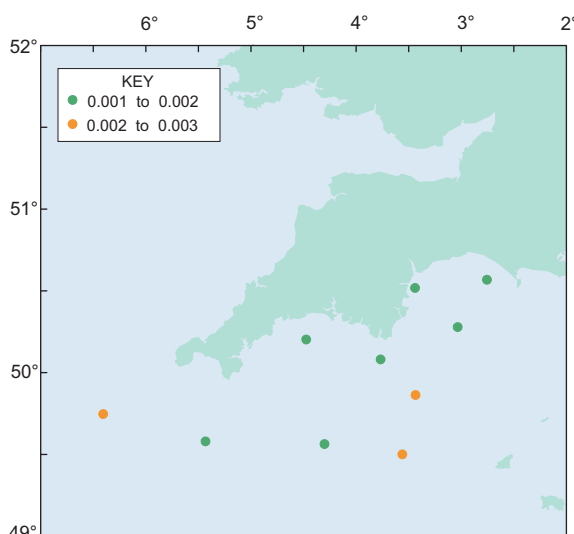
### 1.3.3 Other radionuclides

Concentrations of  $^{99}\text{Tc}$  in seawater are now decreasing, following the installation of new effluent treatment procedures at Sellafield. The results of research cruises involving studies of this radionuclide have been published by Leonard *et al.* (1997a and b, 2001, 2004) 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 East Atlantic has been published by OSPAR (2000).

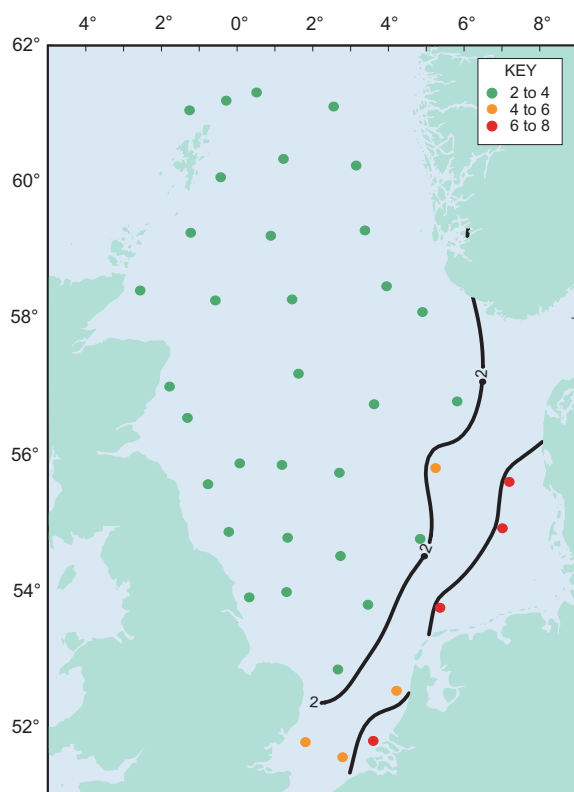
**Figure 1.1a.** Concentrations ( $\text{Bq kg}^{-1}$ ) of caesium-137 in filtered seawater from the North Sea, August-September 2006



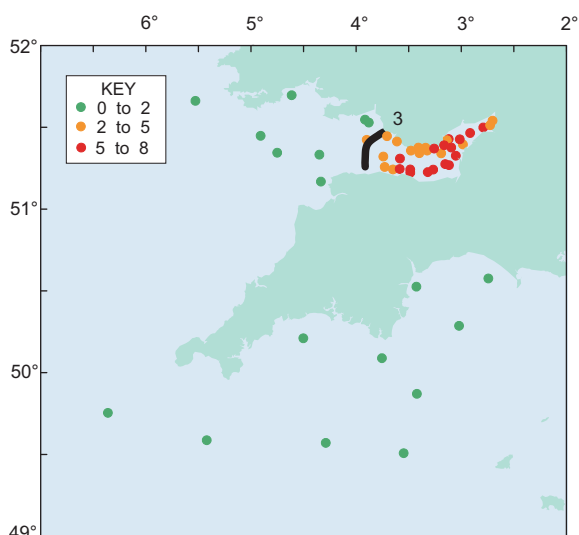
**Figure 1.1b.** Concentrations ( $\text{Bq kg}^{-1}$ ) of caesium-137 in filtered seawater from the western English Channel, September-October 2006



**Figure 1.1c.** Concentrations ( $\text{Bq kg}^{-1}$ ) of tritium in surface water from the North Sea, August-September 2006



**Figure 1.1d.** Concentrations ( $\text{Bq kg}^{-1}$ ) of tritium in surface water from the Bristol Channel and western English Channel, September-October 2006



## Healthy and biologically diverse seas

### 2. Contaminants in marine mammals

Author: Robin Law

#### 2.1 Introduction

As a result of their wide use, perfluorinated organic acids (including perfluorooctane sulphonate; PFOS) are widely distributed in the environment on a global scale, and time-trend studies have shown increasing concentrations in wildlife (Giesy & Kannan, 2001; Houde *et al.*, 2006a). Little information is available on toxic effects, although they may adversely effect cell membranes and intercellular communication (Houde *et al.*, 2006b). Within the OSPAR Hazardous Substances Strategy, PFOS and its salts are listed as chemicals for priority action (OSPAR, 2007). In 2000, the total global production of PFOS by the US 3M corporation was estimated to be 3,700 tonnes. 3M phased out production in 2001, but production continued in Germany, Japan, Russia and Switzerland. As synthetic chemicals, OSPAR's intention is that, in the future, environmental concentrations should fall to zero, or close to zero. In order to demonstrate effective controls, baseline data are needed from which such a decline can be monitored. Marine mammals, as top predators, can accumulate high concentrations of persistent and bioaccumulative organic contaminants, and so can act as effective sentinel organisms for monitoring purposes. For this purpose, we have determined concentrations of PFOS and PFOA (perfluorooctanoic acid) in the livers of harbour porpoises stranded or bycaught around the UK in 1992-2003 (Figure 2.1). Details of the LC-MS based methodology are given elsewhere (Law *et al.*, in press 2008).

PFOA was not detected in any of the 58 porpoise liver samples analysed. PFOS concentrations ranged from < 16 to 2,420  $\mu\text{gkg}^{-1}$  wet weight, and the data are presented in Table 2.1. Only two animals, from the Shetland Islands (collected in 1992) and the Isle of Islay (collected in 2002) did not contain PFOS above the limit of quantification. Where PFOS was detected, concentrations ranged from 22 to 2,420  $\mu\text{gkg}^{-1}$  wet weight with a mean concentration of  $546 \pm 610 \mu\text{gkg}^{-1}$  wet weight. These concentrations are of a similar magnitude to those reported in other studies of porpoise livers (Van de Vijver *et al.*, 2003 & 2004) and reflect a significant contamination of marine mammals from the UK with PFOS. Further determinations will be made in the future in order to evaluate possible reductions in concentrations.



**Table 2.1.** Concentrations of PFOS in porpoise liver ( $\mu\text{gkg}^{-1}$  wet weight).

Reference number	Date	Location	PFOS concentration
SW1992/157a	06/07/1992	Cuddie Point, Western Isles	86
SW1992/168a	24/07/1992	West Hamnavoe, Shetland	<16
SW1992/208a	03/11/1992	Lunan, Tayside	152
SW1993/82a	20/07/1993	off Troup Head, Grampian	43
SW1994/63	24/04/1994	Chantry Point, Orford, Suffolk	2390
SW1995/131a	17/11/1995	Myre Bay, Orkney	75
SW1996/52a	15/03/1996	off Shandwick, Highland	68
SW1996/90b	21/05/1996	Balmedie, Grampian	22
SW1996/126	25/07/1996	Whitby, North Yorkshire	215
SW1996/139	27/08/1996	Redcar, Cleveland	189
SW1996/175	09/12/1996	Nolton Haven, Pembrokeshire	89
SW1997/135d	20/08/1997	off the Minches, Western Isles	85
SW1997/143a	13/09/1997	Crovie, Grampian	185
SW1998/155d	13/08/1998	Whitehills, Grampian	271
SW1999/25a	12/02/1999	St Andrew's, Fife	489
SW1999/30a	17/02/1999	Sound of Bute, Strathclyde	865
SW1999/72d	09/04/1999	Alturlie, Highland	247
SW2000/83a	23/04/2000	St. Cyrus, Grampian	918
SW2001/15b	18/01/2001	Lunan Bay, Tayside	948
SW2001/40	07/03/2001	Swansea	1700
SW2001/43a	08/03/2001	Carnoustie, Tayside	237
SW2001/73a	30/03/2001	Aberdeen, Grampian	959
SW2001/79a	08/04/2001	Findhorn Bay, Highland	151
SW2001/83a	17/04/2001	Crovie, Grampian	409
SW2001/85d	24/04/2001	Balmedie, Grampian	138
SW2001/206d	15/09/2001	Burghead, Grampian	955
SW2001/210	18/09/2001	Poppit Sands, Ceredigion	1420
SW2001/251	09/11/2001	Aberavon, Port Talbot,	1810
SW2002/3	04/01/2002	Swansea	2420
SW2002/11a	07/01/2002	Uiskentuie, Isle of Islay, Strathclyde	<16
SW2002/95	07/02/2002	Blackpool, Lancashire	538
SW2002/149b	02/04/2002	off South Sutor, Highland	848
SW2002/169a	16/04/2002	Speybay, Grampian	184
SW2002/170	17/04/2002	Porth y post, Anglesey	1370
SW2002/214	18/06/2002	Tal-y-bont, Gwynedd	119
SW2002/294e	15/08/2002	Kames Bay, Isle of Bute, Strathclyde	245
SW2002/308	02/09/2002	off Bridlington, East Yorkshire	334
SW2002/309	02/09/2002	off Bridlington, East Yorkshire	1200
SW2002/311a	06/09/2002	Blairmore, Dunoon, Strathclyde	78
SW2002/321c	23/09/2002	North Berwick, Lothian	<16
SW2002/350c	11/11/2002	Lundin, Fife	242

**Table 2.1 continued.** Concentrations of PFOS in porpoise liver ( $\mu\text{gkg}^{-1}$  wet weight)

Reference number	Date	Location	PFOS concentration
SW2002/351c	22/11/2002	Otter Ferry, Loch Fyne, Strathclyde	200
SW2002/372c	13/12/2002	Balmedie, Grampian	222
SW2002/382	24/12/2002	Heacham, Norfolk	120
SW2003/190	02/04/2003	Tywyn, Gwynedd	83
SW2003/194	05/04/2003	Minsmere, Suffolk	202
SW2003/220	27/04/2003	Hessle, East Yorkshire	771
SW2003/236	10/05/2003	Gibraltar Point, Lincolnshire	309
SW2003/257c	08/06/2003	off Bridlington, East Yorkshire	115
SW2003/260	11/06/2003	off Bridlington, East Yorkshire	1820
SW2003/271	25/06/2003	off Bridlington, East Yorkshire	1550
SW2003/274	27/06/2003	Tywyn, Gwynedd	112
SW2003/296	23/07/2003	off Bridlington, East Yorkshire	148
SW2003/312	05/08/2003	off Bridlington, East Yorkshire	823
SW2003/334	26/08/2003	Minsmere, Suffolk	353
SW2003/337	27/08/2003	Fishguard, Pembrokeshire	202
SW2003/353	26/09/2003	Morfa Dyffryn, Gwynedd	199
SW2003/385	23/11/2003	Walton Backwaters, Essex	449

### 3. Functional diversity of nematode communities in the southwestern North Sea

*Authors: Michaela Schratzberger, Karema Warr and Stuart Rogers*

#### 3.1 Introduction

The traditional methods of community analyses, deriving diversity and community structure of assemblages from species abundance data do not take account of the diverse biology and autecological requirements of the taxa. Natural-history information on many marine invertebrates is scant, so studies which require information on the ecology of benthic species have used a functional group approach. Species in functional groups share morphological traits that are thought or known to represent an important ecological function.

Studies on macrobenthic invertebrates have shown that linking taxonomic and functional diversity, i.e. pooling species from different taxonomic entities into functionally similar groups, can reveal different relationships between assemblages (e.g. Bremner *et al.*, 2003b; Boström *et al.*, 2006). This suggests that taxonomic and functional analyses should complement each other when deriving general descriptions of benthic diversity, and that using only taxonomic analyses to infer the effects of environmental variables and human activities on biota may omit key functional attributes (Frid *et al.*, 2000b; Bremner *et al.*, 2003b).

Four of every five bottom-living multicellular animals on earth are nematodes (Bongers & Ferris, 1999). Whereas the importance of parasitic nematodes has been recognised for many decades, this is not the case for the free-living species, especially those of aquatic environments. They remain poorly understood, despite the fact that they are extremely abundant and diverse, often numbering millions per square metre in sediments, and occur in more habitats than any other metazoan group (Heip *et al.*, 1985).

There are several morphological features of free-living nematodes thought to be related to important ecological functions (Table 3.1). Nematode species and genera can be classified according to these features, related to the morphology of the mouth cavity (buccal morphology), tail shape, body size, body shape and life history strategy. The reduction of a generally high species diversity into a smaller number of single functional groups, suggesting a very limited functional diversity, risks underestimating the true functional complexity of nematode communities (Thistle *et al.*, 1995). We addressed this by combining a range of biological traits of species and genera to identify patterns in the functional diversity of nematodes from the south-western North Sea. We describe nematode assemblages on the basis of the

**Table 3.1.** Morphological characteristics of nematodes and their functional importance.

Characteristic	Functional importance
Buccal morphology	The buccal cavity shows great diversity in form and reflects the food ingested by the nematodes. It can thus be a good indicator of a species' feeding strategy. Trophic groupings are fundamental to carbon and energy fluxes through ecosystems, and linked to nutrient cycling.
Tail shape	The tail shape is important in locomotion and reproduction. Long, filiform tails, for example, are considered a special adaptation to fine sand and muddy sediments where only an incomplete interstitial system exists. In these sediments, the tail enables animals to retract from dead-end interstitial passageways that are too narrow to allow the worm to turn around and escape.
Body size and shape	Body size and shape affect physiological and ecological features of populations, including metabolic rates, tolerance to chemicals and anoxia, ability to move or migrate, vulnerability to predation etc. Slender nematodes are able to move swiftly through the sediment, but are vulnerable to predation. Predation pressure on stout species may be reduced but so is mobility.
Life history strategy	Many small species have short generation times of usually about one month or less with high reproduction rates. This r-selected life history strategy is in contrast to the longer life-cycles and fewer offspring of more K-selected congeners. Some of the larger species have an annual reproductive cycle.

In ecology, **r/K selection** theory relates to the selection of traits which promote success in particular environments. In unstable or unpredictable environments **r-selection** predominates, as the ability to reproduce quickly is crucial, and there is little advantage in adaptations that permit successful competition with other organisms, because the environment is likely to change again. Traits that are thought to be characteristic of **r-selection** include high fecundity, small body size, short generation time and the ability to disperse offspring widely. In stable or predictable environments **K-selection** predominates, as the ability to compete successfully for limited resources is crucial. Traits that are thought to be characteristic of **K-selection** include large body size, long life expectancy and the production of fewer offspring.

functional attributes of species and genera, and show how the functionally defined assemblages vary spatially in response to environmental variables.

### 3.2 Material and methods

In 2000/2001, 19 stations in the south-western North Sea, all located away from known point-source impacts, were sampled for meiofauna and a suite of environmental variables (Figure 3.1). At each station, three replicate samples were taken with a 0.1m<sup>2</sup> Day grab from within a 100m range ring. From each deployment, two sub-samples, one for particle size and organic carbon content analysis and one for the study of meiofauna, were collected with a perspex corer (3cm diameter) to a depth of 5cm. All meiofauna samples were fixed in 5% formaldehyde in 63µm filtered seawater and samples for particle size and organic carbon content analysis were frozen at -20°C pending analysis.

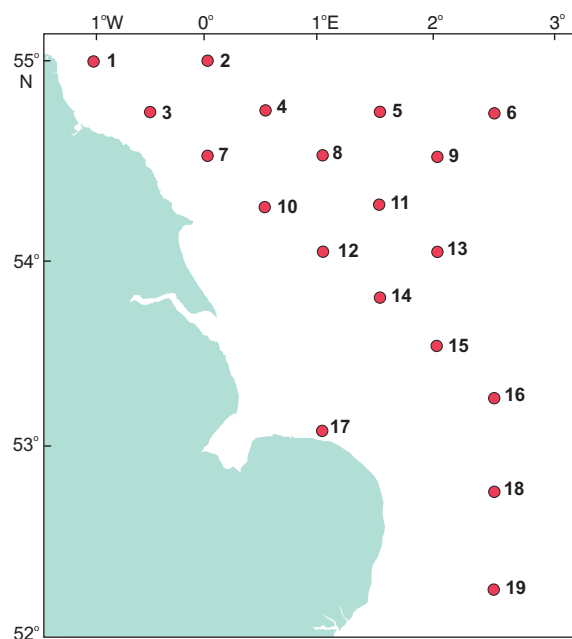
One replicate sample collected for the analysis of environmental variables and all meiofauna samples were processed per station. Sediment granulometry was determined by a combination of dry sieving and laser sizing to give the full particle size distribution (Dyer, 1986). The organic carbon content of the sediment fraction < 63µm was determined with a Leeman CE 440 elemental analyser. Meiofauna samples were washed onto a 63µm sieve and

processed following the extraction protocol described by Somerfield and Warwick (1996). All nematodes were counted and identified to genus or species level.

The 169 nematode species recorded were classified according to their buccal morphology (Wieser 1953), tail shape, adult length, adult shape and life history strategy (Bongers, 1990; Bongers *et al.*, 1991, 1995). A biological traits analysis was carried out, based on these five traits and a number of categories within each trait. A biological traits matrix was constructed by assigning to each nematode species/genus its affinity to each trait category (Figure 3.2). The biological traits matrix was then raised by the relative species abundance to give abundance-weighted traits matrices for each sampling station (Figure 3.2).

Non-metric multi-dimensional scaling (MDS) ordination using the Bray-Curtis similarity measure was applied to relative species abundance data and the abundance-weighted biological traits matrix to elucidate spatial patterns in the taxonomic and functional composition of nematode communities at the 19 sampling locations. Analysis of similarities (ANOSIM) was used to test for significant differences between stations and the Similarity Percentages (SIMPER) procedure was applied to identify the trait groups that were primarily responsible for the dissimilarities observed between locations.

**Figure 3.1.** Location of the 19 stations in the southwestern North Sea sampled for nematodes and a suite of environmental variables.



The relationship between the structure of nematode assemblages and environmental variables was explored by calculating Spearman rank correlations ( $r_s$ ) between similarity matrices derived from the faunal data (based on Bray-Curtis similarity) and matrices derived from various subsets of environmental data (based on normalised Euclidean Distance), thereby defining suites of environmental variables which best explained the biotic structure (BIOENV procedure). A permutation test was applied to assess the significance of these relationships. Five environmental parameters were included in the data analyses (median particle diameter, total organic carbon and silt content, sorting coefficient and water depth) together with a derived measure of sediment heterogeneity following Ward (1975). All

statistical analyses were performed using the software package Primer version 6.1.5 (Clarke & Warwick, 1994, Clarke & Gorley, 2006).

### 3.3 Results

A total of 79 trait combinations were represented amongst the nematode fauna. The biological traits matrix revealed several notable relationships between traits. For example, large-bodied nematodes generally had a K-selected life-style whilst smaller species were generally r-strategists. Equally, in contrast to the generally small-sized selective deposit feeders, predators were usually large. While ecologically implausible trait combinations such as, for example, small

**Figure 3.2.** Biological traits analysis. 1A = selective deposit/bacteria feeders, 1B = non-selective deposit feeders, 2A = epigrowth feeders, 2B = predators (Wieser, 1953); c-p = coloniser-persister score (Bongers et al., 1991, 1995).

Step 1: Assign to each species/genus its affinity to each trait category				Step 2: Raise biological traits matrix by (relative) species/genus abundance			Step 3: Obtain abundance-weighted traits matrices for each station			
Trait	Trait category	Species a	Species b	Station	Species a	Species b	Trait	Trait category	Station 1	Station 2
<b>Buccal morphology</b>	1A	0	1	1	3	5	<b>Buccal morphology</b>	1A	5	9
	1B	0	0	2	7	9		1B	0	0
	2A	0	0	..	..	..		2A	0	0
	2B	1	0	..	..	..		2B	3	7
<b>Tail shape</b>	round	0	0	..	..	..	<b>Tail shape</b>	round	0	0
	filiform	0	0	..	..	..		filliform	0	0
	conical	0	0	..	..	..		conical	0	0
	clavate	1	1	..	..	..		clavate	8	16
<b>Adult length</b>	>1mm	0	1				<b>Adult length</b>	>1mm	5	9
	1-2mm	0	0					1-2mm	0	0
	2-4mm	1	0					2-4mm	3	7
	>4mm	0	0					>4mm	0	0
<b>Adult shape</b>	stout	0	0				<b>Adult shape</b>	stout	0	0
	slender	1	1					slender	8	16
	long	0	0					long	0	0
<b>Life history</b>	cp2	0	0				<b>Life history</b>	cp2	5	9
	cp3	1	0					cp3	3	7
	cp4	0	0					cp4	0	0

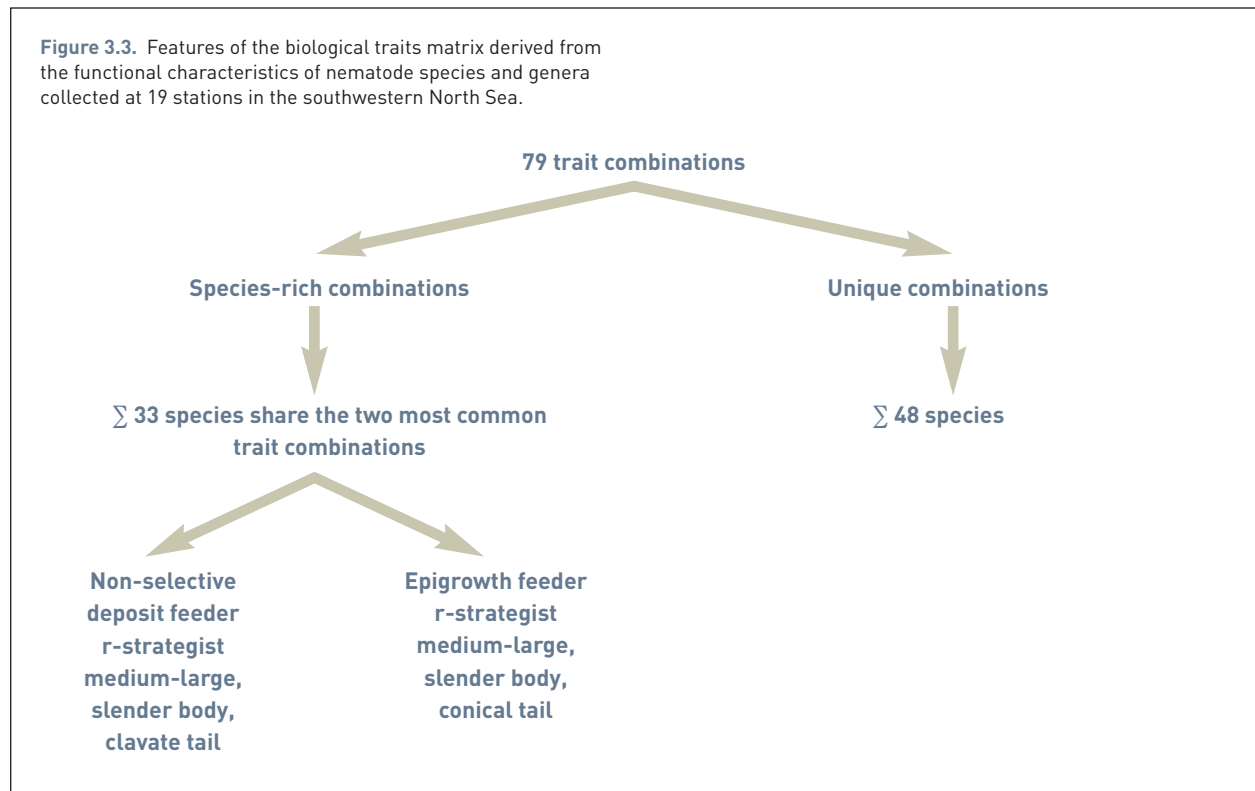
body size combined with a K-selected life history strategy were absent, the traits matrix revealed some combinations of functional groups to which no species belonged (e.g. no epigrowth feeders with rounded tails), although these combinations are known from other environments. A total of 33 species shared the two most common combinations of traits, 48 species each had a combination of trait categories that was unique only to them (Figure 3.3).

Assemblages collected at the 19 stations differed both taxonomically ( $R = 0.897$ ,  $p < 0.01$ , based on the relative abundance of species) and functionally ( $R = 0.697$ ,  $p < 0.01$ , based on the abundance-weighted biological traits matrix). In the ordinations based on the relative abundance of nematode species, stations in the northern part of the study site tended to cluster to the left while the southern stations were grouped to the right (Figure 3.4). This geographic separation was less pronounced in the ordinations derived from functional characteristics of nematode communities. Station 13 diverged notably from other locations when a range of biological traits expressed by species and genera was considered (Figure 3.4). The two most species-rich trait combinations (see Figure 3.3) were primarily responsible for the

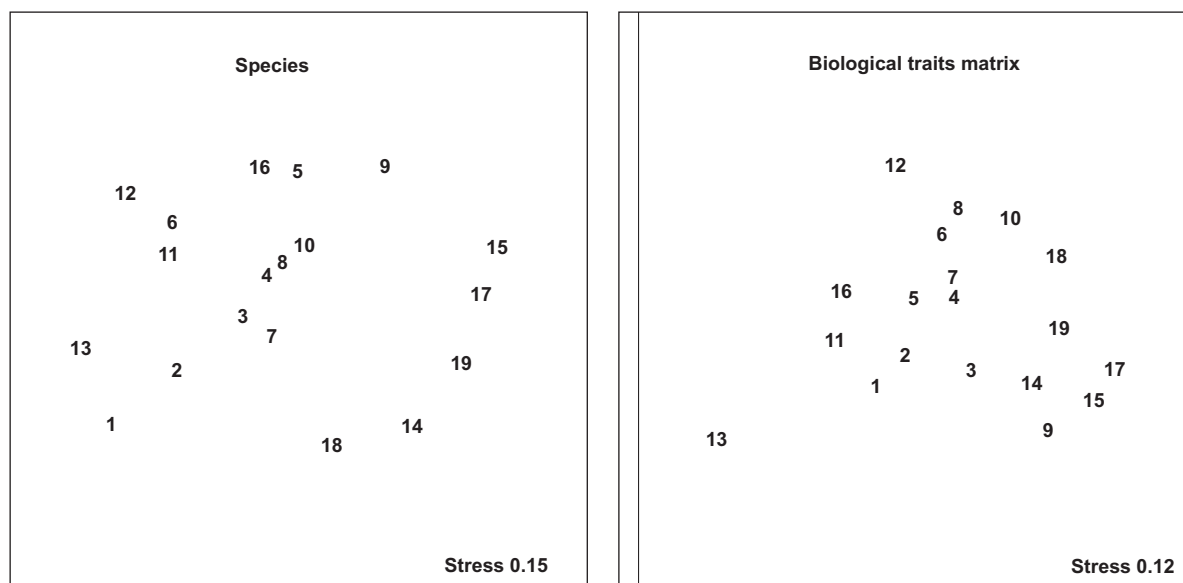
difference between this and other stations. These discriminating trait combinations were functionally quite similar but differed primarily with respect to their feeding strategy. A high proportion of a *Leptonemella* species, representing a unique trait combination (bacteria feeder, K-strategist, long, thin body with conical tail), distinguished nematode communities at station 12 from those at other locations. Functional differences were primarily related to differences in its body shape as well as its feeding and life history strategy.

Nematode distribution patterns based on proportions of species and genera were strongly linked to sediment heterogeneity, a derived measure combining sorting coefficient, median particle diameter and silt content ( $r_s = 0.652$ ,  $p = 0.01$ ). The composition of assemblages in terms of biological traits was best explained by a combination of factors related to sediment granulometry (median particle diameter and silt content) and water depth ( $r_s = 0.431$ ,  $p = 0.03$ ). The number of species, genera and trait groups generally increased with increasing water depth and decreased with increasing mean particle diameter and sediment heterogeneity.

**Figure 3.3.** Features of the biological traits matrix derived from the functional characteristics of nematode species and genera collected at 19 stations in the southwestern North Sea.



**Figure 3.4.** Non-parametric multi-dimensional scaling (MDS) ordination based on relative species abundance data (left) and the abundance-weighted biological traits (right).



### 3.4 Discussion

The 169 nematode species identified in the south-western North Sea had 79 different combinations of biological traits, and 33 species shared the two most common combinations of traits. To some extent, this pattern has been caused by the allocation of nematodes to only 19, partly interrelated, functional groups. The functional groups used represent the major trophic and morphological categories available to the phylum, and each could be sub-divided further to provide more species with unique combinations of traits. Although it is unlikely that further sub-division of existing traits would be meaningful, it is unclear whether the inclusion of additional traits, for example related to the physiology (e.g. respiration rates, Warwick & Price, 1979) of species, would provide greater differentiation in the functional roles of nematodes.

Spatial patterns in the functional structure of assemblages were primarily related to differences in the two most species-rich trait combinations. These trait combinations included both dominant and low-abundance species with different taxonomic affiliation. Walker *et al.* (1999) hypothesised that many of the low-abundance species are analogues of the dominants with respect to their ecological functions. They differ in terms of their capabilities to respond to environmental stresses and disturbance, thereby conferring resilience on the community.

To date, few studies have tested the concept of functional redundancy in free-living nematode communities (Mikola & Setälä, 1998; De Mesel *et al.*, 2003). These inves-

tigations into the contribution of species to ecosystem processes revealed effects of individual species rather than functional groups (e.g. feeding types). A more reliable approach to assessing the functional structure of nematode communities might therefore be to consider combinations of biological traits expressed by organisms (i.e. biological traits analysis) rather than relying on single functional groups. Postma-Blaauw *et al.* (2005), for example, showed that differences in life history strategies between nematode species of the same trophic group is of importance for their communal effect on soil ecosystem processes.

Functional diversity is an important component of biodiversity, yet in comparison to taxonomic diversity, methods of quantifying functional diversity are less well developed (Petchey & Gaston, 2002). Although the biological traits approach is no more powerful than traditional taxonomic methods in detecting spatial differences between communities, it is of additional ecological importance. Our results from the MDS showed that assigning species and genera to biological traits provided additional insights to those from traditional taxonomic analyses. This suggests that measures based on a phylogenetic classification do not alone capture all of the important, heritable differences in nematode attributes (Walker *et al.*, 1999). Improving our understanding of diversity-function relationships across ecosystems will require a categorisation of species attributes that can be related to function. Consequently, obtaining a greater knowledge of the functional roles of nematode species will be the key to improve the sensitivity and interpretation of biological traits analyses of marine benthic communities.

## 4. The ICES North Sea Benthos Project 2000: Species distributions and changes since 1986

*Authors: Jacqueline Eggleton, Rebecca Smith and Hubert Rees*

### 4.1 Introduction

The North Sea benthic communities have been studied on localised scales for many years; however, it was not until 1986 that a synoptic sampling exercise for the entire North Sea was undertaken (see Künitzer *et al.*, 1992). A second North Sea-wide survey was initiated in 2000 where effort was made to either re-sample stations from the 1986 North Sea Benthos Survey (NSBS) or seek contributions from ongoing national research and monitoring effort that might, collectively, allow a comparable holistic assessment to that achieved in 1986. The ICES Study Group on the North Sea Benthos Project 2000 (NSBP 2000) undertook to integrate the recent macrobenthic infaunal and environmental data from 14 institutes (taken between 1999 and 2002) and compare it with the data from 1986. Preliminary findings of benthic community patterns and changes in the western North Sea were published in 2005 (Cefas, 2005). The full results of North Sea-wide study are presented in an ICES Co-operative Research Report (Rees *et al.*, 2007).

The following account summarises an investigation into the distributions and changes of selected infaunal species in the entire North Sea, using grab and core data from both the 1986 NSBS and NSBP 2000 surveys.

### 4.2 Methods

Community analyses highlighted several major divisions in the benthic communities of the North Sea. The most distinct separations were at the 50m and 100m depth contours, distinguishing the central and northern North Seas. The Dogger Bank and Oyster Ground in the southern North Sea also exhibited distinctive communities in contrast to the greater community heterogeneity in this sea area. Similar major divisions have also been identified for plankton and epifaunal communities in the North Sea (Dyer *et al.*, 1983; Adams, 1987). Using this information, assemblage 'indicator' species were selected from both 1986 and 2000. The densities and distributions of these species for each year (all stations) were then mapped using MapInfo® v.8.0. A short-list of species was chosen for further investigation based on the following rationale; where appreciable changes in species density and/or distribution were apparent between sampling occasions, where species were characteristic of, for example, certain environmental conditions (e.g. northerly distributed, restricted to coarse gravels) (some of which corresponded with those previously selected by Kunitzer *et al.*, 1992), species that are known to be fragile or sensitive to

certain anthropogenic stressors such as mechanical disturbance (e.g. fishing) or smothering.

The density of sampling stations in 2000 was significantly greater than in 1986, particularly in the eastern North Sea. Therefore, in order to reduce erroneous conclusions concerning the distributional changes of species in heavily sampled areas, only data from 'matching' stations from the 1986 and 2000 surveys (156 stations, up to 40km distance) have been used in this account. Whilst most stations in the central and southern North Sea had directly matching stations in both years (85 stations), those in the northern North Sea were opportunistically sampled in 2000 and therefore may not exactly represent the same sampling area or communities. It must therefore be recognized that a component of observed changes may be due to the mismatches between stations in 1986 and 2000, especially in the northern North Sea.

### 4.3 Discussion and Conclusions

Research has shown that benthic species distributions and abundances are governed by extrinsic factors, largely food availability, sediment composition and stability, temperature, salinity and hydrodynamics, and by intrinsic factors, mainly competition and predation. Changes in dominant or 'indicator' species over time may also be due to recruitment success, feeding activities and lifestyle (burrowers/tube-builders). Benthic species can therefore be subject to large natural changes in abundances and distribution on various time scales (seasonal, inter-annual and multi-decadal) (Reiss and Kröncke, 2005; Schroeder, 2005; Reiss and Kröncke, 2006). Anthropogenic pressures such as fishing (Frid *et al.*, 2000; Rumohr and Kujawski, 2000; Bremner *et al.*, 2003a), organic enrichment (Pearson and Rosenberg, 1978; Rees *et al.*, 2006) and chemical pollution also structure communities by excluding certain sensitive species and/or encouraging density increases in others.

In general, the information from the NSBP 2000 survey suggests that, while there is some evidence of flux which may be attributable to natural variation in the recruitment process of relatively short-lived species, there is no indication of a consistent directional trend and, for the majority of species investigated, the distributions remain broadly similar to those in 1986. This may be due largely to the close association of many species with their sedimentary environment. Local time-series studies undertaken between the two sampling occasions revealed that, whilst the densities of some species remained fairly stable, others tended to

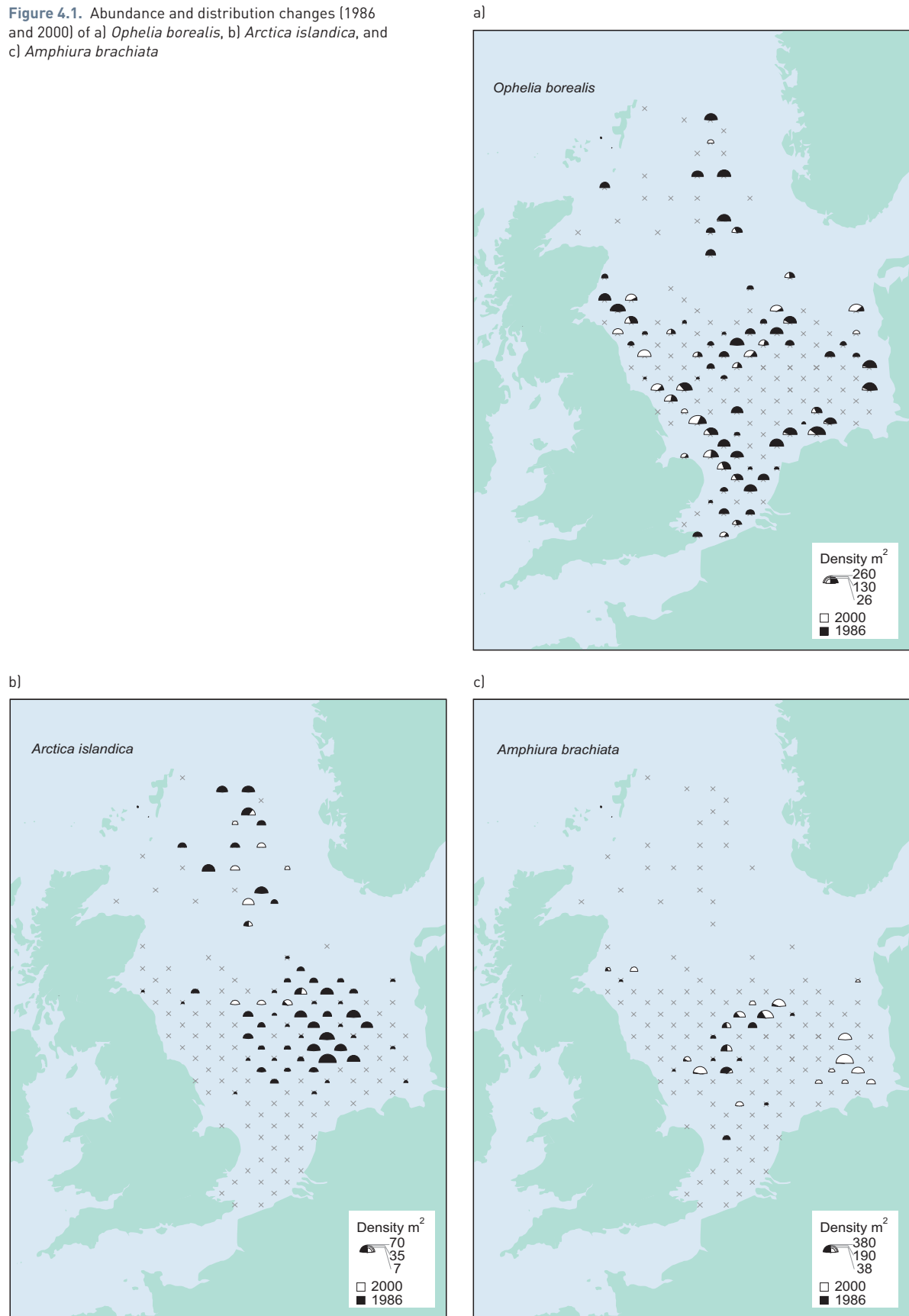
fluctuate widely both on a seasonal and yearly basis (e.g., Reiss and Kröncke, 2005; Daan and Mulder, 2006). Food supply and quality have, understandably, been suggested as major factors affecting species abundances (Weiking and Kröncke, 2005). Species that inhabit more exposed and unstable environments are also likely to show higher temporal variability than those in the deeper stable environments. Direct competition for space may also structure species distributions. For example, this study supports findings of a species 'regime shift' observed at the Frisian Front (southern North Sea) in the mid-1990s. This was mainly attributed to instability of the sediments, caused by the burrowing activity of the mud shrimp *Callinassa subterranea*, which resulted in a negative effect on *Amphiura filiformis* populations (Van Nes *et al.*, 2007).

In this study, there is some evidence to suggest that three species (the polychaete, *Ophelia borealis* (Figure 4.1a), and the bivalves *Chamelea gallina* and *Nuculoma tenuis*) have shown movements away from the eastern North Sea in 2000, extending their distribution to the deeper waters of the western North Sea. In addition, we cannot discount the possibility that demersal fishing may also have influenced the abundances and distributions of *Chamelea gallina* and the

long-lived bivalve *Arctica islandica* (Figure 4.1b). Species such as the brittlestar *Amphiura brachiata* (Figure 4.1c), which require warmer temperatures in order to reproduce successfully, have shown an increasing presence in the shallow eastern North Sea. The abundances of the bivalves *Corbula gibba* and *Abra alba* also increased significantly in 2000. Both species are efficient deposit feeders and are known to predominate after milder winters.

Periodic sea-wide synoptic surveys are important to underpin the interpretation of local environmental assessments. For example, this study has helped to evaluate the significance of species distributional changes, which may not be readily identifiable over smaller scales. It is likely that the major divisions between community types in the North Sea will still be evident in future synoptic surveys, but predicting the path of population changes within communities is more difficult. For example, the patterns of both temperature-sensitive and opportunistic species may be expected to follow any directional climatic changes, but are not expected to follow the same trajectory throughout the North Sea. Future observations in a North Sea-wide setting will therefore be important to identify the range of ecological consequences of any directional climatic change.

**Figure 4.1.** Abundance and distribution changes (1986 and 2000) of a) *Ophelia borealis*, b) *Arctica islandica*, and c) *Amphiura brachiata*



## 5. Fish health status in the North Sea and Irish Sea 2006

*Authors: Stephen Feist, Brett Lyons, John Bignell and Grant Stentiford*

### 5.1 Introduction

The quality and health of the marine environment and coastal environments surrounding the United Kingdom are assessed and monitored using a wide variety of chemical, biological and ecological approaches. The use of fish health parameters, including overt disease and the presence of organ pathology, provides a robust tool for the assessment of health status, both at the organism and population levels. In this way, pathology provides an important component of the UK Clean Seas Environment Monitoring Programme (CSEMP), linking effects of environmental contaminants inducing biomarker responses to larger scale assessment of population health.

The utility of this approach has been recognised internationally and it is included in the Oslo and Paris Commission (OSPAR) Co-ordinated Environmental Monitoring Programme (CEMP) (OSPAR, 1995) where it is accorded CEMP 1 voluntary ranking. The ICES Working Group on Pathology and Diseases of Marine Organisms (WGPDMO) has developed assessment tools for fish disease measurements. With these in place, it is possible that fish disease information will be elevated to CEMP 1 mandatory status.

Fish disease data have been used for environmental assessments for the North Sea and, more widely, for the north-east Atlantic under the auspices of the North Sea Task Force and its Quality Status Report (QSR) (North Sea Task Force, 1993), the OSPAR Quality Status Report 2000

(OSPAR, 2000) and the 3<sup>rd</sup> and 4<sup>th</sup> Helsinki Commission (HELCOM, 1996, 2002). Currently, preparations are underway for the next OSPAR QSR for the north-east Atlantic, due for publication in 2010.

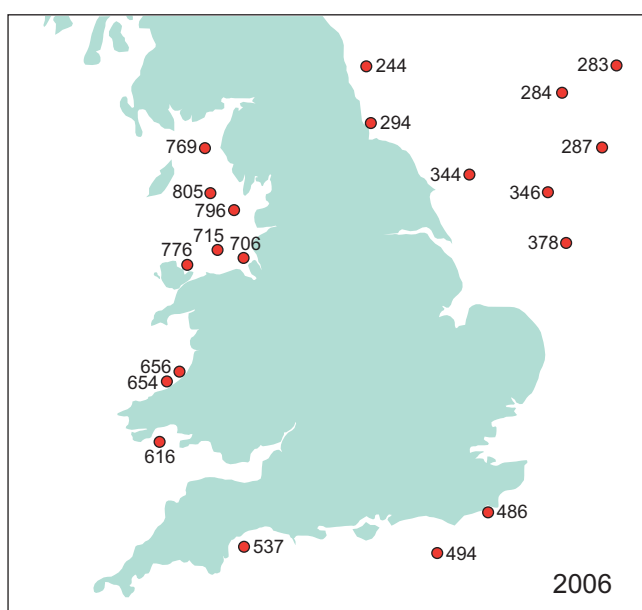
The fish disease monitoring programme also seeks to gather information on the health status of commercial species where conditions present may have human health implications i.e. zoonotic potential or render the fish unsightly or unmarketable. This chapter provides information on the disease status of a variety of fish species in the North Sea, English Channel and Irish Sea from data obtained during 2006 and includes information obtained from observations made by Cefas Industry Liaison Officers during monitoring of commercial fishing activities.

### 5.2 Materials and methods

Monitoring was undertaken as part of the integrated biological effects monitoring cruises that take place annually during the summer (June and July). In 2006, a total of 21 sites were assessed for external fish disease and the presence of macroscopic liver nodules and 24 sites were sampled specifically for liver pathology (for site locations see Figure 5.1).

Sampling protocols followed those established by ICES (Bucke *et al.*, 1996) for external diseases. Target species were dab (*Limanda limanda*) and cod (*Gadus morhua*) for offshore sites and dab and flounder (*Platichthys flesus*) at inshore locations. Where sufficient numbers of other

**Figure 5.1.** Locations sampled for external fish disease, 2006.



species were caught, a disease assessment was undertaken. Species sampled included plaice (*Pleuronectes platessa*), haddock (*Melanogrammus aeglefinus*) and whiting (*Merlangius merlangus*). For each, a careful assessment of external condition and parasite presence was made. Internal examination was also undertaken, with emphasis on the condition of the visceral organs and the liver in particular. The degree of infection with nematode parasites and the presence of melanomacrophage aggregates on the liver surface were recorded. Specimens exhibiting undiagnosed lesions were removed and placed in fixative for histological examination in the laboratory. Samples of liver, gonad, and kidney were taken from dragonets (*Callionymus lyra*) from the Irish Sea stations: Inner Cardigan Bay (n=14), Burbo Bight (n=10), off St Bees (n=20) and in Dundrum Bay (n=20), with additional samples obtained from the English Channel sites south of Eddystone (n=20) and Lyme Bay (n=5). Forty flounder and a total of thirty four-bearded rockling (*Enchelyopus cimbrius*) were taken for histological evaluation.

From all dab examined for external disease that harboured liver nodules greater than 2mm in diameter, a section of the liver incorporating the suspected tumour was taken for confirmatory histological analysis. Samples were fixed in neutral buffered formalin for between 24 and 48 hours and stored in 70% alcohol prior to further processing. Samples for other fish species requiring histological confirmation were treated similarly. In addition, standard sections of liver and gonad tissue were sampled from 50 dab greater than 20cm in length for the assessment of pathological changes. At each site sampled, the first 20 fish were also sampled for study of other biomarkers. The otoliths were also removed from each of these fish for age assessment (data not reported here). Histological methods and diagnostic criteria followed those developed by ICES and were undertaken according to the quality assurance requirements required under the Biological Effects Quality Assurance in Monitoring (BEQUALM) Programme (Feist *et al.*, 2004). Pathological changes to the liver are presented here under the broad categories of 1) non-specific inflammatory lesions, 2) non-neoplastic toxicopathic lesions, 3) foci of cellular alteration (FCA), 4) benign neoplasms and 5) malignant neoplasms. Fish displaying no liver pathology are reported as 'No Abnormalities Detected' (NAD).

Multivariate statistics using PRIMER software (Clarke and Warwick, 2001) were applied to the data since this approach provides increased sensitivity for the detection of differences in liver disease patterns between sites and between years compared to univariate analyses. Cluster analysis, Principal Component Analysis (PCA) and Multi-dimensional

scaling (MDS) were employed to compare liver pathology data for all sites visited. The combination of these techniques allows for site similarity to be classified and importantly allows drivers for site similarity and difference to be identified.

## 5.3 Results

### 5.3.1 Dab diseases

Disease prevalence data according to size category are presented in Table 5.1. For most sites visited, the overall disease prevalence levels are similar to previous years with higher numbers of dab exhibiting liver cancer and other disease conditions from Liverpool Bay in the Irish Sea and the Dogger Bank in the North Sea (Cefas, 1998, 2000, 2003a, Feist and Stentiford, 2005). Dramatic increases in the prevalence of hyperpigmentation were recorded from dab from the central North Sea and Cardigan Bay, with several other locations also showing elevated levels of the condition compared to previous years (Feist *et al.*, 2007). Dab from Irish Sea locations continue to remain relatively free of the condition.

### 5.3.2 Assessment of dab liver pathology

Analysis of liver samples from dab collected at the 24 sampling stations revealed an array of previously identified pathologies. These included the presence of non-specific inflammatory pathologies, toxicopathic pathologies, foci of cell alteration (FCA) and benign and malignant neoplasms (tumours). Multivariate assessment of liver pathology data using the PRIMER® statistical package revealed a clear clustering of sites with those in the English Channel, Tees Bay and Carmarthen Bay discriminating from those in the Irish Sea and particularly offshore North Sea sites (such as North and North East Dogger) (Figures 5.2 and 5.3). In particular, fish from Channel sites such as Rye Bay, Lyme Bay and Newhaven were least similar (in terms of liver disease) to those from the Dogger Bank, Cardigan Bay and other sites in the Irish Sea. The greatest driver for this discrimination was the high prevalence of pre-cancerous (FCA) and cancerous lesions in fish from the Dogger Bank, Cardigan Bay and certain Irish Sea sites compared to those from the English Channel (Figures 5.4, 5.5 and 5.6). These discriminations are similar to those observed in previous years and support the separation of sites into distinct 'Types' based upon the liver pathology profile in fish captured at those sites (see Feist *et al.*, 2007). In this respect, sites from the English Channel are classified as Type A sites while those on the Dogger and certain regions within the Irish Sea would group as Type C sites. A range of sites in the inner North

**Table 5.1.** Summary catch data and disease prevalence in dab (*Limanda limanda*) by size category on stations sampled during 2006.

CSEMP	Area	Lat decimal mins	Long decimal mins	Size	M	F	Ly	U	Ep	Hyp	Ln	Mln	Mmc	X	St	Lp	Ac	Nm	Gl
244Fi	Amble	55 19.116	1 15.183 W	15-19	2	1	0	0	0	0	0	0	0	0	1	0	0	2	0
				20-24	25	19	4	1	0	7	0	0	12	0	10	0	0	36	0
				25>	0	3	0	0	0	1	0	0	0	0	1	0	1	2	0
706Fi	BurboBight	53 28.206	3 17.795 W	15-19	76	36	1	14	2	3	0	0	1	0	2	32	0	0	0
				20-24	27	107	1	14	4	4	6	1	7	0	0	80	0	0	11
				25>	0	9	0	2	0	1	1	0	0	0	0	5	0	0	1
656Fi	Cardigan Bay Inner	52 18.560	4 15.049 W	15-19	89	43	1	4	2	13	1	0	2	0	8	34	2	0	6
				20-24	2	7	0	0	0	0	1	0	0	0	0	2	0	0	1
				25>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
654Fi	Cardigan Bay South	52 10.685	4 31.069 W	15-19	110	111	1	2	8	20	7	0	3	0	6	29	0	0	11
				20-24	12	56	2	0	0	9	11	0	7	0	2	18	0	0	7
				25>	0	2	0	0	0	0	0	0	1	0	0	1	0	0	0
616Fi	Camarthen Bay	51 32.867	4 33.888 W	15-19	79	24	0	7	0	0	0	0	0	0	2	1	0	0	2
				20-24	42	91	1	17	3	0	0	0	0	0	2	12	1	1	15
				25>	2	61	0	9	1	0	0	0	0	0	1	11	0	0	7
287Fi	Central Dogger	54 29.986	2 42.008 E	15-19	72	69	1	11	1	21	0	0	0	0	37	26	0	0	0
				20-24	84	153	2	53	5	76	4	1	4	0	44	96	3	23	5
				25>	0	35	0	8	1	14	3	0	2	0	2	17	1	6	1
378Fi	Indefatigable Bank	53 32.432	2 05.602 E	15-19	85	122	0	4	0	11	0	0	0	0	9	5	1	0	0
				20-24	23	169	2	4	0	39	3	0	1	0	5	24	7	33	3
				25>	4	49	1	4	1	16	2	0	0	0	0	18	3	13	2
715Fi	Liverpool Bay	53 28.097	3 42.272 W	15-19	68	40	3	12	0	1	0	0	0	0	2	14	0	0	2
				20-24	36	99	1	25	2	6	5	1	7	0	1	42	1	0	23
				25>	2	75	1	19	2	8	1	0	0	0	0	37	0	0	7
537Fi	Lyme Bay	50 36.941	2 57.550 W	15-19	11	23	0	1	0	0	0	0	0	0	1	0	0	0	0
				20-24	1	18	0	0	0	2	0	0	0	0	0	0	0	4	1
				25>	1	5	0	0	0	0	0	0	0	0	0	0	0	1	0
283Fi	Dogger North East	55 16.212	2 54.070 E	15-19	55	48	0	15	0	9	0	0	0	0	28	0	0	1	0
				20-24	70	66	9	36	4	33	9	1	1	0	52	6	3	18	1
				25>	15	88	2	29	0	33	5	1	7	0	25	24	1	36	3
494Fi	Newhaven	50 45.619	0 01.066 W	15-19	148	43	0	5	0	4	0	0	0	0	2	7	1	1	1
				20-24	40	92	0	2	0	5	0	0	0	0	0	20	1	15	3
				25>	1	14	0	1	0	2	0	0	1	0	0	3	0	4	2
284Fi	Dogger North	55 04.471	2 06.540 E	15-19	65	39	3	13	1	17	0	0	0	0	29	3	1	0	0
				20-24	71	60	7	24	0	52	7	0	5	0	41	19	2	24	5
				25>	5	102	6	23	0	52	11	4	6	0	22	27	2	29	1
344Fi	Flamborough Off	54 13.384	0 33.788 E	15-19	84	31	4	2	2	7	0	0	0	0	14	0	0	11	0
				20-24	99	84	6	12	3	31	2	0	9	0	26	2	2	163	0
				25>	0	2	0	0	0	0	1	0	0	0	0	0	0	1	0
346Fi	Humber Off	54 03.389	1 47.091 E	15-19	50	50	0	1	1	7	0	0	0	0	26	4	0	0	0
				20-24	41	59	3	8	1	25	0	0	4	0	42	9	0	42	0
				25>	0	15	0	1	0	6	0	0	0	0	2	1	2	12	0

Key:

M = Male

U = Epidermal ulceration

LN = Liver nodules

X = X-cell disease

AC = *Acanthochondria* sp.

F = Female

EP = Epidermal papilloma

MLN = Multiple liver nodules

ST = *Stephanostomum* sp.

NM = Nematodes

LY = Lymphocystis

HYP = Hyperpigmentation

MA = Macrophage aggregates

LP = *Lepeophtheirus pectoralis*GL = *Glugea* sp.

**Table 5.1 continued.** Summary catch data and disease prevalence in dab (*Limanda limanda*) by size category on stations sampled during 2006.

CSEMP	Area	Lat decimal mins	Long decimal mins	Size	M	F	Ly	U	Ep	Hyp	Ln	Mln	Mmc	X	St	Lp	Ac	Nm	Gl
796Fi	Morecambe Bay Off	53 53.749	3 24.364 W	15-19	104	105	0	15	2	0	0	0	1	0	13	44	0	0	2
				20-24	32	103	1	17	3	0	2	0	3	0	5	80	0	0	13
				25>	1	26	0	1	0	0	2	0	1	0	0	22	0	0	3
776Fi	Red Wharf Bay	53 21.638	4 08.77 W	15-19	131	84	3	19	2	3	0	0	0	4	22	0	0	1	
				20-24	25	153	2	8	4	2	11	0	4	0	0	43	0	1	3
				25>	0	26	1	5	0	0	2	0	1	0	0	15	1	0	1
486Fi	Rye Bay	50 47.010	0 47.433 E	15-19	125	42	1	8	0	4	0	0	0	0	3	4	1	3	
				20-24	41	88	2	6	0	3	1	0	0	0	1	19	1	20	3
				25>	1	21	0	0	0	1	0	0	0	0	0	8	1	6	0
805Fi	South East Isle Of Man	54 03.535	3 52.695 W	15-19	174	32	1	7	0	0	0	0	0	59	8	0	0	1	
				20-24	29	32	2	8	1	0	5	0	4	0	11	21	1	0	4
				25>	1	13	0	0	0	0	1	0	2	0	0	8	0	0	1
769Fi	St Bees	54 30.375	3 47.266 W	15-19	141	82	1	12	3	0	0	3	0	113	37	0	0	2	
				20-24	6	38	0	4	2	0	5	2	2	0	15	21	1	0	4
				25>	0	11	0	0	0	0	2	0	1	0	2	5	0	0	0
294Fi	Tees Bay	54 45.893	1 08.293 W	15-19	35	76	0	2	0	1	0	0	0	16	0	0	11	0	
				20-24	60	127	7	4	1	10	1	0	8	0	28	0	4	184	0
				25>	0	7	2	1	0	1	0	0	0	0	1	0	0	7	0
294 Fi	Dogger West	54 47.175	1 17.203 E	15-19	66	34	4	8	0	22	0	0	0	27	2	1	0	0	
				20-24	30	120	3	24	1	57	8	1	11	0	67	10	2	37	1
				25>	0	3	0	1	0	2	0	0	1	0	1	0	0	1	0

Key: M = Male  
U = Epidermal ulceration  
LN = Liver nodules  
X = X-cell disease  
AC = *Acanthochondria* sp.

F = Female  
EP = Epidermal papilloma  
MLN = Multiple liver nodules  
ST = *Stephanostomum* sp.  
NM = Nematodes

LY = Lymphocystis  
HYP = Hyperpigmentation  
MA = Macrophage aggregates  
LP = *Lepeophtheirus pectoralis*  
GL = *Glugea* sp..

Sea and Irish Sea that contain fish with intermediate prevalence of pre-cancerous and cancerous liver pathologies would be classified accordingly as Type B. The consistent grouping of sites in the 2006 data reinforces the use of a site-typing scheme based upon liver pathology and should allow for improvement or degradation in fish health at particular sites to be recorded over time.

### 5.3.3 Analysis of liver pathology in other species

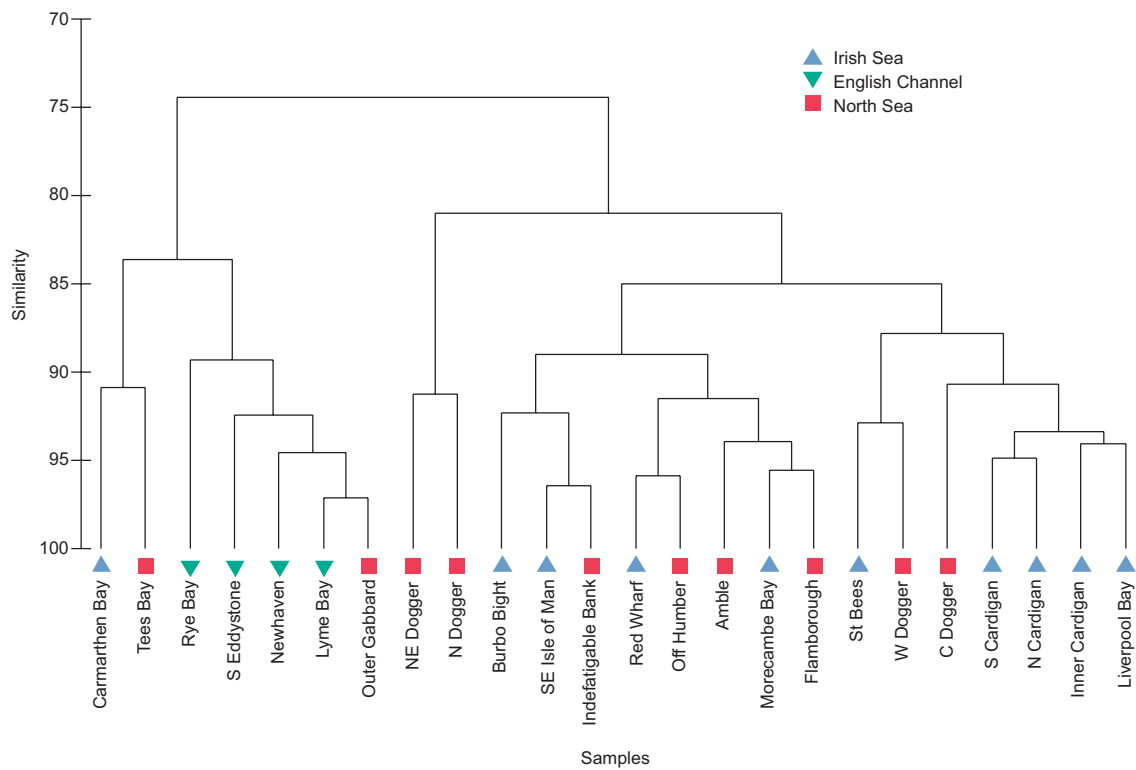
A total of six cod from the outer Thames estuary (Outer Gabbard) were sampled for histological examination. One specimen exhibited multiple granulomas in the visceral organs, including the liver. These lesions were typical of those associated with infections with the bacteria *Fransicella*, which has been reported from farmed cod and previously seen in North Sea cod. Occasional reports of wild cod with this infection occur (see Feist *et al.*, 2007). A second fish revealed the presence of a small basophilic focus of cellular alteration in the liver (Figure 5.7).

Three categories of liver pathology were detected in four-bearded rockling from the sampling locations off the

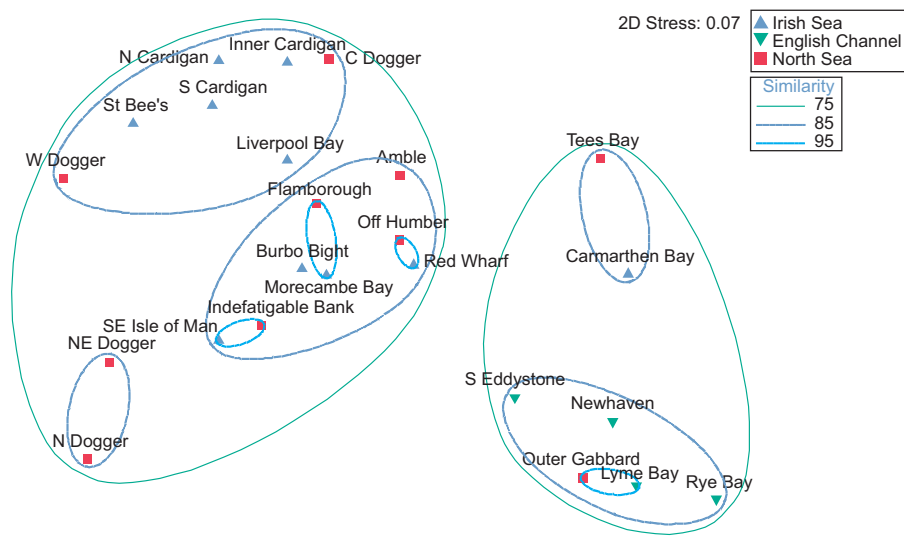
Humber and off the Cleaver Bank in the North Sea. Hepatocellular and nuclear pleomorphism (Figure 5.8) was detected in 30% (n=10) of fish sampled from the Humber and a further 17% (n=18) fish from the Cleaver Bank. Most fish from both locations exhibited macrophage aggregates in the liver and a putative vacuolated focus of cellular alteration was detected in a single fish from the Humber. No pathology was seen in the gonads of these fish (n=23).

Previous investigations of the health status of dragonets revealed the presence of a number of liver lesions of significance for environmental monitoring purposes (Feist *et al.*, 2007). During 2006, samples were obtained to provide an additional data set in order to compare lesion occurrence with 2005 and augment reference material of different lesion types. The presence of non-specific inflammatory lesions, non-neoplastic toxicopathic lesions, pre-neoplastic foci of alteration (Figure 5.9) and infections with coccidian (Figure 5.10) and myxozoan parasites were again detected in dragonets from the Irish Sea (Table 5.2). Benign liver neoplasia was not detected during 2006. Incidental infections

**Figure 5.2.** Multivariate assessment of liver pathology data from 24 sites sampled during 2006. Cluster analysis (dendrogram) depicting site-site similarities based upon the array of liver pathologies detected at those sites.

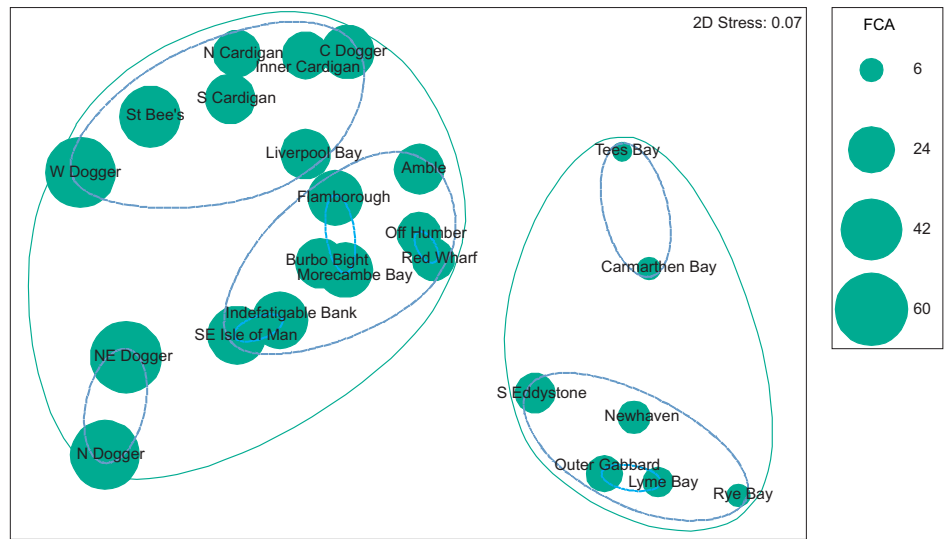


**Figure 5.3.** Multi-dimensional scaling (MDS) plot representing the data shown in Figure 5.2. Sites in the bottom right quadrant of the plot are predominantly those from the English Channel and Inner North Sea while sites at the top left of the plot are those from the Dogger bank, Cardigan Bay and Liverpool Bay. This MDS plot can be cross-referred to the bubble plots depicted in Figures 5.4, 5.5 and 5.6.

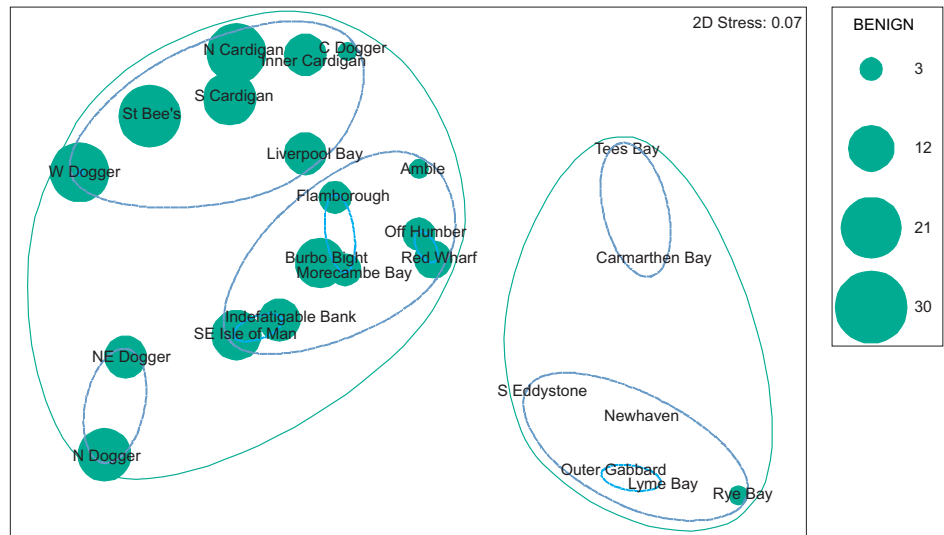


**Figures 5.4, 5.5 and 5.6.** Bubble plot overlays of the MDS plot shown in Figure 5.3.

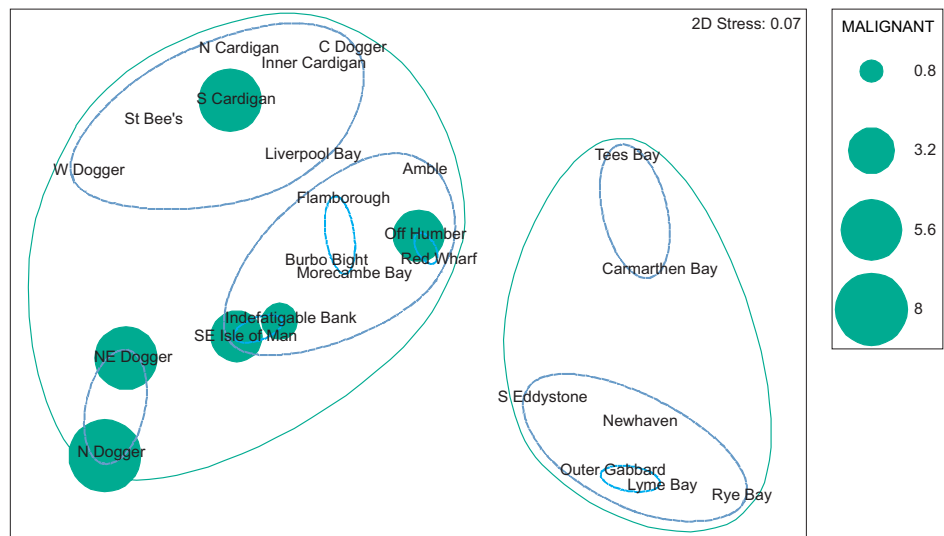
**Figure 5.4.** Foci of cellular alteration (FCA).



**Figure 5.5.** Benign tumours.



**Figure 5.6.** Malignant tumours. Sites in the bottom right quadrant are defined by low prevalence of FCA, benign and malignant tumours while those in the upper left quadrant contain dab populations with the highest prevalence of these pre-cancerous and cancerous liver pathologies. Note the almost complete absence of benign and malignant tumours at sites in the English Channel and inner North Sea (B, C).



**Table 5.2.** Numbers of dragonet exhibiting liver pathology from sites in the Irish Sea and English Channel.

	Location (No. fish sampled)					
	Inner Cardigan Bay (n=10)	Red Wharf Bay (n=10)	St Bees (n=20)	Dundrum Bay (n=20)	Eddystone (n=20)	Lyme Bay (n=5)
FCA	0	0	1	0	0	0
MA	0	0	2	1	0	0
VMA	3	0	1	5	0	0
Myxo.	10	10	19	17	15	1
Cocc.	2	0	0	0	3	1

Key:

FCA = focus of cellular alteration

MA = macrophage aggregates

vMA = vacuolated MA

Myxo. = Myxosporean parasite *Myxidium incurvatum*

Cocc. = Unidentified coccidian parasite

with cestodes and nematodes were also recorded in a few fish.

A sample of fifty flounder from Rye Bay was screened for the presence of intersex and liver pathology. Two cases of vacuolated foci of cellular alteration were detected. No other liver pathology was detected and none of the fish exhibited intersex.

#### 5.3.4 Disease status of other species

As in previous years, only a few sites yielded sufficient numbers of commercial species for disease evaluation. Disease levels were low and mainly restricted to the occurrence of parasites (Table 5.3). A total of fifty-nine cod were examined from six sites off the east coast of England, with 22% of these harbouring infection with nematodes. As in the previous two years no other parasite species were detected. Sufficient whiting were collected at three sites in the North Sea. All fish obtained from the Farne Deep were found to harbour nematode infections, with 71% of whiting from Flamborough also harbouring these parasites. A range of other parasite species were detected, including 7% of whiting which were infected with the gill copepod *Lernaecera branchialis* and two fish which exhibited skeletal deformity (scoliosis). Similarly, haddock from Flamborough and Amble also harboured nematode parasites at incidences of 63% and 49%, respectively. Sufficient plaice for examination were obtained from the central Dogger Bank. Of these, 10% were infected with visceral nematodes and 16% harboured the external copepod parasite *Lepeophtheirus pectoralis*. In all of the cases of parasitism detected, there was little evidence of adverse host reaction and in most cases the fish appeared to be in good condition.

## 5.4 Conclusions

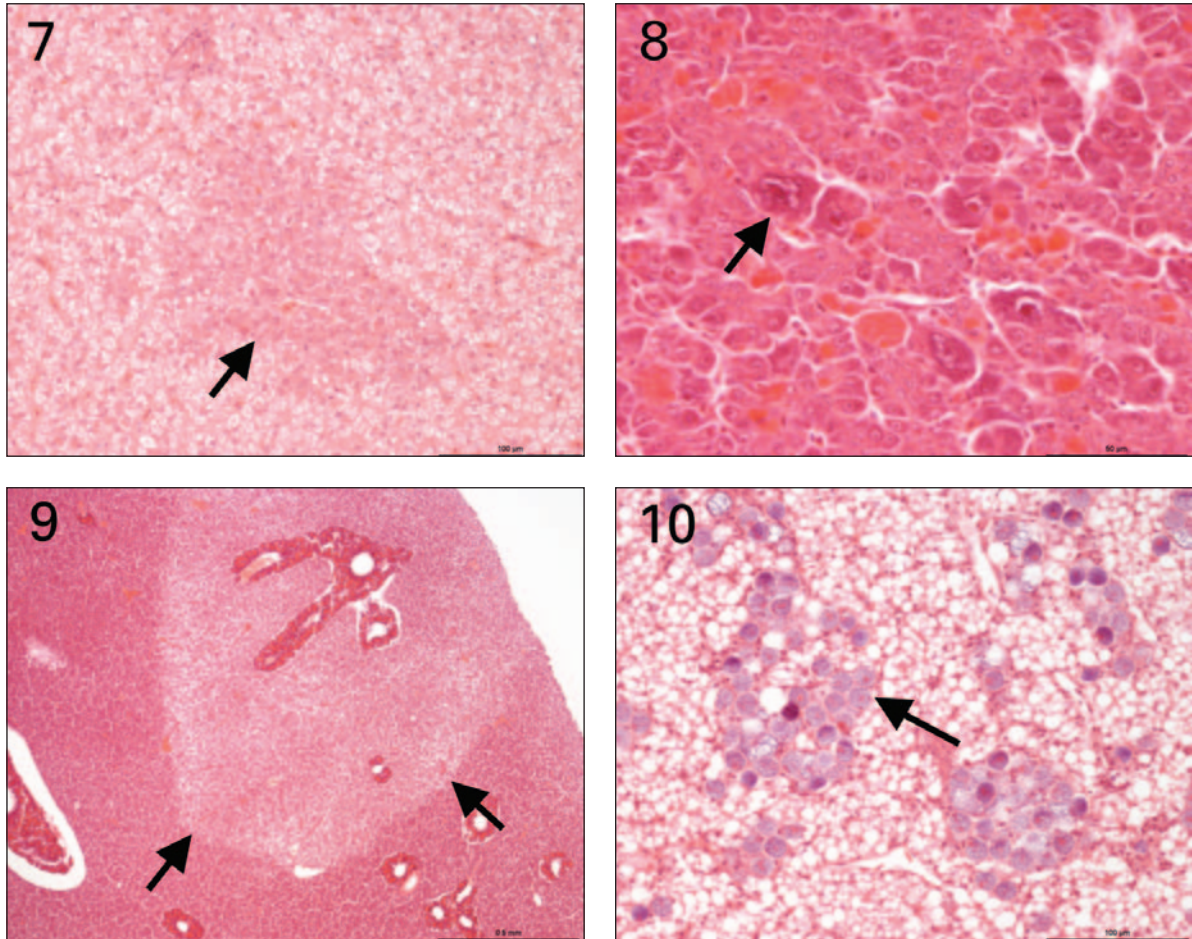
- The continued increase in prevalence of hyperpigmentation in dab from the North Sea and Cardigan Bay requires further investigation. Various causes have been postulated, including exposure to UV radiation and contaminants, viruses and other prokaryote organisms. However, to date investigations using histology and electron microscopy have failed to reveal the presence of

infectious agents and the aetiology of the condition is unknown.

- A site-typing scheme based upon the use of liver pathology and its co-correlation with certain external diseases (e.g. hyperpigmentation) has been confirmed using the 2006 data. Type A, B and C sites consistently discriminate based upon the prevalence of pre-cancerous and cancerous lesions discovered in fish from these sites. Furthermore, higher levels of certain external diseases correlate well with these groupings.
- Rockling showed a high prevalence of hepatocellular and nuclear pleomorphism, a pathology seen in flatfish and generally thought to be induced by exposure to contaminants. However, further work is required before such an aetiology can be proposed for rockling since little is known about the baseline appearance of the liver in this species. The range of liver pathology seen in dragonets during 2006 matches that recorded during 2005 with the exception of additional severity categories of parasitic infections. The species is susceptible to tumour formation with similar lesions to those seen in flatfish (FCA and adenoma). As such, dragonets may prove to be a valuable species for monitoring in regions where the main target species are rare or absent.
- Although information on the health status of commercial fish species was obtained during 2006, only whiting and haddock were obtained in sufficient numbers for a confident assessment of disease prevalence. General information on disease occurrence in commercial species is being collected by Cefas Industry Liaison Officers and this may provide an extremely useful source of data in the future from fish stocks sampled at fishing grounds.
- Together, the information collected on the health status of commercial and non-commercial fish species provides an important indicator of marine environmental health. New approaches for analysis of fish disease and liver pathology data are providing novel insights into relationships between locations in the North Sea and Irish Sea and is successfully being used for integration with other biological and contaminant data. Such information will be of direct relevance for the forthcoming OSPAR Quality Status Report 2010.

**Figure 5.7.** Basophilic focus of cellular alteration (arrow) in the liver of cod. H&E, Bar = 100µm. **Figure 5.8.** Hepatocellular and nuclear pleomorphism in the liver of a rockling. Note the conspicuously enlarged hepatocytes (arrow) containing large misshapen nuclei with prominent nucleoli and a coarse chromatin pattern. Bar = 50µm. **Figure 5.9.** Section through a large vacuolated focus of cellular alteration (arrows) in dragonet

extending from the periphery of the liver. Note the nests of exocrine pancreatic tissue present within the lesion as well as the surrounding normal liver tissue. Bar = 0.5mm. **Figure 5.10.** Intense infection with numerous macrogamete stages of an unidentified coccidian parasites in the liver of dragonet. Note the relative lack of host response. Bar = 100µm.



**Table 5.3.** Disease status of non-target species from locations in the North Sea sampled in 2006.

Species	No. examined	Size range (cm)	Location	Parasites/Pathology (No. affected)
Cod	6	36-52	Thames Gabbard	NM(2)
	1	80	Smith's Knoll	NAD
	22	30-77	Humber Off	NM(10)
	5	24-66	Cleaver Bank	NM(1)
	12	27-62	Off Tees	NAD
	12	22-43	Amble	NAD
Whiting	102	19-35	Thames Gabbard	NM(7), CLV(3), ULC(3), MMC(1), LB(7), CR(7), SKD(2)
	100	21-36	Farne	NM(100), CLV(4)
	100	22-39	Flamborough	NM(71), CLV(2), MMA(1), CR(1)
Haddock	48	19-27	Amble	NM(19)
	100	23-29	Flamborough	NM(63), LP(1), LB(1)
Plaice	50	16-46	Central Dogger	NM(5), LP(8)

Key:

NAD = No abnormalities detected

LP = *Lepeophtheirus pectoralis*

LB = *Lernaecocera branchialis*

NM = Nematodes (*Anisakis* spp.)

ULC = Ulceration

CR = *Cryptocotyle*

CLV = *Clavella adunca*

MMA = Melanomacrophage aggregates

SKD = Skeletal deformity

## Productive seas

### 6. Licensing of deposits in the sea

#### 6.1 Introduction

This section gives information about the licensing of deposits in the sea around the coasts of England and Wales in 2006 under Part II of the Food and Environment Protection Act 1985 (as amended) (FEPA) (Great Britain Parliament, 1985). 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 disposal of dredged material (as opposed to discharge into the sea via pipelines) and the use of material during marine construction and coastal defence works, is controlled by a system of licences issued under Part II of FEPA. Certain operations (eg the deposit of scientific equipment or navigation aids) are exempt from licensing under the Deposit in the Sea (Exemptions) Order 1985 (Great Britain Parliament, 1985a & b).

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 (then SEERAD). In Northern Ireland the issuing of licences remained the responsibility of the Environment and Heritage Service, an agency of the Department of the Environment for Northern Ireland.

#### 6.3 Enforcement

Scientists from the Cefas Burnham Laboratory have the powers to enforce Licence provisions. Visits are made to construction sites and disposal vessels. Samples are taken and records, including logbooks, are checked. Scientific staff carried out 18 inspections in 2006.

Officers of the Department's Marine and Fisheries Agency (MFA) are charged with enforcing the provisions of FEPA (Part II) and undertake regular inspections from a network of port offices in England and Wales. The MFA carried out 232 inspections in 2006 in relation to construction works and the disposal of waste materials (dredged materials and a small amount of shellfish waste) at designated disposal areas. Further details are given in Table 6.1.

In England and Wales, 1 written warning letter was issued for apparent breaches of licensing controls in 2006. Details are as follows:

*Author: Chris Vivian*

- Investigations into unlicensed construction works at Exmouth resulted in an official warning letter being issued.

In England and Wales in 2006 there were no successful prosecutions for illegal marine works

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 5 enforcement visits in 2006.

In Northern Ireland the Environment and Heritage Service (EHS) made 14 enforcement/investigation visits in 2006 which resulted in 1 warning letter being issued to terminate the unlicensed activities.

#### 6.4 Licensing of dredged material disposal

Table 6.2 gives details for the period 2002 to 2006 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. A proportion of the trace metals in this dredged material is natural, but the mineral structure is such that it will not be available to marine organisms.

Figure 6.1 shows the main disposal sites used in 2006 and the quantities used 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 for disposal, and

**Table 6.1.** Inspection activity by the MFA during 2006.

District	No. of Inspections		No. of Infringements
	Construction	Disposal	
Central	9	7	0
Eastern	51	3	1
London	1	0	0
Northern	6	8	1
South Eastern	49	8	1
South Western	11	3	0
Western	0	2	1
Wales	67	7	1
<b>Annual Total</b>	<b>194</b>	<b>38</b>	<b>5</b>

**Table 6.2.** Summary of dredged material licensed and disposed of at sea in 2006.

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	2002	124	72,851,190	27,884,495	14,725,603	5.53	912	457	4.66	409	1,166	2,664
	2003	97	31,836,123	29,526,580	15,800,897	5.41	950	498	4.29	443	1,183	2,694
	2004	80	44,790,919	28,516,645	14,949,123	5.27	886	513	4.35	412	1,190	2,648
	2005	87	37,483,750	27,729,366	14,774,821	4.91	759	571	4.28	419	1,031	2,594
	2006	65	21,076,535	26,833,340	13,989,803	4.41	622	422	3.55	362	914	2,085
Scotland	2002	21	2,959,045	2,203,016	1,188,129	0.33	59	46	0.85	29	69	134
	2003	29	3,573,981	2,764,020	1,647,881	0.61	70	57	1.40	41	101	175
	2004	23	2,412,670	1,484,408	742,204	0.19	27	19	0.51	14	31	54
	2005	20	5,293,220	2,723,703	1,376,334	1.23	181	112	1.59	69	174	360
	2006	24	4,566,531	1,701,046	850,523	0.21	58	36	0.88	29	62	124
Northern Ireland	2002	8	1,161,500	976,102	458,108	0.46	31	19	0.19	19	26	86
	2003	2	189,900	115,404	73,382	1.47	8	4	0.06	3	2	12
	2004	4	432,904	111,208	79,135	0.04	3	1	0.06	1	1	7
	2005	3	37,800	585,187	308,111	0.11	23	10	0.03	13	14	47
UK Total	2006	3	176,999	833,426	507,942	1.01	68	49	0.33	42	59	209
	2002	153	76,971,735	31,063,613	16,371,841	6.31	1,003	522	5.70	457	1,261	2,884
	2003	128	35,600,004	32,406,004	17,522,159	7.50	1,027	559	5.75	487	1,286	2,881
	2004	107	47,636,493	30,112,261	15,770,462	5.50	917	533	4.92	427	1,223	2,709
	2005	110	42,814,770	31,038,256	16,459,266	6.25	963	692	5.89	501	1,219	3,000
2006	92	25,820,065	29,367,812	15,348,268	5.63	748	508	4.76	433	1,034	2,418	

Notes: Tonnes deposited relate to quantities in the calendar year 2006, which may be covered by 2 or more licences, including one or more issued in previous years.

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.

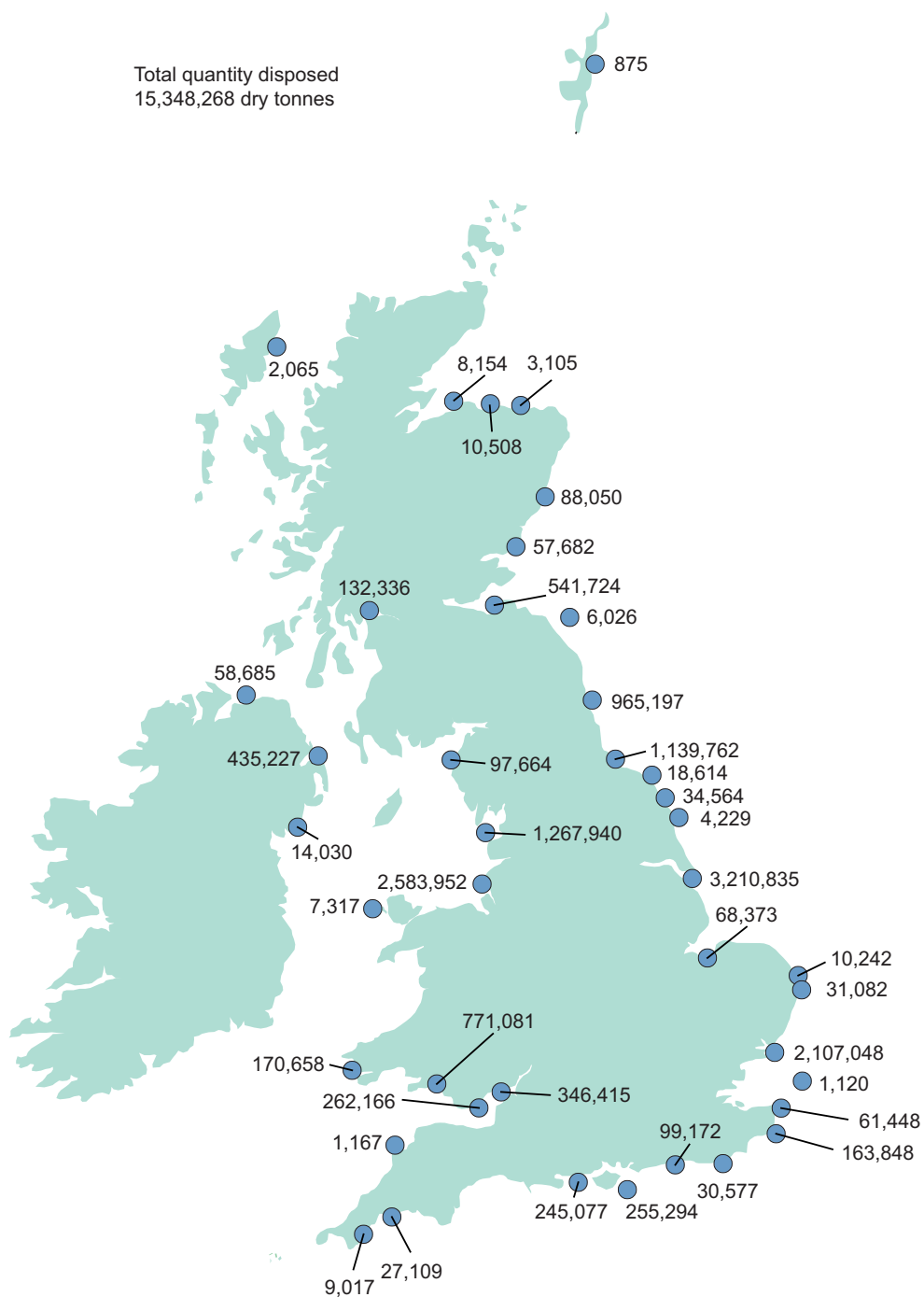
## 6.5 Other licensed activity

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 issued in 2006 are shown in Table 6.3.

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. Details of these licences issued in 2006 are also shown in Table 6.3.

Licences have also authorised the disposal of a small amount of fish waste, details are given in Tables 6.4(a) and (b).

**Figure 6.1.** Amounts of dredged material disposed of at sea in 2006, in dry tonnes.



**Table 6.3.** Other categories of licences issued in 2006.

Licence category	England and Wales	Scotland	Northern Ireland	Total
Construction - new and renewal	192	88	18	298
Tracers, biocides etc.	9	1	0	10
Burial at sea	8	0	0	8

**Table 6.4a.** Fish waste licensed for disposal at sea in 2006<sup>(1)</sup>.

Country	Licensed Quantity (tonnes) <sup>(1)</sup>	Company and source of waste	Disposal sites	Quantity deposited (wet tonnes)	Quantity deposited (dry tonnes)
England and Wales	0	Quay Fresh and Frozen Foods Ltd, New Quay	New Quay	1,203	1,203

Notes: <sup>(1)</sup> No Fish Wastes were licensed or disposed of in Scotland or Northern Ireland during the period covered by this report. For information on licensed quantities and tonnages deposited see footnote to Table 6.1.

**Table 6.4b.** Summary of fish waste licensed and disposed of at sea in 2006.

Country	Year	Licences issued	Licensed quantity (tonnes)	Wet tonnage deposited	Dry tonnage deposited
England and Wales	2002	2	2,200	808	808
	2003	1	6,000	953	953
	2004	0	0	1,834	1,834
	2005	0	0	1,988	1,988
	2006	0	0	1,203	1,203
Scotland	2002	0	0	0	0
	2003	0	0	0	0
	2004	0	0	0	0
	2005	0	0	0	0
	2006	0	0	0	0
Northern Ireland	2002	0	0	0	0
	2003	0	0	0	0
	2004	0	0	0	0
	2005	0	0	0	0
	2006	0	0	0	0
U.K. Total	2002	2	2,200	808	808
	2003	1	6,000	953	953
	2004	0	0	1,834	1,834
	2005	0	0	1,988	1,988
	2006	0	0	1,203	1,203

Notes: For information on licensed quantities and tonnages deposited see footnote to Table 6.2.

## 7. Radionuclide concentrations in dredged sediments

Authors: Kins Leonard & David McCubbin

### 7.1 Introduction

In England and Wales, Defra issues licences to operators for the disposal of dredged material under the Food and Environment Protection Act, 1985 (Great Britain Parliament, 1985a). 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 dredging assessments were undertaken in 2006. However, an assessment was carried out concerning the impact of replacing the existing beach sediment material at Carlyon Bay (Cornwall) with material from the china clay works at St. Austell.

### 7.2 Materials and methods

Samples of the current beach sediment, and emplacement material from the china clay pit, were collected to assess the extent of disparity in radionuclide composition.

Radionuclide assay was achieved using gamma-ray spectrometry by which it is possible to simultaneously measure a wide range of radionuclides commonly found in radioactive wastes.

### 7.3 Results and discussion

Results from the sediment analyses are provided in Table 7.1.

The only nuclides detectable in both the existing sediment, and placement sediment samples, were primordial radionuclides and therefore of natural origin. There was no evidence of anthropogenic contamination in either sample. Projected dose rates, arising from the levels found in the existing and placement sediment, were minimal being <100µSv per annum. These exposure levels are placed in perspective by the fact that the average natural background radiation dose rate to the world population due to cosmic rays, terrestrial gamma rays, inhalation of radon and from foodstuffs is ~2400µSv per annum.

Table 7.1. Concentrations of radionuclides in material from Carlyon Bay and St Austell China Clay Pit, Cornwall.

Area	Radioactivity concentration (dry), Bq kg <sup>-1</sup>			
	<sup>40</sup> K	<sup>226</sup> Ra (via <sup>214</sup> Pb) <sup>(1)</sup>	<sup>232</sup> Th (via <sup>228</sup> Ac) <sup>(1)</sup>	<sup>238</sup> U (via <sup>234</sup> Th) <sup>(1)</sup>
Existing sediment	113	33	10	41
Placement Sediment	740	53	22	56

<sup>(1)</sup> Parent nuclides not directly detected by the method used. Instead, concentrations were estimated from levels of their daughter products.

Suction dredger



Grab dredger



## 8. Advice on fishery implications of pipeline discharges

*Authors: Simon Kershaw and Richard Acornley*

### 8.1 Introduction

This section gives a brief summary of activities carried out during 2006 in connection with the provision of advice on fishery implications of pipeline discharges.

Cefas appraisal of applications for pipeline discharges involves consideration of fishery resources in the area, toxicity of the effluent, local hydrographic conditions and any standards set out in national policy or European Union (EU) Directives. This includes the impact of discharges on marine fauna, including fish nurseries and shellfish populations, and specific interactions of chemicals and the marine environment. One important issue in relation to sewage discharges is the microbiological contamination of bivalve mollusc shellfisheries and the associated human health concerns. The reduction of sewage contamination at source is the most effective way of reducing the health risk. It also reduces

the burdens on the industry and increases acceptability of product to supermarkets.

### 8.2 Summary of pipeline discharge applications

During 2006, Cefas assessed applications for a total of 189 individual discharges. Of these, a total of 137 (72%) were assessed for their potential to impact on shellfish waters and/or production areas. Shellfish hygiene issues therefore continued to be the most common concerns addressed. Table 8.1 shows the types of discharge application commented on in 2006. The majority of applications were for discharge of domestic or combined domestic and industrial sewage, including storm and emergency sewage overflows.

During periods of prolonged or heavy rainfall, surface water run-off will add to the domestic and industrial sewage

Figure 8.1: A pipeline discharge.



substantially increasing the volume of wastewater entering the sewerage system. Although the sewerage networks and sewage treatment works are designed to store and treat multiples of the flows experienced in dry weather, it is not feasible to treat all flows from these combined foul and surface water sewer systems, Combined Sewer Overflows (CSOs). In pipe-full conditions, storm overflows are required to allow a proportion of the untreated dilute sewage to discharge from the sewerage system. Intermittent discharges from storm tanks and CSOs may therefore by-pass the treatment works with the potential to impact on receiving waters.

Applications for 79 storm overflow discharges were received in 2006 of which 61 were identified as potentially impacting on shellfisheries. Where water company discharge improvements are identified to benefit shellfish waters, Environment Agency policy requirements restrict overflow operation to a maximum of ten spills per annum (in aggregation with other impacting storm discharges averaged over a ten year period). Previously this requirement had to be negotiated by Cefas on a case-by-case basis.

Cefas continues to request that the water companies provide an annual report of spills from each of these overflows and, where necessary, asked for clarification that discharges had been considered in aggregation with others impacting on the same fishery. The review of annual spill reports is important for evidence-based decision-making, proving useful in identifying problem discharges that require further improvement. It has also highlighted the (often large) discrepancies between predicted and actual spill frequencies.

Emergency overflows only come into operation when there is a major failure at the sewage treatment works or pumping station. If this should occur, it may cause severe contamination of fisheries in the area. Applications for 35 emergency discharge applications were received, of these 26 had the potential to affect shellfisheries. In advising on such applications Cefas therefore requested urgent notification of emergency events to the local food authority so that appropriate action could be taken to protect public health.

A total of 44 applications were received for continuous discharges of secondary (biologically treated) effluent (26 affecting shellfisheries); these included upgrading of existing works and new treatment works, reed bed systems and package plants. In addition, 4 applications were received for sewage discharges receiving tertiary treatment (ultra violet disinfection or membrane filtration) in order to reduce microbiological contamination. Two of these benefited shellfish areas.

### 8.3 Impact of discharge improvements on bivalve mollusc shellfisheries

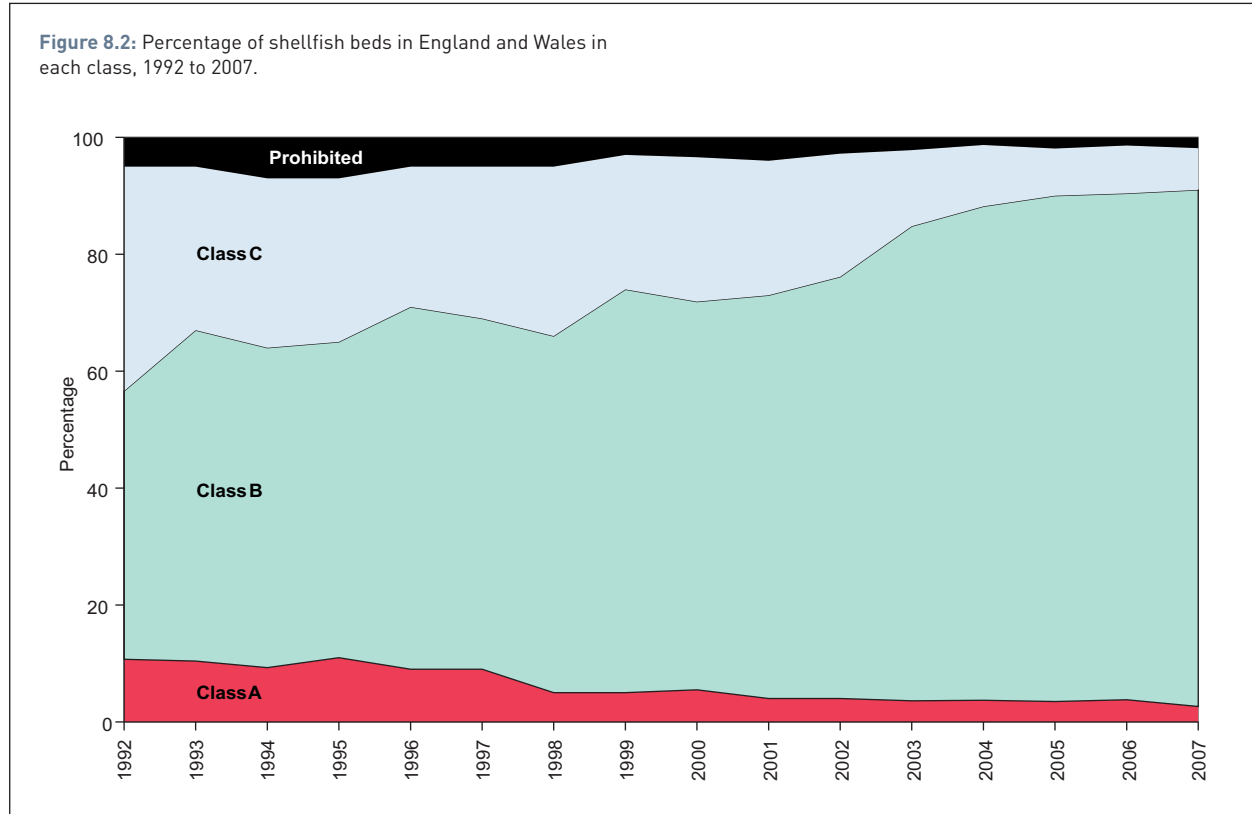
The Government has set a target for all commercially harvested shellfish beds in England and Wales to achieve a microbiological classification for bivalve mollusc shellfish of at least Class B as categorised under Regulation (EC) No. 854/2004, see Table 8.2. The proportion of Class B beds has increased from 45.9% in 1992 to 88.4% in 2007 (Figure 8.2). The proportion of Class C areas decreased from 38.4% to 7.1% and the number of prohibited areas decreased from 5.0% to 1.8% in the same period. This increase in Class B areas and decrease in Class C and prohibited areas during this period reflects water company investment targeting discharges to tidal waters and, in particular, those improvements identified as benefiting shellfish waters. The decrease in the proportion of Class A areas (10.7% to 2.7%) is of concern, however, as Class A confers benefits of access to markets and premium market prices for the fishing industry. Despite significant improvements in water quality as a result of investment in discharge improvements, fewer than 3% of shellfish production areas in England and Wales achieve the 'Class A' standard which reflects water quality clean enough to allow marketing of shellfish directly for human consumption without further processing. To achieve Class A status for many fisheries it is likely that a combined programme of additional discharge improvements and/or measures to tackle diffuse pollution issues will be required in the future.

**Table 8.1.** Numbers of applications of various types commented on within 2006.

Type of application	Total	Shellfish-related
<b>Continuous sewage discharges</b>		
Primary treatment	4	2
Secondary treatment	44	26
Tertiary treatment	4	2
<b>Intermittent sewage discharges</b>		
Storm overflow	79	61
Emergency overflow	35	26
<b>Trade discharges</b>	13	12
<b>Other discharges</b>	10	8
<b>Total</b>	<b>189</b>	<b>137</b>

**Table 8.2.** Classification categories under the Shellfish Hygiene Regulations.

Class	Criteria	Requirements
A	<300 faecal coliforms or 230 <i>E. coli</i> per 100g	Can be collected for direct human consumption
B	90% compliance with 6,000 faecal coliforms or 4,600 <i>E. coli</i> per 100g	Must be purified or relayed to meet class A; may also be heat treated by an approved method
C	<60,000 faecal coliforms or <46,000 <i>E. coli</i> per 100g	Must be relayed for at least 2 months to meet class A or B; may also be heat treated by an approved method.
Prohibited	>60,000 faecal coliforms or >46,000 <i>E. coli</i> per 100g	Commercial harvesting prohibited

**Figure 8.2:** Percentage of shellfish beds in England and Wales in each class, 1992 to 2007.

## 8.4 General advice

In addition to assessment of applications for consent to discharge, a variety of other advice relating to pipeline discharges was provided during the year.

General support was provided for water quality liaison with the Environment Agency regions. This has proved effective in championing the consideration of the marine environment and fisheries interests and influencing scheme outcomes, prior to any formal discharge consent application.

Support was provided for REDRISK, a pan-European research project to identify pollution sources and conditions responsible for viral contamination of shellfish. The project aims to provide a framework to allow the development of a preventative strategy for reducing the virus risk associated with the consumption of bivalve mollusc shellfish.

Following initial discussions with the EA in 2005, an application was received for a secondary treated discharge to serve a first time rural sewerage scheme in the River

Helford catchment. Whilst this did not meet Cefas's recommendation for tertiary treatment it should deliver an improvement on the current situation of numerous crude discharges. We advised that emergency spills should be notified to the Environment Agency and the local food authority, given that the appropriate telemetry will be installed. Aggregation of spills from the inter-stage pumping station and STW storm discharges was also requested.

Advice and liaison with the Environment Agency continued on the discharge of effluent from a meat-processing factory to the Menai Strait and on the implementation of a package treatment plant to provide a higher level of treatment. The need to consider shellfish issues was highlighted.

Other areas of advice included provision of information to Isle of Wight Council on pipeline discharges to the Medina Estuary, advice to Canterbury City Council on pipeline discharges at Whitstable and advice relating to a farm discharge to the Solent.

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## 8.5 Database maintenance

All applications, consents and authorisations continue to be entered onto a database that contains details of all discharges to saline waters in England and Wales. The database is being continually developed, provides unique intelligence and is a strategic tool used alongside other Cefas tools to underpin impact assessments and policy decisions in the marine environment.

## 9. Comparison of methods used for trace metal analyses by FEPA regulators and the FEPA monitoring programme: Rame Head 2005 case study

**Authors: Claire Mason, Peter Kershaw, Thi Bolam and Nicola Lauder**

### 9.1 Introduction

When the Regulatory Assessment and Monitoring teams were completing an integrated assessment of the Rame Head disposal site in 2005, it proved difficult to relate concentrations measured at the disposal site and the surrounding area with concentrations in the dredged material. This was because different methods were used to analyse trace metals in dredged material and in environmental samples.

Action Levels (see summary in Text box 9.1) are used by licensing assessors to determine the extent of contamination of dredged material prior to issuing a license for disposal. Analysis is by partial digest of the whole sediment. Analysis of environmental samples is by total digest of the fine fraction (< 63 µm), and therefore Action Levels cannot be applied to monitoring data.

#### **Text box 9.1: Explanation of Action Levels used by the Regulatory Team to assess dredged material**

In order to assess the suitability of dredged material for disposal to sea, Action Levels for contaminants are used as part of a 'weight of evidence' approach. Action Levels are applied in conjunction with a range of assessment methods (e.g. bioassays, knowledge and historical data, the characteristics of the dredging site, the physical properties of the dredged material and the disposal site). This integrated approach is in line with current thinking on approaches to environmental management of sediments (Batley *et al.*, 2002, Chapman and Mann, 1999).

In general, contaminant levels in dredged material below Action Level 1 (AL 1) are of no concern and are unlikely to influence the licensing decision. In contrast, dredged material with contaminant levels above Action Level 2 (AL 2) is generally considered unsuitable for sea disposal. The latter situation most often applies only to a part of a proposed dredging area, so material from that area can be excluded from disposal at sea and disposed of by other routes e.g. to landfill. Dredged material with contaminant levels between Action Levels 1 and 2 requires further consideration and testing before a decision can be made. An explanation as to how these values were set has been reported by Defra (Cefas, 2003b).

OSPAR Background Assessment Concentrations (BACs), (see summary Text box.2) have been recommended as a means of assessing the degree of contamination of environmental samples. BACs could not be applied to dredged material trace metal concentrations, as they require normalisation of the metal concentrations to 5% aluminium content. Aluminium is not determined in dredged material samples as the partial digest is not able to fully extract aluminium from the sediment matrices.

Normalisation allows trace metal concentrations from different sediment types to be compared. As trace metals have a higher affinity to clay, concentrations will be higher for sediments with a high clay content than for sediments made up mostly of sand. The concentration of aluminium is indicative of the amount of clay in a sample, and the aluminium concentration can therefore be used a normaliser for trace metal concentrations (Rowlatt & Lovell, 1994).

While the determination of trace metal concentrations is performed in the fine fraction (<63 µm) for sediments from disposal site monitoring studies, which is one type of normalisation, further normalisation to 5% aluminium content is required to further improve this determination as sieving at 63 µm still enables some coarser sediment to get into the <63 µm fraction.

Therefore, trace metal concentrations from the dredged material could not be related to trace metal concentrations from the environmental samples to determine directly the amount of anthropogenic contamination in the disposal site and the extent of contamination in the surrounding area.

In order to investigate this issue further, a case study was proposed to show differences between the two methods, and to use this work as part of a wider plan to resolve this issue in the longer term. It is clearly desirable to analyse source material and monitoring data together to determine anthropogenic impact and determine source of elevations more conclusively at disposal sites.

Aims of this case study:

- To compare both methods and see how different the results are overall
- To determine whether it is possible to show relationships between the two methods

**Text box 9.2: Explanation of OSPAR BACs used to assess trace metal concentrations from monitoring samples**

OSPAR BACS (OSPAR, 2005) are defined as the typical range of values found in uncontaminated sediments. They are based on monitoring data from remote sites in the OSPAR area (the North-East Atlantic).

Each metal concentration is normalised to 5% aluminium content, using a pivot point (the concentration of these metals in uncontaminated sand, ideally close to the area of interest). The exact calculation is defined below:

$$C_{ss} = C_x + (C_s - C_x) / (N_s - N_x) * (N_{ss} - N_x)$$

Where

- Trace metal concentration normalised to 5% Al content, related to pivot point
- $C_{ss}$  Concentration of metal at pivot point
- $C_x$  Concentration of metal recorded
- $N_x$  Concentration of normaliser at pivot point
- $N_s$  Concentration of normaliser recorded
- $C_s$  Concentration of metal recorded
- $N_{ss}$  Concentration of normaliser = Aluminium = 5

These values are internationally agreed. However, they should be used with some care, particularly around the UK, as the natural background is very variable, with a diverse geological coast-line.

## 9.2 Case study details: Rame Head Monitoring survey 2005

In 2005, 22 sediment samples were collected using a Shipek grab (samples with a G prefix) or hand-held grab for inner shore samples (samples with RH prefix), from the Rame Head disposal site and surrounding area for monitoring purposes, as shown in Figure 9.1. G34, not shown on the map, is 9km south of G33.

## 9.3 Methods

Each environmental sample underwent analyses as outlined in the Flow chart shown in Figure 9.2.

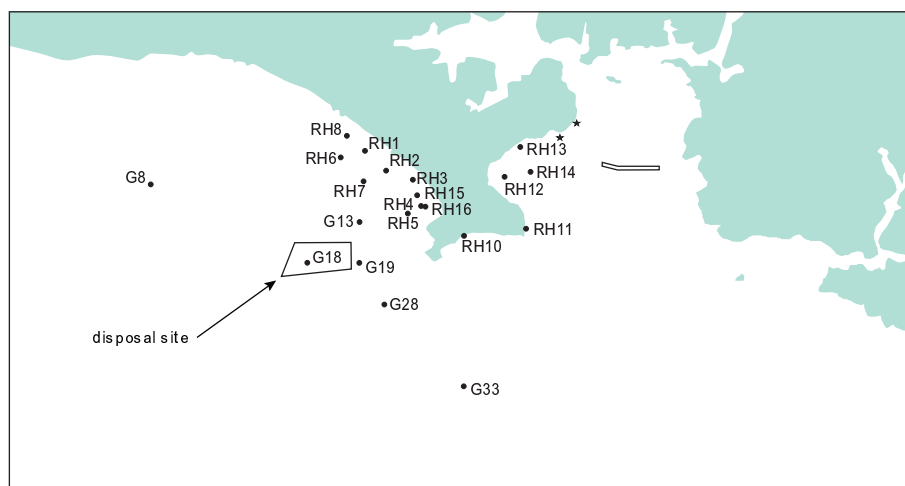
### 9.3.1 Particle size analyses (PSA)/preparation of sediment for metals analysis

PSA was completed on each sample by wet sieving at 63  $\mu\text{m}$ . The >63  $\mu\text{m}$  fraction was dry sieved at 1/2 Phi intervals down to 4 Phi (63  $\mu\text{m}$ ). The <63  $\mu\text{m}$  fraction was freeze-dried and analysed using a Malvern Mastersizer 2000. The sieve and laser diffraction data were merged to form a complete particle distribution for each sample (shown on Flow chart in Figure 9.2).

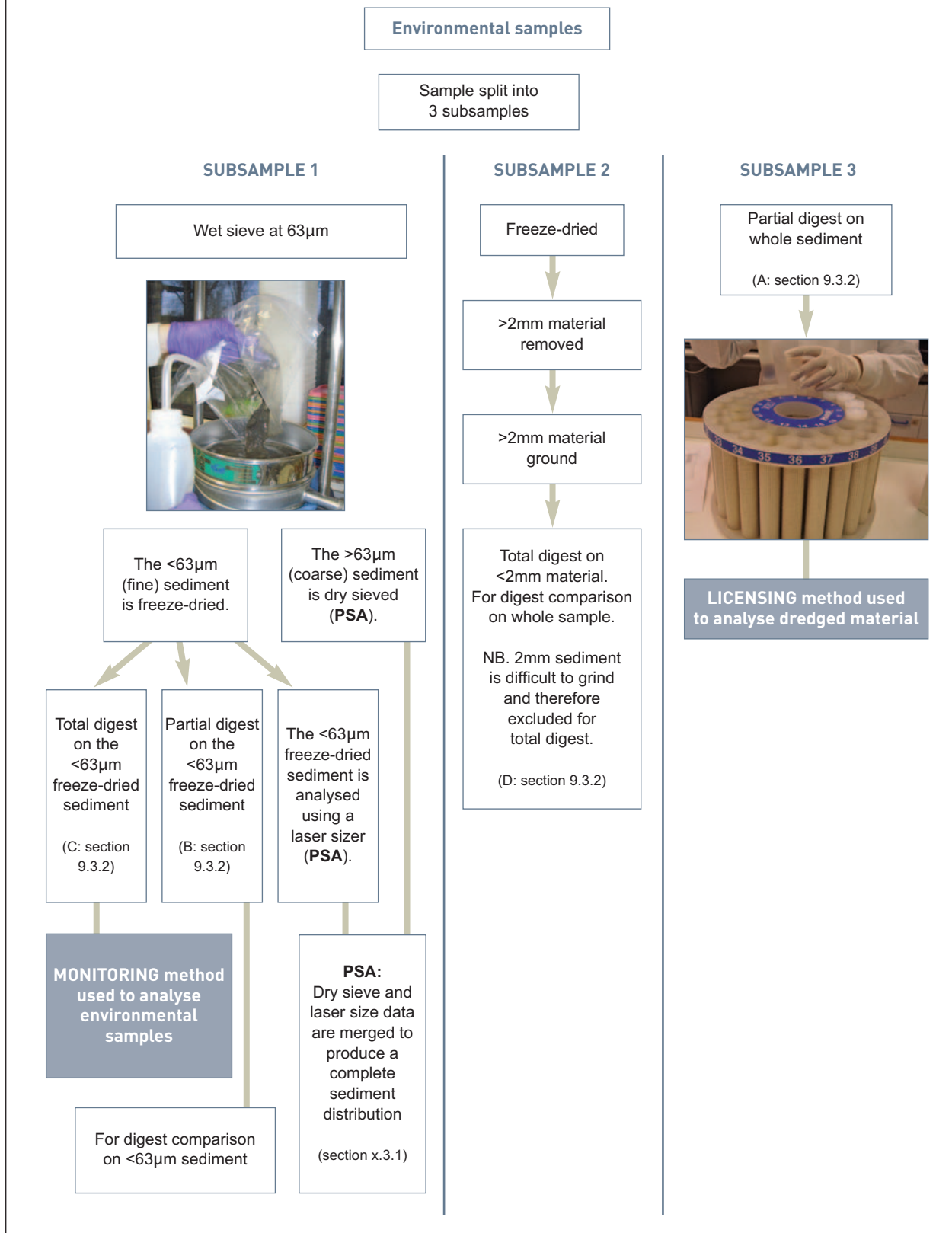
### 9.3.2 Trace metal determination

These samples were analysed using a combination of methods in order to help determine in greater detail the cause for differences observed. It is important to note that the methods use different acid digests applied to different size fractions of the sediment. The methods are described below:

**Figure 9.1:** Sample locations for sediment samples collected in 2005 from the Rame Head disposal site and surrounding areas.



**Figure 9.2:** Flow chart showing analyses completed on each environmental sample in Rame Head 2005 trace metal methods case study.



- *Whole sediment, partial digest* (routine method for dredged material sample trace metal analyses: A on Flow chart in Figure 9.2):

Trace metal analyses are completed on the whole sediment.

Partial digest:

As, Cd, Cr, Cu, Hg, Ni, Pb, Zn are determined using a microwave assisted nitric acid digestion, the final digest is made up in 1% nitric acid and further diluted prior to analysis by Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES) and Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). (Jones and Laslett, 1994).

- *<63  $\mu\text{m}$ , partial digest* (B on Flow chart in Figure 9.2):  
The sample is sieved at 63  $\mu\text{m}$ , and trace metal analyses are completed on a subsample of the fine fraction (<63  $\mu\text{m}$ ).  
Digest details as for whole sediment, partial digest above.
- *<63  $\mu\text{m}$ , total HF digest* (routine method used for monitoring sample trace metal analyses: C on Flow chart in Figure 9.2):  
The sample is sieved at 63  $\mu\text{m}$ , and trace metal analyses are completed on a subsample of the fine fraction (<63  $\mu\text{m}$ ).

Total digest:

Al, As, Cd, Cr, Cu, Fe, Li, Mn, Ni, Pb, Rb, Zn are determined using a microwave assisted hydrofluoric, hydrochloric and nitric acid digestion, HF is then evaporated and the digest is made up in 1% nitric acid and further diluted prior to analysis by ICP-AES and ICP-MS. Due to the simultaneous evaporation of Hg while eliminating HF, Hg analysis is conducted as for a partial digest (Jones and Laslett, 1994).

- *<2mm, total HF digest* (D on Flow chart in Figure 9.2):  
Sediment >2mm is discarded. The <2mm sediment is ground, and trace metal analyses are completed on the <2mm ground material.  
Digest details as for <63  $\mu\text{m}$ , total HF digest above.

## 9.4 Results

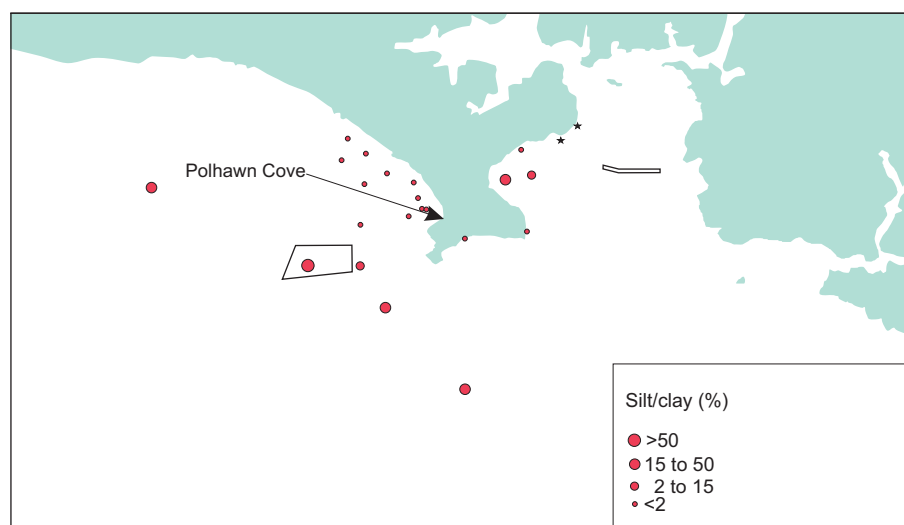
### 9.4.1 Sediment characterisation (PSA)

Generally, as shown in Figure 9.3, samples consist of sand in the Polhawn cove area with < 3% silt/clay becoming more muddy further away from the coast, in the area of the disposal site. The disposal site sample (G18) has the highest proportion of silt/clay at 59%.

### 9.4.2 Trace metals

Trace metal results are presented in Table 9.1 for each of the four analyses completed.

**Figure 9.3:** Silt/clay (%) for Rame Head samples.



#### 9.4.2.1 Dredged material method assessment (in relation to Action Levels as explained in Text box 9.1)

Table 9.2 shows trace metal concentrations, from the licensing method assessed against ALs (see text box 9.1). Only one concentration is higher than AL2 (Arsenic at site G8, Figure 9.1). There are some values between AL1 and AL2, and elevations in a range of metals are observed at stations G28, G18 and G8. (Sample locations are labelled on Figure 9.1).

#### 9.4.2.2 Monitoring method assessment (in relation to OSPAR BACs)

G34 has been cited as a good background reference material for this survey (Okada, *et al*, awaiting publication), and so trace metal concentrations from this site have been used as the pivot point to complete the 5%AI normalisation required, as explained in Text box 9.2. The pivot point data has been adjusted to account for the small amount of silt/clay present in the sample, as ideally the pivot point is based on con-

centrations in the >63 µm (sand), and G34 contained 5% silt/clay.

Table 9.3 shows enrichment of the 5%AI normalised trace metal concentrations relative to the OSPAR BACS. Enrichment has been calculated by dividing the 5%AI normalised concentration by the relative OSPAR BAC value. This has been done for both the <2mm total digest and the <63 µm total digest results.

Most concentrations of the offshore samples are higher than the OSPAR BACs background level. Levels above BACs can be caused by local natural sources, and, as the South-West peninsula of the UK is heavily mineralised as well as having a past of extensive mining, the overall trend in elevations is not surprising. (Langston, *et al*, 2003).

However, at site G28 (Figure 9.1), which had elevated trace metal concentrations between AL1 and AL2 for some metals using the partial method (see above), there are concentrations below the BACs limits for several metals using the total method.

**Table 9.1.** Trace metal analysis

Stn Code	Latitude	Longitude	%Gravel	%Sand	%Silt/clay
G34	50.2080	-4.2200	0.17	94.78	5.05
G33	50.2802	-4.2101	23.41	60.86	15.74
G28	50.2999	-4.2403	0.22	51.27	48.51
RH13	50.3383	-4.1886	0.18	98.56	1.26
RH12	50.3310	-4.1945	0.56	78.96	20.47
RH14	50.3321	-4.1844	0.51	97.11	2.38
RH11	50.3184	-4.1865	0.05	99.73	0.22
RH10	50.3169	-4.2109	65.57	33.23	1.20
RH5	50.3221	-4.2319	0.08	99.75	0.17
RH16	50.3237	-4.2250	0.13	99.23	0.64
RH4	50.3238	-4.2265	0.27	99.15	0.58
RH15	50.3267	-4.2286	0.20	99.30	0.50
RH3	50.3303	-4.2301	0.02	99.37	0.61
RH2	50.3325	-4.2405	0.02	99.78	0.20
RH1	50.3373	-4.2484	0.14	99.66	0.20
RH8	50.3409	-4.2555	0.04	99.75	0.22
RH6	50.3358	-4.2577	0.09	99.59	0.32
RH7	50.3299	-4.2491	2.28	97.16	0.56
G19	50.3100	-4.2500	21.74	75.81	2.45
G18	50.3100	-4.2701	0.38	40.95	58.66
G13	50.3200	-4.2499	0.02	98.89	1.09
G8	50.3292	-4.3298	46.75	50.39	2.86

Table 9.1 continued. Trace metal analysis

**TOTAL (HF) DIGEST (mg/kg) <63µm**

Stn Code	Al	As	Cd	Cr	Cu	Fe	Hg	Li	Mn	Ni	Pb	Rb	V	Zn
G34	38835	18	0.22	91	26	29967	0.17	60	293	34	59	120	90	111
G33	20492	21	0.13	75	49	26817	0.68	95	300	30	100	127	84	130
G28	67193	33	0.14	81	59	29062	0.39	123	366	35	79	160	74	117
RH13	48568	37	0.98	166	55	40158	0.4	87	772	42	80	54	91	146
RH12	45146	27	0.54	95	36	24542	0.28	85	391	26	59	101	71	89
RH14	50831	38	0.67	112	35	28272	0.21	81	508	31	57	97	71	95
RH11	80797	83	0.39	121	110	42188	0.77	86	762	47	191	127	110	172
RH10	63097	36	0.13	105	54	30343	0.51	93	542	49	103	126	104	118
RH5	71129	35	0.8	165	64	39492	no sample	80	742	51	121	97	88	74
RH16	48905	72	1.8	130	56	39956	0.15	76	732	40	41	139	90	101
RH4	45244	46	1.2	134	55	37828	0.77	87	707	44	55	130	96	111
RH15	42537	42	1.3	168	54	37147	0.15	69	665	39	56	112	93	111
RH3	27104	8.7	0.15	49	16	14036	0.07	39	253	20	39	74	46	45
RH2	56401	35	0.73	139	85	38212	no sample	87	735	47	68	159	108	146
RH1	72868	36	0.61	122	51	38528	no sample	101	721	47	71	201	103	119
RH8	48731	16	0.27	77	27	24758	no sample	73	394	33	23	142	70	103
RH6	69193	36	0.79	103	56	36761	no sample	113	816	40	78	219	106	142
RH7	59770	35	0.29	90	57	33102	0.49	112	610	41	102	188	114	158
G19	39077	50	0.16	95	70	39903	0.9	129	1331	48	177	31	149	164
G18	52175	57	0.19	87	144	36056	0.86	127	402	41	136	35	114	234
G13	30679	38	0.16	82	50	32111	1.5	111	665	38	124	51	108	153
G8	33721	40	0.16	81	52	30867	0.4	136	562	39	103	74	119	149

**TOTAL (HF) DIGEST (mg/kg) <2mm**

Stn Code	Al	As	Cd	Cr	Cu	Fe	Hg	Li	Mn	Ni	Pb	Rb	V	Zn
G34	17692	13	0.16	26	7.4	15056	0.03	31	210	11	13	35	29	40
G33	40143	25	0.76	41	29	30643	0.44	76	340	23	73	95	64	148
G28	52303	25	1.2	60	48	26184	0.56	101	342	29	64	130	74	115
RH13	32899	16	0.29	38	15	24482	0.15	48	307	22	21	42	55	55
RH12	37472	14	0.66	62	21	22123	0.16	51	343	26	26	61	55	66
RH14	31233	12	0.43	34	11	21022	0.1	24	377	29	27	27	42	63
RH11	24853	14	0.58	30	12	20182	0.09	27	403	22	41	37	45	64
RH10	13033	8.1	0.15	20	6.6	10969	0.04	11	317	14	22	15	23	36
RH5	28357	13	0.35	31	7.1	21133	0.05	20	396	24	17	29	38	51
RH16	28285	14	0.59	40	9	21079	0.05	26	452	27	19	29	46	61
RH4	29548	14	0.32	39	8.7	20583	0.06	43	467	26	20	50	52	53
RH15	31729	13	0.2	45	8.3	21822	0.03	43	461	27	16	50	53	56
RH3	28090	14	0.2	37	6.9	18172	0.03	40	414	29	14	48	48	50
RH2	28785	13	0.2	41	7.6	20490	0.04	46	479	27	15	49	55	55
RH1	28655	12	0.2	39	7	20489	0.03	42	434	27	12	39	46	51
RH8	24656	13	0.2	31	6.2	17511	0.04	32	385	25	11	35	40	43
RH6	27524	14	0.2	38	7.3	23078	0.05	39	493	27	17	36	50	52
RH7	24383	21	0.2	32	6.6	20001	0.04	30	393	26	19	30	46	50
G19	31647	24	0.22	39	19	22840	0.12	68	724	23	63	80	62	84
G18	29973	34	0.32	59	92	21533	0.7	113	392	29	101	130	80	141
G13	19497	23	0.2	27	9.1	17099	0.19	53	410	16	51	52	51	55
G8	18901	69	0.2	33	14	27895	0.06	49	754	20	77	49	111	68

Table 9.1 continued. Trace metal analysis

PARTIAL DIGEST (mg/kg) <63µm								
Stn Code	CR	NI	CU	ZN	AS	CD	PB	HG
G34	36	23	19	108	12	0.15	55	0.17
G33	31	24	43	139	19	0.12	90	0.68
G28	28	25	49	118	24	0.13	70	0.39
RH13	26	26	40	115	25	<0.14	67	0.4
RH12	22	22	33	92	25	<0.08	54	0.28
RH14	17	20	23	73	23	<0.08	36	0.21
RH11	38	37	102	196	55	<0.44	167	0.77
RH10	36	31	44	120	25	0.08	93	0.51
RH5	no sample	no sample	no sample	no sample	no sample	no sample	no sample	no sample
RH16	25	32	47	88	57	<0.22	48	0.15
RH4	24	30	41	84	28	<0.11	50	0.77
RH15	28	29	50	83	49	<0.08	52	0.15
RH3	17	21	15	47	9.1	<0.12	67	0.07
RH2	no sample	no sample	no sample	no sample	no sample	no sample	no sample	no sample
RH1	no sample	no sample	no sample	no sample	no sample	no sample	no sample	no sample
RH8	no sample	no sample	no sample	no sample	no sample	no sample	no sample	no sample
RH6	no sample	no sample	no sample	no sample	no sample	no sample	no sample	no sample
RH7	32	29	44	129	26	<0.11	94	0.49
G19	22	33	56	143	40	0.11	183	0.9
G18	28	26	97	176	39	0.25	97	0.86
G13	25	27	40	132	32	<0.07	125	1.5
G8	31	26	37	116	28	<0.08	88	0.4

PARTIAL DIGEST (mg/kg) whole sediment								
Stn Code	CR	NI	CU	ZN	AS	CD	PB	HG
G34	15	7.5	3.1	33	6.5	0.06	11	0.030
G33	15	16	26	66	10	<0.02	36	0.210
G28	29	30	51	128	21	0.06	70	0.510
RH13	19	27	8.3	70	13	<0.02	31	0.430
RH12	24	31	20	79	12	0.02	35	0.160
RH14	15	23	6.6	49	8.7	<0.02	24	0.090
RH11	16	22	9.4	53	13	<0.02	35	0.07
RH10	8.7	13	4.5	24	5.1	<0.01	12	0.01
RH5	19	29	5.1	51	13	<0.01	18	0.03
RH16	15	24	5.5	45	11	<0.02	15	0.05
RH4	16	24	4.5	45	9.8	<0.02	15	0.03
RH15	24	38	5.7	63	12	<0.02	15	0.04
RH3	15	24	3	92	10	<0.02	8.2	<0.01
RH2	21	32	4.5	54	12	<0.01	9.9	0.01
RH1	9.9	17	2	27	6	<0.02	8.3	<0.01
RH8	13	21	2.2	34	9.8	<0.01	8.1	0.01
RH6	16	27	3.4	45	9.9	<0.02	13	<0.01
RH7	12	18	2.3	34	13	<0.01	13	<0.01
G19	9.7	15	13	50	20	0.15	34	0.07
G18	37	37	134	218	46	0.3	131	1.3
G13	14	15	7.3	87	22	0.08	44	0.15
G8	17	26	16	82	101	0.03	81	0.06

## 9.5 Method comparison

There are noticeable differences in the patterns of results determined by the two methods. Lead concentrations for each method are shown in figure 9.4, as an example of the differences in patterns observed. It is clear that elevations for map a) are different to elevations for map b).

There are two main differences between the two methods:

- different digests
- different fractions of sediment

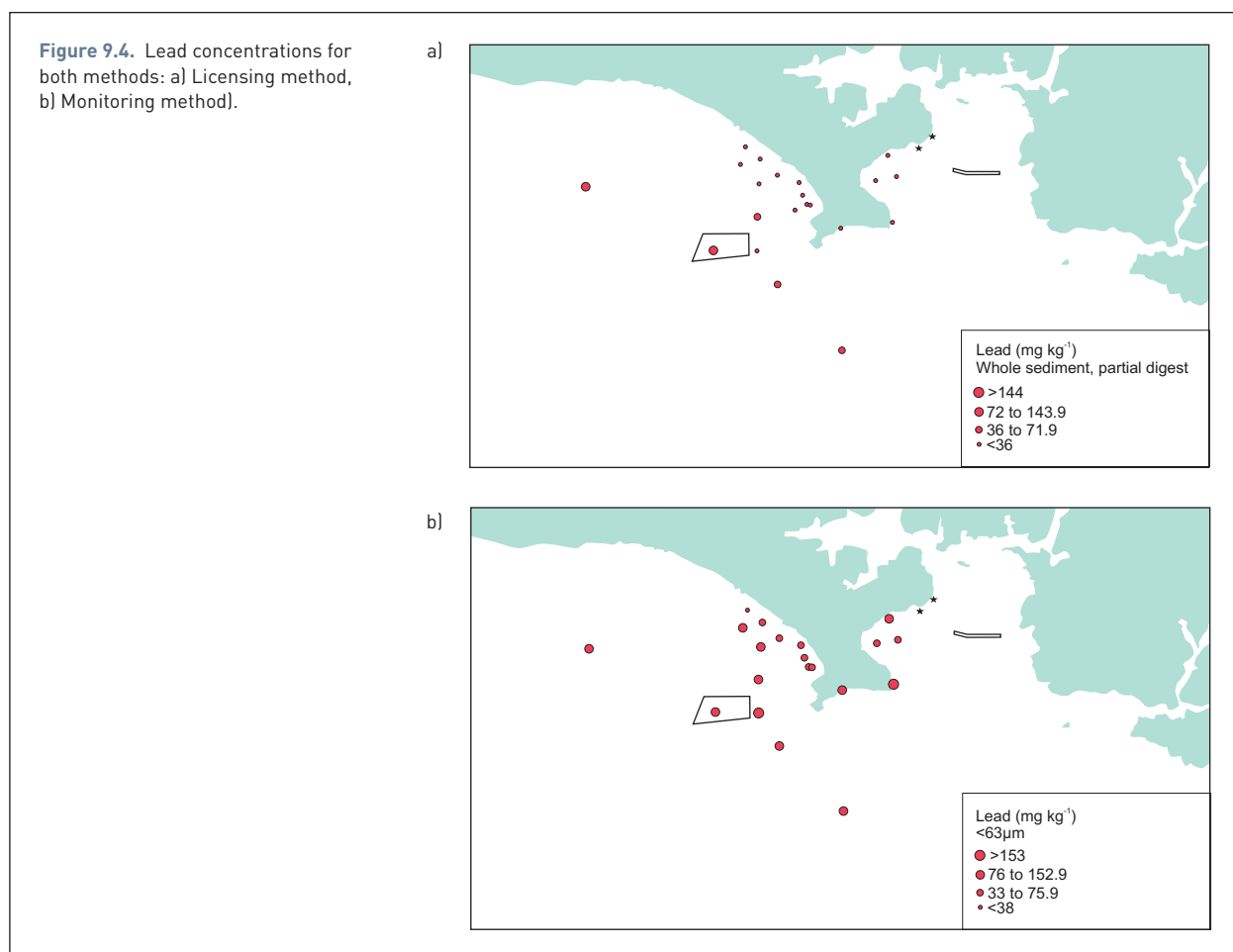
### 9.5.1 Comparison of Partial and Total digest

When trace metal concentrations for partial and total digest are compared on a sample by sample basis they are generally well correlated (Table 9.4), so samples with relatively high concentrations using the partial digest also have rela-

tively high concentrations using the total digest. For example, Figure 9.5 shows correlation of lead concentrations from partial digest and total digest for both whole sediment and <63  $\mu\text{m}$ .

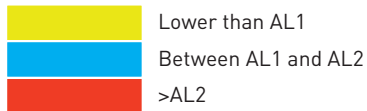
Cadmium was not included as several concentrations were below the detection limit. Mercury was not included as partial digest of mercury is used when completing total digest for trace metals since the mercury is volatile and is lost from the total digest (as explained in total digest details in 4.3.2).

Chromium is the only metal tested that has a low R value (0.1) for correlation between partial and total digests in the <63  $\mu\text{m}$  fraction. This may be due to differing recoveries within the partial digest, which can vary for different sediment types (Bolam, T. in prep). The sandy samples from Polhawn cove have relatively much higher chromium concentrations than the partial digest, which may mean that the sediment making up the matrix of the <63  $\mu\text{m}$  sediment

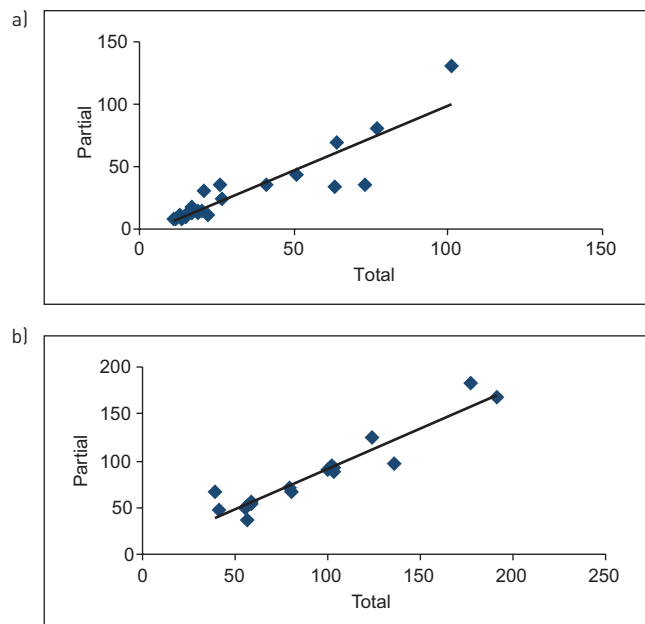


**Table 9.2.** Correlation R values for partial against total digest trace metal concentrations of Rame Head 2005 environmental samples. The closer R is to 1.0 the better the relationship between the two digests.

Station code	Arsenic (mg kg <sup>-1</sup> )	Cadmium (mg kg <sup>-1</sup> )	Chromium (mg kg <sup>-1</sup> )	Copper (mg kg <sup>-1</sup> )	Mercury (mg kg <sup>-1</sup> )	Lead (mg kg <sup>-1</sup> )	Nickel (mg kg <sup>-1</sup> )	Zinc (mg kg <sup>-1</sup> )
G34	6.5	0.06	15	3.1	0.03	11	7.5	33
G33	10	<0.02	15	26	0.21	36	16	66
G28	21	0.06	29	51	0.51	70	30	128
RH13	13	<0.02	19	8.3	0.43	31	27	70
RH12	12	0.02	24	20	0.16	35	31	79
RH14	8.7	<0.02	15	6.6	0.09	24	23	49
RH11	13	<0.02	16	9.4	0.07	35	22	53
RH10	5.1	<0.01	8.7	4.5	0.01	12	13	24
RH5	13	<0.01	19	5.1	0.03	18	29	51
RH16	11	<0.02	15	5.5	0.05	15	24	45
RH4	9.8	<0.02	16	4.5	0.03	15	24	45
RH15	12	<0.02	24	5.7	0.04	15	38	63
RH3	10	<0.02	15	3	<0.01	8.2	24	92
RH2	12	<0.01	21	4.5	0.01	9.9	32	54
RH1	6	<0.02	9.9	2	<0.01	8.3	17	27
RH8	9.8	<0.01	13	2.2	0.01	8.1	21	34
RH6	9.9	<0.02	16	3.4	<0.01	13	27	45
RH7	13	<0.01	12	2.3	<0.01	13	18	34
G19	20	0.15	9.7	13	0.07	34	15	50
G18	46	0.3	37	134	1.30	131	37	218
G13	22	0.08	14	7.3	0.15	44	15	87
G8	101	0.03	17	16	0.06	81	26	82
AL1	20	0.4	40	40	0.30	50	20	130
AL2	100	5	400	400	3.00	500	200	800



**Figure 9.5.** Correlation of lead concentrations from partial against total digest for a) whole sediment v <2mm total, and b) <63µm.



contains higher chromium concentrations, or that the matrix has different chemical properties which make the chromium more resistant to removal by the partial digest.

### 9.5.2 Comparison of different fractions

The OSPAR BACs have been derived using trace metal concentrations from the fine fraction (<63 µm) and then normalised to 5%Al (Text box 9.2). Within the guidance given alongside the BACs (OSPAR, 2002), it is suggested that the BACs are equally applicable to whole sediment trace metal concentrations. The fine fraction (normalised to 5%Al) will have a similar value for a whole sediment (normalised to 5%Al), from the same sample, with the understanding that, the coarser the sample, the greater the degree of variance between these two values will be.

Therefore, trace metals concentrations measured from the <63 µm sediment fraction were compared with trace metals concentrations from the <2mm sediment fraction. Both sets of data were normalised to 5%Al, as described in Text box 9.2. The two datasets were analysed using multivariate analyses, performed in PRIMER®, using the RELATE procedure (Clarke and Warwick, 2001). A MDS (multi-dimensional scaling) plot of trace metal concentrations normalised to 5%Al on the <63 µm sediment fraction and the <2mm sediment fraction is presented in Figure 9.6. The RELATE procedure showed a low degree of similarity (Rho value = 0.338) with a Rho value of 1 showing a high degree of similarity.

The reasons for the low degree of similarity may be caused by:

- Coarseness of the samples- 50% of these samples contain <1% silt/clay (<63 µm fraction).
- Need for wider consultation to resolve further the normalisation procedure, and to get a better perspective on the use of pivot points and how they vary around the UK.

## 9.6 Conclusions

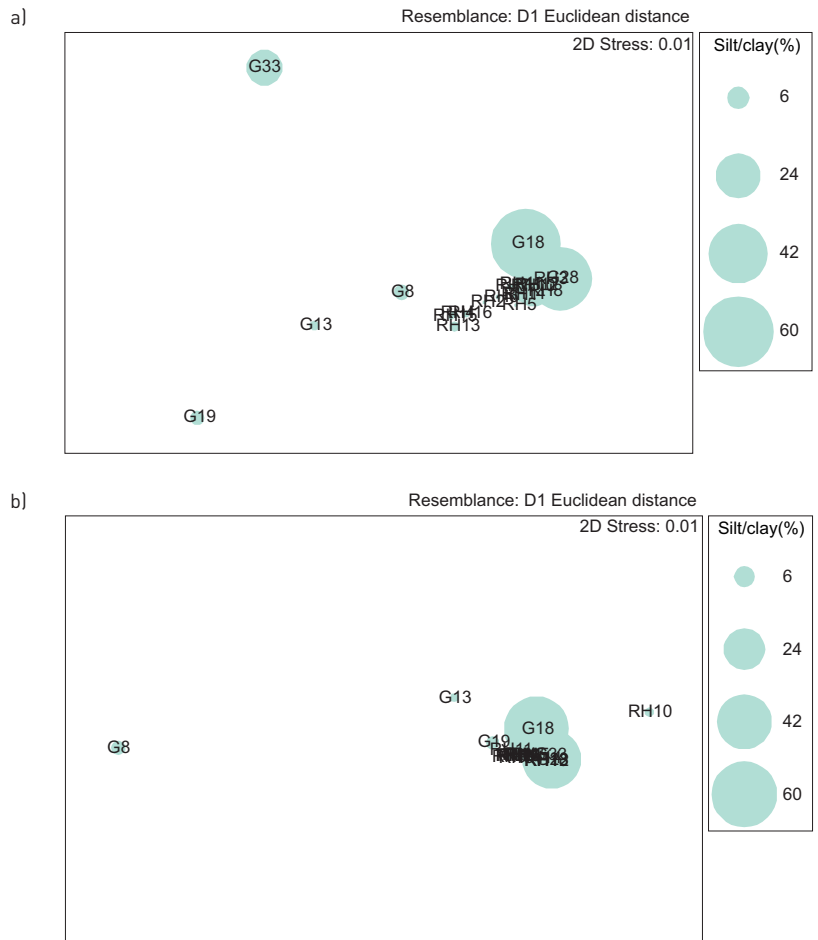
Action levels cannot be applied to monitoring data to determine elevations, and OSPAR BACs cannot be used to determine dredged material elevations.

The results demonstrate that the different methods yield different results and it is not sensible to assume that if there are elevations in one area using one method, these elevations will be replicated using another method in the same area.

The biggest difference in measured concentrations is caused by the different size fractions analysed.

It is planned to use this case study, alongside expert advice, to provide a way forward to ensure that future integration of the two assessment techniques will be possible, as clearly this is important in determining the relationship between dredged material input and environmental assessment at disposal sites.

**Figure 9.6.** MDS for trace metal concentrations (As, Cd, Cr, Cu, Fe, Li, Mn, Ni, Pb, Rb, V and Zn), normalised to 5%Al using G34 trace metal concentrations as a pivot point (as described in Text Box 9.2), overlain with %silt/clay bubbles: A (<63  $\mu\text{m}$ ) and B (<2mm).



**Table 9.3.** Enrichment factors against OSPAR BAC(BRC for Fe, Li and V) for trace metal concentrations (normalised to 5%Al using G34[adjusted to account for silt/clay%]) as a pivot point (OSPAR, 2005) for <2mm and <63µm total digest trace metal concentrations from Rame Head 2005 samples.

Station code	As (5%Al) <2mm	As (5%Al) <63µm	Cd (5%Al) <63µm	Cd (5%Al) <2mm	Cr (5%Al) <63µm	Cr (5%Al) <2mm	Cu (5%Al) <63µm	Cu (5%Al) <2mm
G33	1	3	0	3	5	1	12	1
G28	1	1	0	4	1	1	2	2
RH13	1	2	3	1	2	1	2	1
RH12	1	1	2	3	1	1	2	1
RH14	0	1	2	2	1	1	1	1
RH11	1	2	1	6	1	1	2	1
RH10	2	1	0	0	1	0	2	0
RH5	1	1	2	2	1	1	2	0
RH16	1	3	6	4	2	1	2	1
RH4	1	2	4	2	2	1	2	0
RH15	1	2	5	1	3	1	2	0
RH3	1	0	0	1	1	1	1	0
RH2	1	1	2	1	1	1	3	0
RH1	0	1	1	1	1	1	1	0
RH8	1	1	1	1	1	1	1	0
RH6	1	1	2	1	1	1	1	0
RH7	2	1	1	1	1	1	2	0
G19	2	3	1	1	2	1	4	1
G18	3	2	1	2	1	1	5	8
G13	4	3	1	2	2	1	4	1
G8	25	3	1	2	2	2	3	3
BAC/(BRC for Fe, Li, and V) (mg kg <sup>-1</sup> )	25	25	0.31	0.31	81	81	27	27

n not enough sample to complete analyses.

a minus indicates this concentration is lower than that in found at the pivot point.

above OSPAR BAC (BRC for Fe, Li and V)  
 within OSPAR BAC (BRC for Fe, Li and V)

**Table 9.3 continued.** Enrichment factors against OSPAR BAC(BRC for Fe, Li and V) for trace metal concentrations (normalised to 5%Al using G34(adjusted to account for silt/clay%)) as a pivot point (OSPAR, 2005) for <2mm and <63µm total digest trace metal concentrations from Rame Head 2005 samples.

Station code	Fe (5%Al) <63µm	Fe (5%Al) <2mm	Hg (5%Al) <63µm	Hg (5%Al) <2mm	Li (5%Al) <63µm	Li (5%Al) <2mm	Ni (5%Al) <63µm	Ni (5%Al) <2mm
G33	2	1	68	9	12	2	4	1
G28	0	0	4	8	2	2	1	1
RH13	1	1	6	4	2	2	1	1
RH12	0	0	5	3	2	1	1	1
RH14	0	0	3	3	2	0	1	1
RH11	0	1	6	4	1	1	1	2
RH10	0	1	5	-3	2	6	1	-2
RH5	0	1	n	1	1	0	1	1
RH16	1	1	2	1	2	1	1	2
RH4	1	0	13	2	2	1	1	1
RH15	1	0	3	1	2	1	1	1
RH3	0	0	2	1	1	1	1	2
RH2	1	1	n	1	2	2	1	2
RH1	0	1	n	1	2	1	1	2
RH8	0	0	n	1	2	1	1	2
RH6	0	1	n	2	2	1	1	2
RH7	0	1	6	1	2	1	1	2
G19	1	1	19	3	4	3	2	1
G18	1	1	12	24	3	5	1	2
G13	1	1	49	22	5	6	2	2
G8	1	3	11	6	5	6	2	4
BAC/(BRC for Fe, Li, and V) (mg kg <sup>-1</sup> )	6.30	6.30	0.07	0.07	44	44	36	36

n not enough sample to complete analyses.

a minus indicates this concentration is lower than that in found at the pivot point.

above OSPAR BAC (BRC for Fe, Li and V)

within OSPAR BAC (BRC for Fe, Li and V)

**Table 9.3 continued.** Enrichment factors against OSPAR BAC(BRC for Fe, Li and V) for trace metal concentrations (normalised to 5%Al using G34[adjusted to account for silt/clay%]) as a pivot point (OSPAR, 2005?) for <2mm and <63µm total digest trace metal concentrations from Rame Head 2005 samples.

Station code	Pb (5%Al) <63µm	Pb (5%Al) <2mm	V (5%Al) <63µm	V (5%Al) <2mm	Zn (5%Al) <63µm	Zn (5%Al) <2mm
G33	17	3	4	1	6	2
G28	1	2	1	1	1	1
RH13	2	1	1	1	1	1
RH12	2	1	1	1	1	1
RH14	1	1	1	1	1	1
RH11	3	3	1	1	1	1
RH10	2	-4	1	1	1	0
RH5	2	1	1	0	0	1
RH16	1	1	1	1	1	1
RH4	2	1	1	1	1	1
RH15	2	1	1	1	1	1
RH3	3	1	1	1	1	1
RH2	2	1	1	1	1	1
RH1	1	0	1	1	1	1
RH8	1	0	1	1	1	1
RH6	1	1	1	1	1	1
RH7	2	1	1	1	1	1
G19	7	3	2	1	2	1
G18	3	6	1	1	2	2
G13	7	10	2	2	3	2
G8	5	19	2	8	2	3
BAC/(BRC for Fe, Li, and V) (mg kg <sup>-1</sup> )	38	38	110	110	122	122

n not enough sample to complete analyses.

a minus indicates this concentration is lower than that in found at the pivot point.

	above OSPAR BAC (BRC for Fe, Li and V)
	within OSPAR BAC (BRC for Fe, Li and V)

**Table 9.4.** Correlation R values for partial against total digest trace metal concentrations of Rame Head 2005 environmental samples. The closer R is to 1.0 the better the relationship between the two digests.

Trace metal	Whole sediment	<63µm
Arsenic	1.0	0.9
Chromium	0.8	0.1
Copper	1.0	1.0
Nickel	0.7	0.8
Lead	0.9	0.9
Zinc	0.7	0.9

## 10. Swanage Bay dredged material disposal ground 2006 – Post capital dredged material disposal survey

**Authors: Matthew Curtis and Marie Pendle**

### 10.1 Introduction

In 2003, it was recognised by Poole Harbour Commission that there was a trend towards an increase in the size of new vessels and that for the port to remain commercially successful, the access channel to the port would have to be deepened. In particular, the ferry used for the roll-on roll-off (Ro-Ro) ferry service operating from Poole to Cherbourg was to be replaced with a larger vessel which would not be able to access the harbour without the channel deepening. If no action were taken, this would cause the ferry company to seek a new harbour from which to operate the ferry route.

Poole Harbour Commission, in order to accommodate the new ferry and to improve the diversity of cargo vessels which could access the port, decided to undertake the project of deepening the existing channel. This had been maintained at 6 metres below chart datum and it was decided to increase this depth by 1.5 metres, to 7.5 metres below chart datum.

The Swanage Bay dredgings disposal ground is a large circle of 1 nautical mile diameter centred around 50°37.5'N and 01°52.6'W (Figure 10.1). Only the northwest quadrant of the disposal ground is utilised for maintenance dredged material disposal for economic reasons as it is closest to the harbour, thus allowing shorter turnaround times and the least fuel utilised per journey.

It was decided that the much larger quantities of the capital disposal operation would probably have an adverse impact

on local *Sabellaria spinulosa* populations if disposed of in the northwest quadrant along with the maintenance dredged material disposal. The *Sabellaria spinulosa* populations to the southwest of the Swanage Bay dredgings disposal ground are probably dependent on the maintenance disposal supplying a small amount of fine material in an otherwise gravelly sand environment. An increase in the quantity of fine material in the environment may have a detrimental effect on these *Sabellaria spinulosa* populations. Because of this, it was decided to use the southeast quadrant of the disposal ground so that any fine material liable to be transported away from the disposal ground would be less likely to impact upon these known *Sabellaria spinulosa* populations.

Approximately 679,000 dry tonnes of material from the capital dredging operation was unsuitable for beneficial use, due to its silt/clay and/or gravel content, and was disposed of at the Swanage Bay dredgings disposal ground over the winter of 2005–2006.

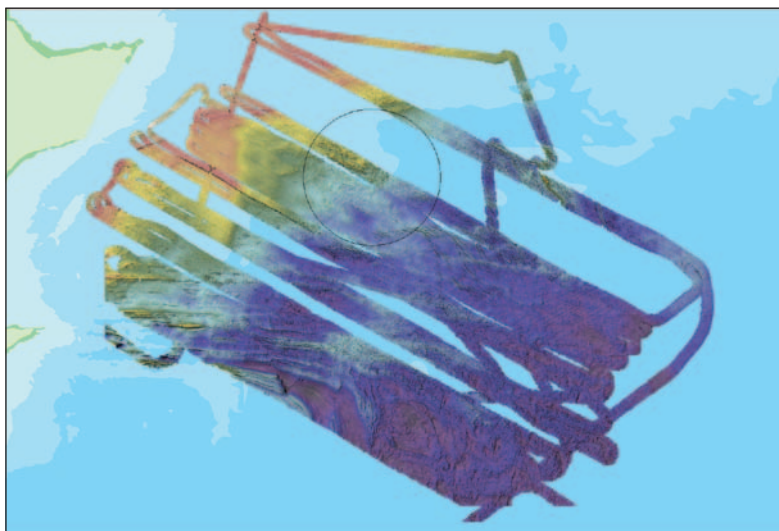
Cefas first surveyed the Swanage Bay dredgings disposal ground in 2004 using replicate benthic sampling and multi-beam acoustics to acquire information on biological, bathymetric and sedimentary features in and around the disposal ground (Cefas, 2006) and again in 2005 using multibeam acoustics and video sledge tows to infill some areas not covered by the 2004 survey (Figures 10.2 and 10.3); all prior to the capital disposal event.

The Swanage Bay dredgings disposal ground was surveyed, post capital dredged material disposal, on the 7th

**Figure 10.1.** Location of the Swanage Bay dredged material disposal ground.  
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**Figure 10.2.** 2004 and 2005 multibeam acoustic data with overlaid with the Swanage Bay dredged material disposal ground.  
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June 2006 using the RV *Cefas Endeavour* (Figure 10.4). The survey effort included conventional grab-sampling techniques along with multibeam acoustics to monitor any effects of this capital disposal on the Swanage Bay dredgings disposal ground and nearby areas.

## 10.2 Methods

### 10.2.1 Survey design

The grab-sampling survey was designed to take into account the most likely route of any dispersing material away from the southeast quadrant of the disposal ground, due principally to tidal action. The stations were positioned in areas of probable sediment deposition derived from dispersion modelling data for the area (Royal Haskoning, 2004). Seven stations were sampled in triplicate for the benthic macrofauna and sediments (Figure 10.4) to provide an assessment of the extent of any effects of the capital dredged material disposal activity.

The acoustic survey was designed to give a 100% coverage of a rectangular area covering most of the Swanage Bay dredged material disposal ground, including the south-east quadrant, and some of the surrounding area to identify the boundaries and extent of the capital dredge disposal.

### 10.2.2 Field sampling procedure

Replicate samples of sediments for the later analysis of benthic macrofauna and sediment particle size distribution were collected using a 0.1m<sup>2</sup> Hamon grab. Following estimation of sample volume, a sub-sample was removed for particle size analysis. The whole sample was then washed over 5mm and 1mm sieve meshes to remove fine sediment. The two fractions were combined and back-washed into an appropriate container and fixed in 4 – 6% buffered formaldehyde solution.

The acoustic system used for this study was a 300kHz, Kongsberg Simrad™ EM3000D dual-head “true” multibeam system, which used transducers mounted in ‘V’ formation on the drop keel of the *Cefas Endeavour*. Positioning of the

data was achieved using a Thales 3011™/ Fugro SeaStar™ satellite differential system. Vessel, pitch, roll and heave were measured with a Kongsberg/Seatech™ MRU5 motion reference unit. These parameters were corrected in real time within the EM3000D processing unit, which then outputted the data to a Triton Isis™ logging package. Sound velocity at the sonar head was measured with a Reson™ sound velocity probe. The data were then imported into CARIS™ HIPS where further corrections were made using predicted tidal data and sound velocity profiles. Erroneous soundings were filtered and a corrected XYZ dataset was produced for each survey. These XYZ grids were then imported into the 3D visualisation software package Fledermaus™, where coloured, sun-illuminated topographic images depicting the surface of the seabed were produced.

### 10.2.3 Laboratory procedure

In the laboratory, macrofauna samples from each Hamon grab were first washed with freshwater over a 1mm sieve in a fume cupboard to remove excess formaldehyde solution and then placed on plastic trays and examined under an illuminated magnifier. Specimens were picked from the trays and placed in labelled Petri dishes containing a preservative mixture of 70% industrial methylated spirit for identification and enumeration.

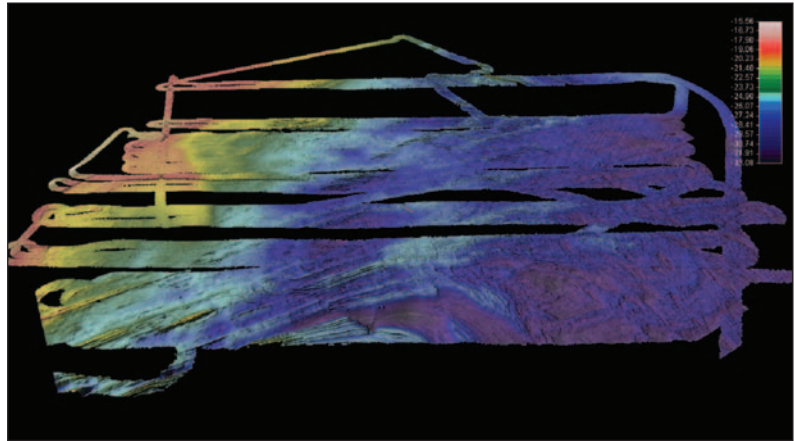
## 10.3 Results

### 10.3.1 Acoustic survey

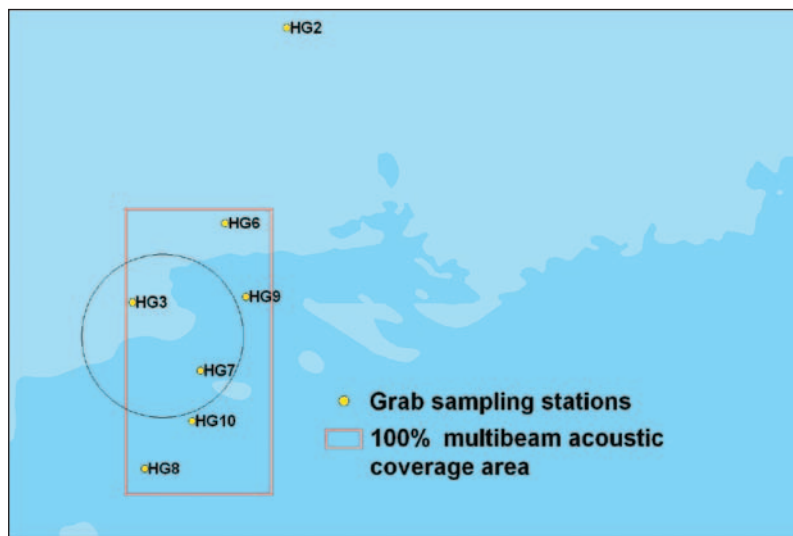
The acoustic survey was carried using a Simrad EM3000D multibeam to give a bathymetric image of the seafloor, the results of which can be seen in Figure 10.5. Figure 10.6 shows the three years of acoustic data combined (2004 – 2006).

Figure 10.7 shows the acoustic data from Swanage Bay dredgings disposal ground prior to the winter 2005/2006 capital disposal. Discreet “doughnut” shaped disposal events can be seen over most of the acoustic data within the disposal ground. These “doughnuts” are approximately

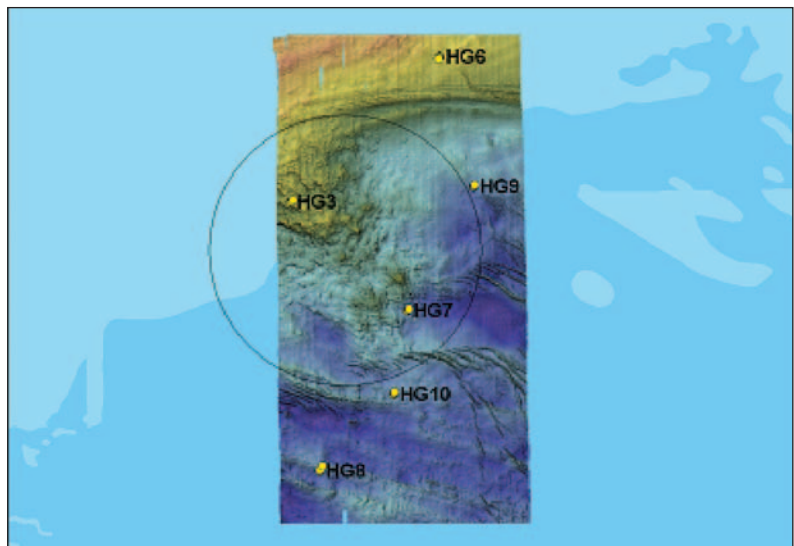
**Figure 10.3.** Fledermaus 3D image of 2004 and 2005 combined acoustic data with colour coded depth key.



**Figure 10.4.** Swanage Bay survey 2006. © British Crown and SeaZone Solutions Limited, 2005. All rights reserved. Data Licence No. PGA042007.001.



**Figure 10.5.** 2006 multibeam survey of Swanage Bay dredged material disposal ground. © British Crown and SeaZone Solutions Limited, 2005. All rights reserved. Data Licence No. PGA042007.001.



30 metres in diameter with the outer ring raised approximately 0.5 – 1 metres above the surrounding seabed. The southeast quadrant of the disposal ground shows little impact from dredged material disposal with just a handful of “doughnut” shaped disposal events within its boundaries.

The 2006 post capital disposal acoustic data can be seen in Figure 10.8. The extent of the capital dredged material can be clearly seen when comparing the acoustic data pre and post-capital disposal (Figures 10.7 and 10.8). The seabed of the southeast quadrant, post-capital dredged material, is now very uneven due to these deposits.

### 10.3.2 Sediments

Table 10.1 shows the sediment descriptions of the stations surveyed in 2006 (Figure 10.4). Station HG7, within the southeast quadrant of the dredged material disposal ground, showed evidence of dredged disposal with all three replicates containing clay lumps and fibrous organic material. These replicates samples also contained numerous empty *Hydrobia* shells which will have probably come from the dredged material as they are not typical species for this loca-

tion because they prefer more sheltered muddy intertidal habitats.

Station HG9, just outside the northeast quadrant of the disposal ground, and station HG8, approximately 550 metres south of the disposal ground, contained clay lumps which may have originated from the disposal ground. Station HG10, approximately 100 metres south of the southeast quadrant of the disposal ground, and station HG6, approximately 550 meters north of the disposal ground, showed no evidence of dredged material disposal activity.

### 10.3.3 Benthic results

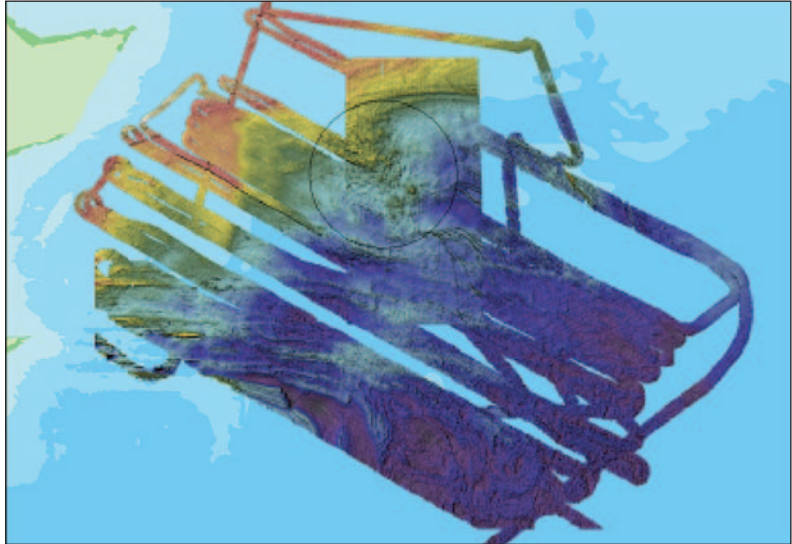
A total of 131 taxa were identified from the seven stations sampled of which 48 occurred only once. The most numerous species found were the bivalve *Goodallia triangularis* and the barnacle *Balanus crenatus* with 612 and 245 individuals identified respectively. Other species found in high numbers were the polychaete worms *Sabellaria spinulosa*, *Lanice conchilega*, *Pomatoceros lamarki* and the slipper limpet *Crepidula fornicata*.

**Table 10.1.** Sediment descriptions taken from Hamon grab samples.

Station code	Sediment description
HG2 A	Slightly shelly, slightly muddy sand.
HG2 B	Shelly, gravelly, slightly muddy sand.
HG2 C	Slightly muddy, shelly gravelly sand with clay lumps.
HG3 A	Clean, coarse, slightly gravelly, shelly sand.
HG3 B	Clean, coarse, slightly gravelly shelly sand.
HG3 C	Clean, coarse, gravelly, shelly sand.
HG6 A	Gravelly shelly sand with cobbles and Sabellaria.
HG6 B	Clean shelly sand.
HG6 C	Gravelly, shelly sand with cobbles.
HG7 A	Slightly shelly, muddy, gravelly sand with cobbles and clay lumps. Also contained numerous <i>Hydrobia</i> shells.
HG7 B	Slightly shelly muddy gravelly sand with clay lumps and fibrous lumps. Also contained numerous <i>Hydrobia</i> shells.
HG7 C	Slightly shelly muddy gravelly sand with clay lumps and fibrous lumps. Also contained numerous <i>Hydrobia</i> shells.
HG8 A	Shelly, gravelly sand with a cobble. Some small clay lumps present.
HG8 B	Gravelly, muddy sand with small boulder. Some small clay lumps present.
HG8 C	Clean, shelly, coarse sand. Some small clay lumps present.
HG9 A	Shelly, muddy, gravelly sand with lumps of black and red clay.
HG9 B	Muddy, shelly, gravelly sand.
HG9 C	Shelly, muddy sand with hard grey clay lumps.
HG10 A	Clean, shelly sand with 1 cobble.
HG10 B	Clean, shelly sand.
HG10 C	Cobbly sand.

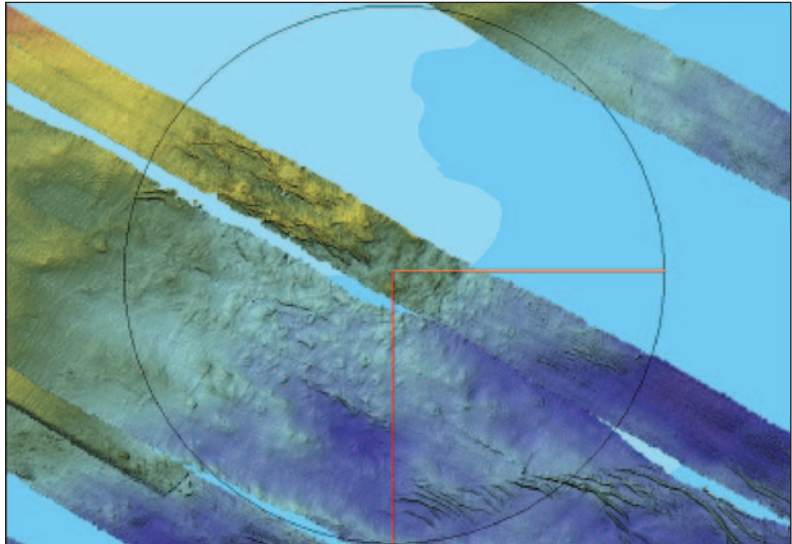
**Figure 10.6.** 2004 – 2006 combined acoustic data for Swanage Bay dredged material disposal ground.

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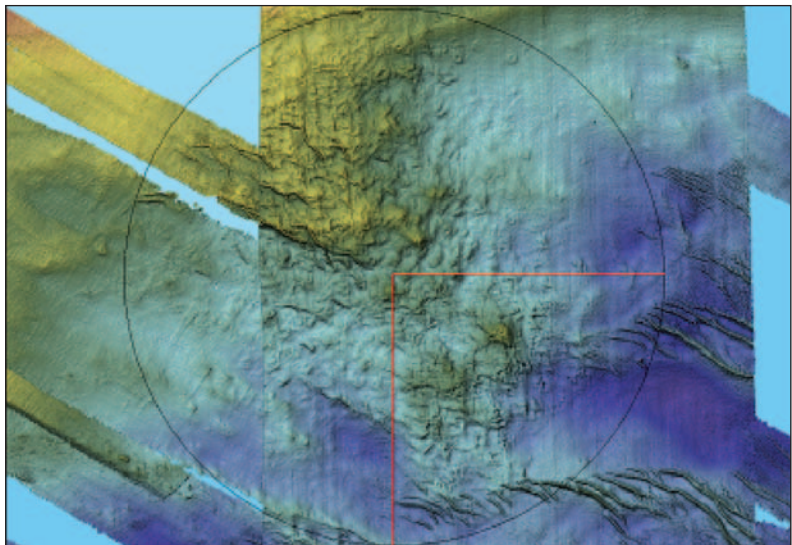
**Figure 10.7.** 2004–2005 acoustic data showing Swanage Bay dredged material disposal ground pre-capital dredged material disposal. Note the southeast quadrant is highlighted and little previous disposal activity is evident.

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**Figure 10.8.** 2006 acoustic data overlaying 2005-2006 data showing Swanage Bay dredged material disposal ground post-capital disposal. Southeast quadrant highlighted.

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Univariate analysis of the benthic macrofauna data showed that station HG7 in the southeast quadrant of the disposal ground had a reduced number of species and stations HG7 and HG10 had reduced numbers of individuals compared with the other stations (Figures 10.9 and 10.10). Station HG8 showed an increased number of species and individuals whilst station HG6 showed an increased number of individuals compared to the other stations.

Multivariate analysis was performed using PRIMER v.6 (Clarke and Gorley, 2006) for windows (Plymouth Routines in Multivariate Ecological Research). Non-parametric multi-dimensional scaling (MDS) ordination using the Bray-Curtis similarity measure was applied to species abundance following square root transformation of data to assess differences in species composition (Figure 10.11). Most of the stations group together closely with the exception of station HG7 in the southeast quadrant of the disposal ground which show a high degree of variability. A high degree of variability between replicates can be an indicator of disturbance (Warwick and Clarke, 1993).

The similarity percentages program (SIMPER) was used to indicate which taxa contributed the most towards similarity between replicates from within each station (Table 10.2). Station HG7 showed a high degree of variability between replicates with only two common species which were the polychaete worms *Lumbrineris gracilis* and *Spio armata*.

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## 10.4 Discussion

The most significant impacts of the capital dredged material disposal seem to have been contained within the designated

southeast quadrant. The reduced number of species and individuals as well as dissimilarity between replicates, seen in HG7, are well-documented consequences of disturbance due to dredged material disposal activity. Stations HG8 and HG9 all contained clay lumps which may have originated from the disposal ground. These stations lie in areas of probable sediment deposition derived from dispersion modelling data of the area (Royal Haskoning, 2004) and therefore it should be expected that some sediment contamination from the disposal ground would occur. None of the stations showed a reduction in number of species and individuals but instead station HG8 showed an increase in both of these.

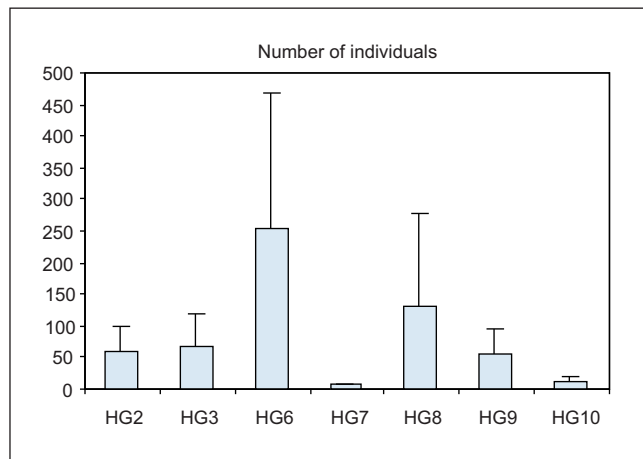
Station HG10 just outside the southeast quadrant of the disposal ground did show a reduced number of individuals, but this is probably not an effect of the disposal but rather because the sediment consisted of clean sand (Table 10.1) which provides a less diverse and probably more mobile habitat compared to other stations.

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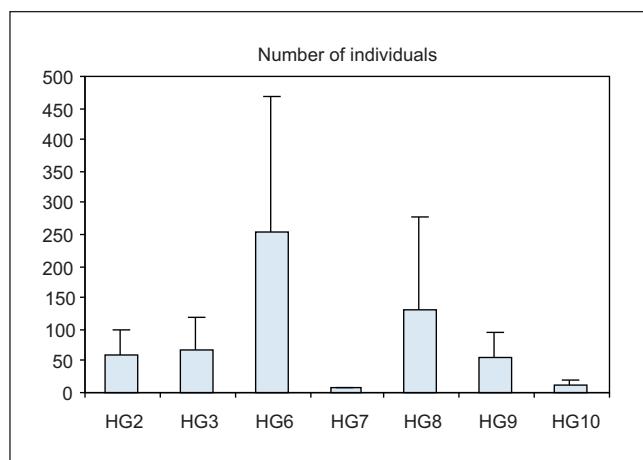
## 10.5 Conclusion

The impacts of the capital dredged material disposal appears to be confined to the disposal ground, with station HG7 showing an altered community structure but not a barren area of seabed. There is no evidence of adverse effects from the tidally induced dispersal of sediments away from the disposal ground on the fauna at the other stations sampled during this survey. Further surveying of the disposal ground will be undertaken to monitor any further effects of this capital dredged material disposal as well as the eventual recovery of this site.

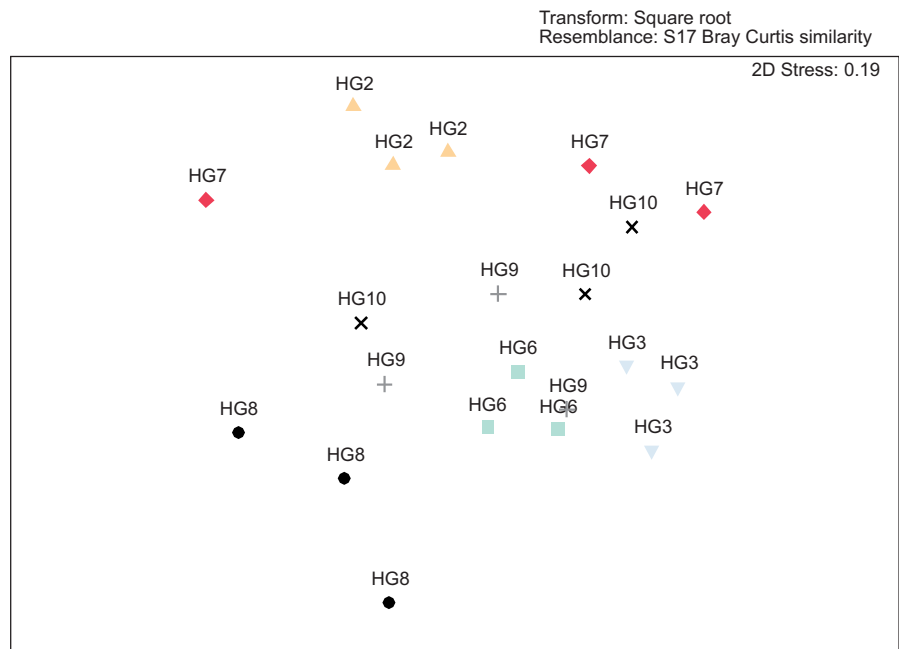
**Figure 10.9.** Mean number of species (+s.d.) at each station.



**Figure 10.10.** Mean number of individuals (+s.d.) at each station.



**Figure 10.11.** Multi-dimensional scaling (MDS) ordination showing differences in species composition.



**Table 10.2.** Results of SIMPER analysis of the benthic macrofauna data showing average abundance, average similarity, and % contribution, both individually and accumulatively.

Station code	Taxonomic group	Average abundance	Average similarity	% Contribution	Cumulative %
HG2	<i>Lanice conchilega</i>	4.9	11.57	28.48	28.48
	<i>Spiophanes bombyx</i>	2.36	8.75	21.53	50.02
	<i>Nephtys kersivalensis</i>	2.39	8.25	20.3	70.32
	<i>Lumbrineris gracilis</i>	1.28	5.57	13.71	84.03
	<i>Spio armata</i>	1.15	2.94	7.24	91.27
HG3	<i>Balanus crenatus</i>	5.24	12.5	31.76	31.76
	<i>Travisia forbesii</i>	2.24	9.1	23.11	54.86
	<i>Crepidula fornicata</i>	2.54	7.84	19.92	74.78
	<i>Pomatoceros lamarcki</i>	2.58	7.45	18.92	93.71
HG6	<i>Goodallia triangularis</i>	11.86	19.56	40.05	40.05
	<i>Syllis cornuta</i>	2.49	5.05	10.34	50.38
	<i>Crepidula fornicata</i>	2.9	4.04	8.26	58.65
	<i>Pomatoceros lamarcki</i>	1.79	3.88	7.95	66.59
	<i>Spio armata</i>	1.49	3.11	6.36	72.95
	<i>Polycirrus medusa</i>	1.14	2.53	5.17	78.12
	<i>Sphaerosyllis bulbosa</i>	1.14	2.53	5.17	83.29
	<i>Syllis</i>	1	2.53	5.17	88.46
	<i>Balanus crenatus</i>	4.5	1.51	3.09	91.55
HG7	<i>Lumbrineris gracilis</i>	0.67	8.18	50.97	50.97
	<i>Spio armata</i>	1.05	7.87	49.03	100
HG8	<i>Spio martinensis</i>	2.53	5.53	27.29	27.29
	<i>Spio filicornis</i>	2.17	3.57	17.62	44.91
	<i>Syllis</i>	3.19	2.61	12.87	57.78
	<i>Polycirrus</i>	1.41	2.4	11.83	69.61
	<i>Spiophanes bombyx</i>	0.8	1.35	6.66	76.27
	<i>Syllis cornuta</i>	1.41	0.76	3.75	80.02
	<i>Minuspio multibranchiata</i>	1.14	0.72	3.56	83.58
	<i>Polydora</i>	2.1	0.72	3.56	87.14
	Maldanidae	1.67	0.54	2.65	89.79
<i>Phoronis</i>	0.67	0.54	2.65	92.44	
HG9	<i>Goodallia triangularis</i>	5.51	16.81	55.53	55.53
	<i>Crepidula fornicata</i>	1.39	2.94	9.72	65.26
	<i>Glycera lapidum</i>	0.91	1.79	5.91	71.17
	<i>Spisula elliptica</i>	0.67	1.79	5.91	77.08
	<i>Bathyporeia pelagica</i>	0.8	1.75	5.77	82.85
	NEMERTEA	0.67	1.75	5.77	88.62
	<i>Pomatoceros lamarcki</i>	0.8	1.75	5.77	94.39
HG10	<i>Goodallia triangularis</i>	1.38	13.3	47.56	47.56
	<i>Spio armata</i>	0.8	4.93	17.62	65.18
	<i>Travisia forbesii</i>	0.91	4.93	17.62	82.79
	<i>Pomatoceros lamarcki</i>	1.32	4.81	17.21	100

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